VDA QMC

Verband der Automobilindustrie
Qualitäts-Management-Center

19 Part 1

Quality management in the Automotive Industry

Inspection of Technical Cleanliness

Particlulate contamination of functionally-relevant automotive components

3rd revised edition, July 2025

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PREFACE TO THE THIRD REVISED AND AMENDED EDITION

Since the first VDA 19 edition was published in January 2004, the relevance of technical cleanliness has steadily increased and is now an integral quality feature in the automotive industry. In the course of this development, hundreds of cleanliness laboratories have been set up in automotive and supplier works, and numerous service laboratories have also come into being. The new job of “technical cleanliness inspector” has been created as well as a multitude of posts (often departments) within affected companies that concern themselves with and coordinate all aspects of technical cleanliness (see also VDA 19 Part 2 “Technical Cleanliness in Assembly”).

Over the years since it was first published, due to its broad application and the wealth of knowledge possessed by the people using VDA 19, it has become necessary to amend and add supplements to the guideline.

After the publication of the second edition, now as VDA 19.1, technical cleanliness continued to grow in importance. In line with the transition from combustion engines to electric vehicles as well as autonomous driving, it is stipulated as a ubiquitous quality characteristic in all new projects, along with corresponding specifications. New technical requirements and methods of cleanliness inspection made it necessary to perform yet another complete revision.

The main goals of the comprehensive revision (February 2023 to May 2025) were to:

- Integrate new dry extraction methods as well as new analysis techniques
- Achieve easily comparable standard analyses while simultaneously allowing for the development of problem-adapted, free inspections within defined requirements
- More precisely describe the inspection of particles < 50 µm
- Develop an SEM/EDX standard analysis with uniform material classes
- Numerous optimizations and clarifications in the elaboration of inspection procedures and adaptation of starting parameters based on years of experience in cleanliness laboratories

The basic methods and processes of component cleanliness inspection which were covered in the first and second edition have proven to be effective, and the latest edition still includes them in full, just in a more detailed and supplemented form.

The chapter structure and numbering of the sub-chapters have mostly stayed the same. New topics and sub-chapters are generally found at the end of a chapter. So references within the VDA 19.1 or from other documents to chapters in VDA 19.1 have been preserved. Only in Chapter 8 ANALYSIS METHOD did the updates require us to modify the chapter structure.

In line with the third revised and amended edition, the following topics and contents are now covered:

- **Chapter 1 SCOPE OF APPLICATION AND VALIDITY** now includes a new overview graphic for the amended and expanded structure. In addition to the new extraction and analysis methods, this chapter now also includes the new concept with two ways of checking cleanliness limit values: Standard analysis with set start parameters for extraction, defined analysis filters and with configured settings for analysis that can be used with a defined scope of application with no need for additional agreement, thus maximizing the reproducibility of inspection results. And also free inspection with flexibility with regard to extraction parameters, filter selection and analysis parameters, allowing an inspection to be adapted to special inspection purposes (e.g. smaller or low-contrast particles). These specially optimized inspections must be agreed in the customer-supplier relationship. What was formerly referred to as the “shortened analysis” can now be found as “(process) monitoring” in accordance with the inspection purpose. The term “extended analysis” has been kept.

- **Chapter 2 CLEANLINESS SPECIFICATION and INSPECTION STRATEGY** has been expanded to include issues that have to be considered when developing an inspection strategy for technical cleanliness as well as a sub-chapter on checking components that cannot be inspected. The annex now also includes typical errors that occur in the creation of cleanliness specifications.

- **Chapter 3 SELECTING THE INSPECTION METHOD** now also includes the new extraction methods “stamping test” and “(brush nozzle) suction,” and the tables for selecting the appropriate extraction method now include corresponding component examples. Annexed to the chapter is an overview graphic on the structuring and on requirements for “inspecting cleanliness limit values”, “(process) monitoring” and “extended analysis”.

- In **Chapter 4 HANDLING COMPONENTS CLEANLY** now differentiates between two types of packaging for the delivery of inspected objects to the cleanliness laboratory - depending on the purpose of the inspection. The chapter also includes a list of inspection staff qualifications as well as an annex with a recommendation for a checklist for (self-)auditing a cleanliness laboratory.

- **Chapter 5 QUALIFICATION TESTS AND BLANK VALUE** has been fine-tuned and optimized based on practical experience in every respect – both as far as text descriptions and as far as graphics and their explanations. This is especially true for the final rinsing procedure and the attribution of the influence of the blank value on analysis results. Particle recovery inspections as part of qualification (of extraction systems, not of individual inspections) and as a contributor to measurement uncertainty is now included in the normative portion.

- In **Chapter 6 EXTRACTION METHOD**, the methods for extraction with liquid now includes a new sub-category – “low-pressure rinsing” – with its own start parameters. The start parameters for rinsing and the ultrasound extraction have been updated based on years of laboratory experience. In dry extraction, the start parameters for blow-off have been revised, and two new methods – the stamping test and (brush nozzle) suction – have been added with defined start parameters. These last two methods are already mentioned in VDA 19.2 and are now also possible for component cleanliness inspection in accordance with VDA 19.1.

- In **Chapter 7 ANALYSIS FILTRATION AND SEPARATION**, filtration has been supplemented with “separation,” since (brush nozzle) suction can also include the use of particle traps which then undergo analysis. Particularly with regard to particle inspection, recommendations for filter selection are now more precise and include a new graphic. New methods for preparing and drying analysis filters have also been added. The graphic pertaining to filter residue and analyzability now also includes information on particle traps and stamps.

- **Chapter 8 ANALYSIS METHOD** now starts with an overview section which presents the new structure of the chapter and explains which analysis technologies are found in which sub-chapters. As before, the chapter is divided into three parts: First comes the inspection of cleanliness limit values. Second is (process) monitoring. And third, extended analysis. These last two parts are slimmed down in the new edition. The methods are explicitly mentioned but without going into detail as to equipment characteristics and procedures. The first part, the inspection of cleanliness limit values, has been greatly expanded and described in more detail. It now includes:

    - Gravimetry, which is mostly unchanged but now features a clearer description of the detection limit as well as a formula for calculating the minimum inspection lot size.

    - Light-optical analysis, in which new methods are described for the typification of metallic shine (which is still optional.) A new criterion has also been added for determining total fiber length as a measure of fiber residue. Light-optical analysis for inspecting cleanliness limit values is now described in more detail in two sub-chapters: One sub-chapter covers standard analysis ≥ 50 µm (not modified,) which was developed to detect dark particles on white filters using incident illumination. Fixed and generally applicable parameters are established for imaging and evaluation, such that this standard analysis can be used without additional coordination, the goal being to maximize the reproducibility of analysis results. In other sub-chapters, a new “free” light-optical analysis method is introduced. This method is used particularly to detect particles < 50 µm, low-contrast particles or for light-optical systems that use equipment other than microscopes or scanners. Example approaches to these issues are presented, but the specific design and parameter configurations can be adapted to the specific task and thus optimized. Only the required optical resolution and full-surface analysis are subject to minimum requirements which must be observed. The use of this free analysis method should be coordinated in the customer-supplier relationship.

  - Automated SEM/EDX analysis, which can now also be used for inspecting cleanliness specifications. As part of the revision of VDA 19.1, a new standard analysis has been developed. This also includes established settings for image formation and particle detection as well as a consistent list of definitions which can be used to group elements analyzed with EDX spectra into material classes. Here too, the approach is that this standard analysis can be applied without additional coordination and produces a significant improvement with regard to the reproducibility of analysis results. As with light-optical analysis, there is also a sub-chapter on free SEM/EDX analysis. This can be used to inspect cleanliness limit values after coordination in the customer-supplier relationship. It is possible to adapt the parameters for image formation and evaluation for the specific issue being investigated as well as to introduce additional material classes.

- In **Chapter 9 DOCUMENTATION**, the corresponding sections and templates for documentation have been supplemented with new extraction and analysis methods.

- **Chapter 10 INTERPRETATION AND REACTION** now includes additional items that need to be factored into the evaluation of an exceeded limit value. Moreover, a third sub-chapter has been added with a recommendation for the evaluation of measurement uncertainty contributions and method verification.

- **Chapter 11 WORK SAFETY AND THE ENVIRONMENT** has been updated.

- In **Chapter 12 CASE EXAMPLES**, new examples have been added for extraction by (brush nozzle) suction and stamping, and one of the existing examples for the agitation method of extraction has been taken out.

- **Chapters 13 DEFINITIONS, ABBREVIATIONS AND SYMBOLS** and **14 INDUSTRIAL ALLIANCE TECSA (INFORMATIVE)** have been updated.

The amendments and refinements to the revised third edition of VDA 19.1 enable this guideline to be used not only for the design, implementation and documentation of cleanliness inspections in the laboratory but also make it suitable for other disciplines such as quality assurance, engineering design and development or supplier management as a quick introduction to the topic. For some basic insights into the topic of technical cleanliness and technical cleanliness inspection, refer to Chapters 2 and 3.

1 SCOPE OF APPLICATION AND VALIDITY

1.1 Introduction

This guideline describes the conditions for the use and documentation of methods of determining particulate contamination and functionally-relevant components (cleanliness inspection.)

Cleanliness inspections are used as a basis for assessing technical cleanliness, e.g. for the purpose of:

- initial sampling and evaluation
- incoming and outgoing inspection
- quality control or monitoring cleanliness-related manufacturing processes (e.g. cleaning, surface treatment or assembly)
- cause analysis (e.g. in cases of damage)

This guideline serves to make inspection results meaningful and reproducible and regulates the standardized representation of cleanliness specifications and cleanliness inspection results in the quality chain of the automotive industry.

Information on references:

When an inspection of cleanliness limit values is performed in accordance with this guideline, it is referenced in documents such as specifications and reports as follows:

“Standard cleanliness inspection according to VDA 19.1” in cases where standard methods and parameters as well as a standard analysis filter are used, extraction is done with start parameters and no other agreements regarding methods and parameters exist in the customer-supplier relationship.

“Cleanliness inspection according to VDA 19.1” in cases where methods of extraction, separation and analysis described in VDA 19.1 are used, the described minimum requirements are met and their application, parameterization and documentation are stipulated in the customer-supplier relationship.

This reference citation corresponds to the two ways of limit value inspection as depicted in Figure 1-1 on the left.

Process monitoring and extended analysis are typically internal inspections for monitoring or optimizing production processes; it is not necessary to provide a reference.

1.2 Excluded topics

The following topics are not covered:

- filmic and ionic contamination (oils, anti-corrosion agents, hand sweat, fluid residues, etc.)
- application of non-quantifiable particulate detection methods on inspected objects (e.g. visual assessment, wipe test with clean cloth, etc.)
- characterization of operating fluids (fuel, oils, coolant, brake fluid, etc.), see VDA 19 Part 2

Moreover, the guideline does not state any concrete cleanliness limit values for specific components or systems. The degree of cleanliness required for a specific component or system is dependent on a number of highly individual factors. Tips for deriving limit values can be found in Chapter 2 CLEANLINESS SPECIFICATION and INSPECTION STRATEGY.

1.3 Cleanliness inspection

The purpose of a cleanliness inspection is to optimally detect the particulate contamination left on the relevant surfaces of the inspected object as a result of the manufacturing process.

In contrast with other inspections, which can generally be performed directly on an inspected object, e.g. optical or tactile (contact) inspections, the inspection of technical cleanliness is typically an indirect inspection that requires a sampling step.

The relevant surfaces of functionally-critical automotive components are often located inside pipes, channels, casings, tanks, pumps, valves or similar components through which particles can move, potentially reaching sensitive areas of systems. These (inner) surfaces are typically not accessible for direct e.g. visual inspection. Furthermore, due to their material composition, roughness or lack of contrast with the particulate contamination, many surfaces are not suitable for visual inspections.

Note 1: If, however, particles on component surfaces are accessible and clearly detectable, then a direct inspection is also permissible, provided that the applicable minimum requirements are met. In certain applications, e.g. with adhesive surfaces, only a direct inspection makes sense.

For the aforementioned reasons, an “extraction” (or sampling) is usually required in order to inspect technical cleanliness. Here, the particles are first removed from the inspected object by means of an inspection cleaning process with or without fluid. All the extraction medium is then filtered, and the particles extracted from the component are separated and deposited on an analysis filter (or a particle trap in certain applications,) which is then analyzed.

This also means that: **it is impossible to repeat the cleanliness inspection on the same inspected object**, because its cleanliness state has been altered (destructive testing) as a result of the inspection method (extraction).

Due to the fact that, in some cases, a single particle may be functionally critical, it is essential that the maximum number of removable particles on the surface be detected and the specified surface be included in full.

Since there are no realistic inspected objects with a defined level of contamination based on which it would be possible to check the efficacy of extraction procedures, extraction procedures first have to be qualified before technical cleanliness can be assessed:

- **Effectiveness of the extraction procedure:** The extraction procedure suitable for an inspected object must be confirmed by means of a declining test (fulfillment of a declining criterion).

- **Effectiveness of the final rinsing procedure:** The application of a suitable final rinsing procedure must be checked based on the specific component.

- **Checking particle recovery:** Sufficient particle recovery must be ensured.

- **Blank value:** In order to reliably check for compliance with cleanliness requirements and reliably determine the cleanliness of a component, additional contamination resulting from the inspection process should not be allowed to skew the results. This is ensured by complying with the corresponding blank value criterion.

The cleanliness inspection is composed as follows:

1. Provision of inspected object
2. Acquisition of particles from the inspected object (extraction)
3. Filtration or separation of the particles
4. Analysis of the particles
5. Documentation of the inspection and the results

Note 2: Steps 2 and 3 are omitted for direct inspection.

Technical cleanliness inspection requires appropriate inspection equipment, suitable spaces and qualified, experienced and motivated personnel (see Chapter 4.2.1).

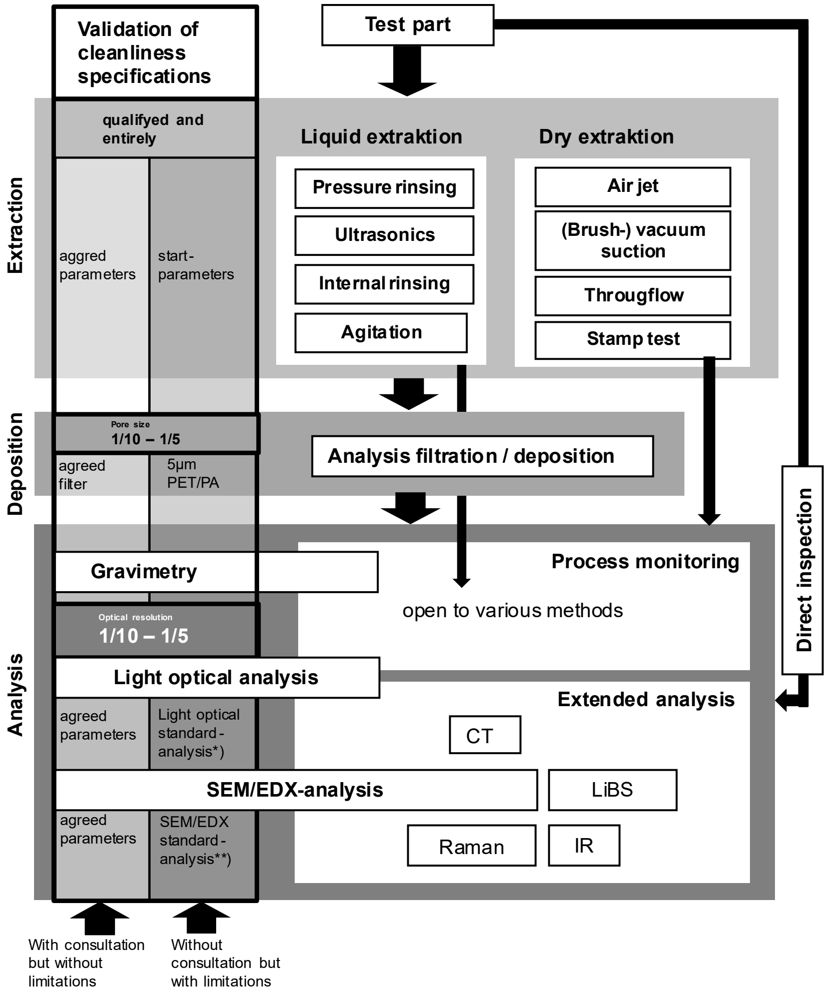


Figure 1-1: Inspection procedure according to VDA 19.1

2 CLEANLINESS SPECIFICATION AND INSPECTION STRATEGY

2.1 Principles

A cleanliness specification (or cleanliness limit value) can be created if particulate contamination restricts or threatens the functionality of the affected system or component. If this is not the case, the cleanliness specification should be omitted.

Since the attainable cleanliness of a component or system depends on its design and the overall manufacturing process, the cleanliness specifications should be worked out and defined by an interdisciplinary team that includes all the departments involved, including Design, Production, Logistics, Quality Assurance and a cleanliness laboratory. It may also be necessary to involve staff from other areas, such as assembly planning or supplier management.

Companies or locations that have been manufacturing components or systems with cleanliness requirements for a long time and have the corresponding expertise will often have designated cleanliness specialists who are preferably able to assist with the definition of cleanliness limit values and initiate accompanying assessments.

Such a team in charge of determining cleanliness specifications should know both the individual component and the system in which it is installed, the later operating conditions, the technical feasibility status and the consequences for production and the supply chain.

An assessment must be done to evaluate the criticality of exceeding the cleanliness limit value and derive any necessary actions (response plan with, as described in Chapter 10 reviews, outlier rules, escalations, etc.). If a limit is exceeded, this does not necessarily lead to a malfunction although it does increase the risk.

The probability of a malfunction occurring also depends on the system concerned (geometry, airflow patterns, cross-sections modifying with time, or similar). This should be assessed in a risk analysis.

The achievable level of cleanliness for a component or system is principally determined by its design. Before establishing cleanliness limit values, the system concerned should first be inspected to assess whether particle compatibility (robustness) can be increased, for example by channeling particles or reducing their migration within the system (by using centrifugal effects, installing a filter, etc.).

Another way of realizing technically feasible and cost-effective cleanliness limit values is to reduce particle generation in production and assembly. This can already be attained by selecting suitable materials and coatings for components and systems, by considering cleanability aspects in their design and by reducing the formation of chips and burrs during machining processes.

Technical cleanliness is not a constant feature, such as the diameter of a borehole, but rather a temporary state that can be influenced by external factors. In the customer-supplier relationship, it should therefore be stipulated when and where a cleanliness specification applies. This can be fixed via generally applicable supply conditions, or be defined for each case individually (e.g. after cleaning, on delivery to the assembly area, etc.).

Any additional arrangements require verification to ensure that they do not conflict with the agreed cleanliness specifications. This may concern a suitable form of packaging or the designation of responsibility for cleaning reusable packaging. However, there may also be a need to assess storage locations and times or the suitability of the assembly processes used with regard to cleanliness.

2.2 Deriving cleanliness limit values for systems

In many cases, fluid systems or electrical, electronic and optical systems contain one or more components sensitive to particles (see Figure 2-3 for examples of damaging mechanisms).

As particles inside such systems are generally mobile – i.e. able to migrate from a non-critical area to a sensitive location – this “weakest link in the chain” usually determines the degree of cleanliness necessary for the whole system.

Examples of affected systems in automobiles that can be relevant, depending on their design:

- Fuel system
- Hydraulics (engine and gearbox)
- Braking system
- Steering
- Air conditioning systems

- Cooling systems (combustion engines and electric mobility)
- Air intake and exhaust tract
- Systems for post-treating exhaust gases
- Systems in electromobility (electric motor and step-down gear)
- Systems in power electronics (inverter, etc.)
- Batteries (cells, modules and trays)
- Fuel cells and hydrogen supply systems
- Headlights
- Electronic compartments
- Electronic products (e.g. radar, camera for autonomous driving)

Note 1: Components may also belong to more than one functional area. In such cases, different cleanliness specifications may apply to different sections of the same component, each section having to be sampled individually in the cleanliness inspection (if this extraction is possible and reasonable easy).

The first step towards deriving a cleanliness specification is to identify the areas which are sensitive to particles, e.g. based on design characteristics, functional elements or media circulation plans.

The aim is to characterize functionally-critical particulate contaminants as accurately as possible, with regard to:

- Damaging mechanisms/damaging effect (e.g. blocking, jamming, electrical shorting, etc.)
- Particle size (relevant dimensions)
- Particle count/quantity
- Material properties/critical particle materials
- Probability of a fault occurring, e.g. during a changeable state such as a valve closing

- (temporary) local concentration in the system

Where possible, the points on the necessity of requirements which are listed in the left-hand section of Figure 2-1 should be taken into account. In the next step, it is necessary to check if the requirements defined thus far can be fulfilled using state-of-the-art technologies – taking into account the sub-points listed in the right-hand section of Figure 2-1. Only after taking both sections into consideration (necessity and feasibility,) can a meaningful cleanliness specification be drawn up for the respective system.

For certain applications, it can also happen that (textile) fibers are categorized as functionally-critical or quality-related. In this case, note the following: (Textile) fibers are particularly pervasive in conventional ambient air. However, (textile) fibers are usually also present in class 2 and even class 1 clean rooms in which people work.

Regulating or entirely excluding (textile) fibers according to a cleanliness specification is costly and demanding with regard to the production environment (clean room) and the protection of sensitive component areas along the entire production and supply chain. Accordingly, it is only seldom technically or economically feasible to exclude fibers in the supply chain using a cleanliness specification.

If (textile) fibers really cannot be tolerated, however, this is usually only feasible if the corresponding fiber-sensitive areas are cleaned directly (location and time) before installation.

Note 2: If only locally limited component areas, e.g. an optical system or a sealing face, need to be protected from fibers during transport or storage, this can be done, for example, by applying a protective film, a sticker or a protective cap that is removed right before installation. However, it is not (economically) possible to reliably protect all larger components, such as a board with components or a housing for an electric motor or a battery tray.

If it is necessary to limit not just individual fibers but the totality of fibers – e.g. in order to prevent the clogging of a narrow point in a fluid system (valve, nozzle, etc.) – this can reasonably be accomplished with a specification on total fiber length. This corresponds to the sum of the stretched out lengths of all fibers, as described in Chapter 8.2.2.1.3.

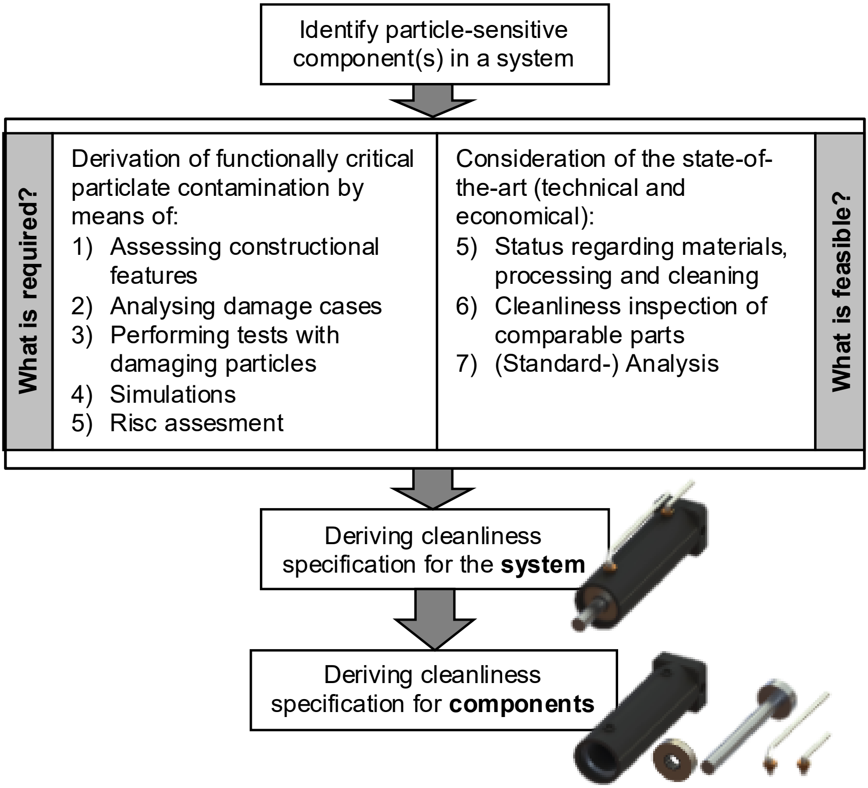


Figure 2-1: Path to development of cleanliness specifications

About 1) Assessing design features: In a first step, the geometric particle sizes (length or width of particles) that could be functionally-critical for a component in the fluid system are determined based on the design characteristics in the system, e.g. gap dimensions, valve stroke, filter mesh size or line separation etc. In fluid systems, the direction of flow and orientation of particles in the flow can also be considered (particle width/height relevant). Where surfaces move against one another, e.g. sliding bearings, the degree of abrasion may be taken into account. With valves that open and close, the shearing action of particles can be considered, and with electronic systems, conductivity may be relevant.

About 2) Analyzing damage cases: If experience has already been obtained with the system (or a similar one) either in practice, in test benches or ongoing serial runs, for example, the encountered function impairments can be taken into account when defining the cleanliness specification. Particles that caused damage can be isolated after disassembly, for example, or be visualized by computer tomography in order determine their size, geometry and material.

About 3) Testing for damaging particles: In order to assess a system's ability to withstand damaging particles, tests can be performed in which the system is deliberately operated with such particles and the effects are analyzed. For example, particles can be injected into the system while it is operated under realistic conditions (pressure, temperature, rpm, etc.) or (for example, with heat-soluble liquid grease) before it is assembled. Such tests can be used to determine the sizes, types and counts of particles which cause a system to fail completely, be irreversibly damaged or shorten its service life. This can be done by monitoring test bench parameters such as oscillations and pressures, or by inspecting component surfaces after dissembling the test system.

Inspected objects or systems can also be built from transparent materials to visualize particle migration or accumulation in order to reach conclusions about damage risks.

About 4) Simulations: Another method of evaluating particle compatibility, especially in fluid systems, is to use software programs to calculate particle-charged flows. This makes it possible to simulate and visualize particle transport.

Note 3: The construction of test benches or modification of software programs to assess resistance to damaging particles varies greatly for each product and may involve major technical and financial outlays.

About 5) risk analysis: Risk due to contaminants can be estimated using models that calculate the probability of particle-related malfunctions. The calculation includes factors such as the size, the position and the orientation of particle-sensitive component areas in closed systems (e.g. an electronic PCB in a housing or components in trays inside a closed unit load). Other factors that may be relevant for the calculation include the quantity, size, orientation and damage potential of the particles and also (as a central point) the potential transport routes and the triggers of particle movement in the system.

About 6) current materials, processing and cleaning methods: Due to the types of materials and processing methods used in automotive manufacturing and the fact that components are produced under high cost pressure in extremely short cycle times, it is not economically feasible to attain levels of cleanliness that are typical for other industries (e.g. semiconductor industry or medical technology). For example, a machined cast aluminum component manufactured in three-shift operation cannot be cleaned as thoroughly as a polished stainless steel component manufactured in the medical device industry. If such facts are not taken into account, it is often impossible to reliably adhere to a cleanliness specification despite major cleaning and post-treatment efforts (see Figure 2-4). Before cleanliness specifications can be definitively determined, the state of machining and cleaning technology must be clarified.

Note 4: Technical limits of the achievable degree of cleanliness are often not determined by the utilized cleaning technology or not by the cleaning technology alone but also by the materials, the primary shaping processes, the surface quality and the processing methods. The size and weight of the components also play a role. Any surface structure – whether it's material roughness, a burr, a machining edge or spike – can be sheared off under stress, turning into a particle of the corresponding size. Oftentimes, this can happen just under the kinds of stresses that occur during normal production processes, e.g. handling (manual or automatic gripping), contact with packing surfaces, contact between components during transport or fixing in workpiece holders.

About 7) analysis of particulate loads (comparable parts): In order to gain a realistic idea about the level of technical cleanliness that can be attained with current manufacturing methods, cleanliness analyses according to VDA 19.1 can be performed on similar or comparable components. However, comparable manufacturing and cleaning processes need to be implemented and logistics processes and environmental conditions also have to be similar. These analyses can also identify any existing potential for improving cleanliness levels. New and alternative production technologies (in production, cleaning and assembly processes) should also be considered and evaluated.

About 8) analysis: The cleanliness specifications derived from Points 1 to 7 should be verifiable by at least one of the analysis methods described in VDA 19.1. Even the best-founded cleanliness specification makes no sense if component cleanliness in the supply chain cannot be validated using state-of-the-art technical equipment or if costs are excessively high. If no special arrangements have been made between the customer and the supplier, cleanliness specifications should be verifiable by the standard analysis described in VDA 19.1.

2.3 Deriving cleanliness limit values for components

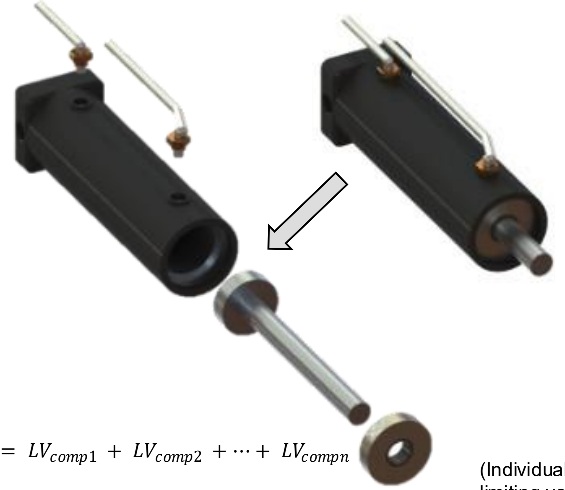
When deriving cleanliness limit values for components from cleanliness limit values for systems, there are two possible cases:

1. The cleanliness limit value for a system is expressed as a rejection criterion, e.g. no particles larger than X µm (except for fibers) are permitted in the system. In this simple case, the cleanliness specification applies to all components involved in the system (or relevant component surfaces).

2. A specific quantity of contamination is permitted for the overall system, e.g. a gravimetric value or a particle size distribution. This total amount of contamination is the sum of the contaminants on the components installed in the system. This means that the sum of the limit values of the individual components i corresponds to the limit value of the system (see first line in Figure 2-2). As large components are generally responsible for more contamination in a system than small ones, the amount of contamination in the system can first be divided among the components in proportion to their relevant surface area in the total system (see second line in Figure 2-2). It is far more practical to apply a modified surface reference. The surface reference initially remains the same. Individual component limit values (LV_{comp}) are calculated from the total limit value (LV_{total}) divided by the total surface area (SA_{total}) of the system and then multiplied by the surface area of the component (SA_{comp}). With this approach, individual component limit values are scaled by weighting factors (A_i) while the system's total particle count remains the same. This enables information on the component, e.g. its cleanability or other cleanliness-related factors, to be included in the scaling process. For example, low-cost small parts which cannot be cleaned cost-effectively or complex components that are difficult to deburr or coated parts are assigned weighting factors a > 1 (i.e. broader component limit values). On the other hand, large components that are easy to deburr and clean are assigned weighting factors a < 1 (i.e. tighter component limit values). Additional particle sources from the production process can also be integrated into overall system cleanliness by including additional summands (b, c, ...), for example the particulate load of an oil poured into the system, or the contamination generated during assembly (see third line in Figure 2-2).

Note 1: This approach can be used, for example, to derive a budget for particle ingression in in-house assembly from a total cleanliness limit value for a finished system and to derive (practical) cleanliness specifications for the individual (purchased) parts.

Note 2: If the part surface of an individual part in the total system is not relevant, e.g. because it is closed by a joining process, then the limit value for the system is smaller than the sum of the limit values of all individual parts.



$$LV_{tot} = LV_{comp1} + LV_{comp2} + \cdots + LV_{compn}$$

$$LV_{tot} = \frac{LV_{tot}}{A_{tot}} * A_{comp1} + \cdots + \frac{LV_{tot}}{A_{tot}} * A_{compn}$$

$$LV_{tot} = a_1 * \frac{LV_{tot}}{A_{tot}} * A_{comp1} + \cdots + \overbrace{a_n * \frac{LV_{tot}}{A_{tot}} * A_{compn}}^{\text{(Individual) limiting value for component } n} + b + c + \cdots$$

LV_{total}:	total limit value of the system
A_{total}:	surface area of the system (in contact with media)
LV_{compi}:	limit value of the component i
A_{compi}:	surface area of component i (in contact with media)
A_{compn}	surface area of component n (in contact with media)
a_i:	component-specific weighting factors
$b, c, \ldots$:	other additive contaminant amounts

Figure 2-2: Deriving component cleanliness specifications

2.4 Consequences drawn from cleanliness limit values

2.4.1 Inspecting technical cleanliness in quality control

When specifications for the technical cleanliness of components are arranged between the customer and the supplier, they have to be validated in accordance with the agreement.

Note 1: Concerns regarding verifiability and achievable cleanliness, etc., must be clarified in advance.

The following general principles apply when inspecting technical cleanliness:

- Special equipment is required, e.g. for the extraction and analysis procedures.

- An inspection can be compared to a laboratory test, i.e. suitable clean facilities are necessary.

- In order to ensure a stable inspection process, manual inspection steps should always be performed by qualified staff (laboratory experience or training with a laboratory background is advisable).

- The inspector has a decisive influence on the quality of the results. The results of cleanliness analyses are highly dependent upon staff experience and consistent quality of inspection performance.

- As some cleanliness inspections are time-consuming and involve manual tasks, much fewer of these inspections can be carried out compared to other quality inspections (e.g. dimensional accuracy). Consequently, established quality control methods cannot be applied indiscriminately to cleanliness inspections.

- The technical cleanliness of components fluctuates much more than other technical features (see also Chapter 10 INTERPRETATION AND REACTION).

- Technical cleanliness is a state that changes in dependence on time and is influenced by a wide range of factors. Therefore, the exact point in time and location of a cleanliness specification should be defined, as well as the procedure for removing the component from the production line and transporting it (together with packaging) to the inspection site.

Note 2: A technical cleanliness inspection does not necessarily have to be performed in a clean room. The cleanliness grade of the inspection environment depends on the blank value determined for the inspection, which in turn depends on the permissible cleanliness limit value for the component (see Chapter 5 QUALIFICATION TESTS AND BLANK VALUE).

2.4.2 Impact on production

Cleanliness specifications should always be defined with due consideration of the aspects of technical feasibility and economic viability (see also Annex A 2.3). Strict cleanliness requirements can lead to immense costs of production and further processing of components along the entire supply chain.

For example, higher costs can be incurred due to:

- The selection of materials or surface coatings
- Production processes such as machining and deburring
- Cleaning (see also Figure 2-4 in the Annex)
- Logistics and packing (external and internal)
- Manufacturing environment
- Staff
- Assembly equipment and joining processes

Therefore, when deriving a cleanliness specification, only the level of cleanliness required for the component to function correctly should be specified and not more (as clean as necessary, not as clean as possible!).

Comments, information and methods regarding the consideration of assembly equipment, logistics, staff and environment from the aspect of cleanliness can be found in the guideline VDA 19.2 “Technical Cleanliness in Assembly”.

2.5 Inspection strategy

Since a technical cleanliness inspection generally takes a lot of (manual) work, higher costs and more time, it is not usually possible to cover as large of an inspection scope as with other quality inspections. It is all the more important to devise a well-adapted inspection strategy in order to appropriately integrate the characteristic of technical cleanliness into quality control. The following terms are used:

- **Inspection strategy:** The inspection strategy is the concept for inspecting the particulate cleanliness of components with the goal of demonstrating or ensuring that cleanliness specifications or cleanliness limit values are observed. It can include different inspection purposes, e.g. demonstrating a cleanliness specification, (process) monitoring or causal analysis and process optimization. It can also include procedures in the event of an exceeded limit value, e.g. retesting, increasing the scope or frequency of the inspection in order to confirm process-related and non-random exceedances of the limit value. The process of identifying and rectifying the causes of a limit value exceedance that is described in the response plan is also accompanied by corresponding inspections.

- **Inspection frequency:** The inspection frequency refers to the ratio of parts tested to parts produced (in %, ‰ or ppm) or the time interval (e.g. per shift, per day, per week, per month or per year) of cleanliness inspections performed on a component.

- **Inspection scope:** The inspection scope is the number of cleanliness inspections performed at a point in time.

- **Inspection lot size:** The inspection lot size is the number of components in an inspection, i.e. how many components are extracted together and included in an analysis.

When defining the inspection frequency or an inspection scope, the following aspects can be considered:

- **Reason for test:**
  - Prototype, start-up, series
  - Process change or approval
  - Start-up or re-start, relocation
- Criticality of a failure (safety, cost-effectiveness, etc.)
- Probability of a failure
- Quality history (experience, process stability)
- Production continuity, quantity per time

- Reaction possibility/speed with NOK results

- Component costs

- Inspection expenditure (time, costs)

- Possibility of component family formation

2.6 Ensuring technical cleanliness for non-testable components or assemblies

The inspection typically requires an extraction step in which the particles to be analyzed are removed from the inspected object and used in the subsequent analysis. So an inspection is not possible unless an extraction can be successfully performed. non-testable components or assemblies are ones that

- are closed, making it impossible to perform an extraction in the function-related interior. These are often fully assembled systems

- with geometries and accessibilities that prevent effective extraction (dead spaces, blind holes, etc.),

- with coatings that would dissolve in a cleanliness inspection and cannot be reasonably inspected by either a liquid or dry extraction process.

The approach to technical cleanliness assurance that can be pursued in such cases is based, first of all, on an assessment or inspection of individual parts and/or (sub-)assemblies if and to the extent that this is possible in the process chain. If this is no longer possible, we proceed to a process analysis in which it is demonstrated indirectly that no relevant reverse contamination of the components or (sub-)assemblies occurs in the subsequent assembly process.

This can be done, for example, using methods according to VDA 19.2 in order to examine the environment, logistical and staff influence and particularly joining and assembly processes. Such examinations can also be supported by evaluating the integrity of surfaces (e.g. checking for traces of scratches or scuffing) with contact and with stress in fixtures or in joining processes or by means of additional inspections.

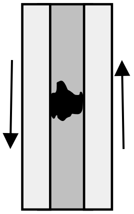
Another approach that can be used to obtain very reliable inferences on the cleanliness level of an untestable assembly is to set up dummy assemblies, e.g. ones that have a special opening that still allows for effective extraction after the assembly is fully installed and closed.

Annex 2 Cleanliness specifications and inspection strategy

A 2.1 Example damaging mechanisms

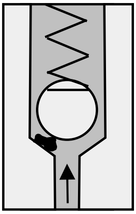
Jaming of bearings or sliding surfaces

- Turbo chargers
- Crankshaft bearings
- Dispensing pumps
- Zylinder linings



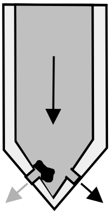
Valve blocking

- ABS, ESP
- Hydraulics
- Bake servo system



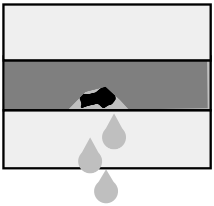
Nozzels or filters clogging up

- Injectors
- Fuel feed lines



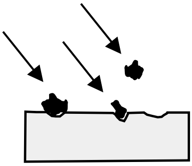
Lekage von gaskets

- Tubes
- Tanks
- Battery trays
- Elektronic housing



Surface damaging

- Ball bearings
- Sensors
- Headlamp screen



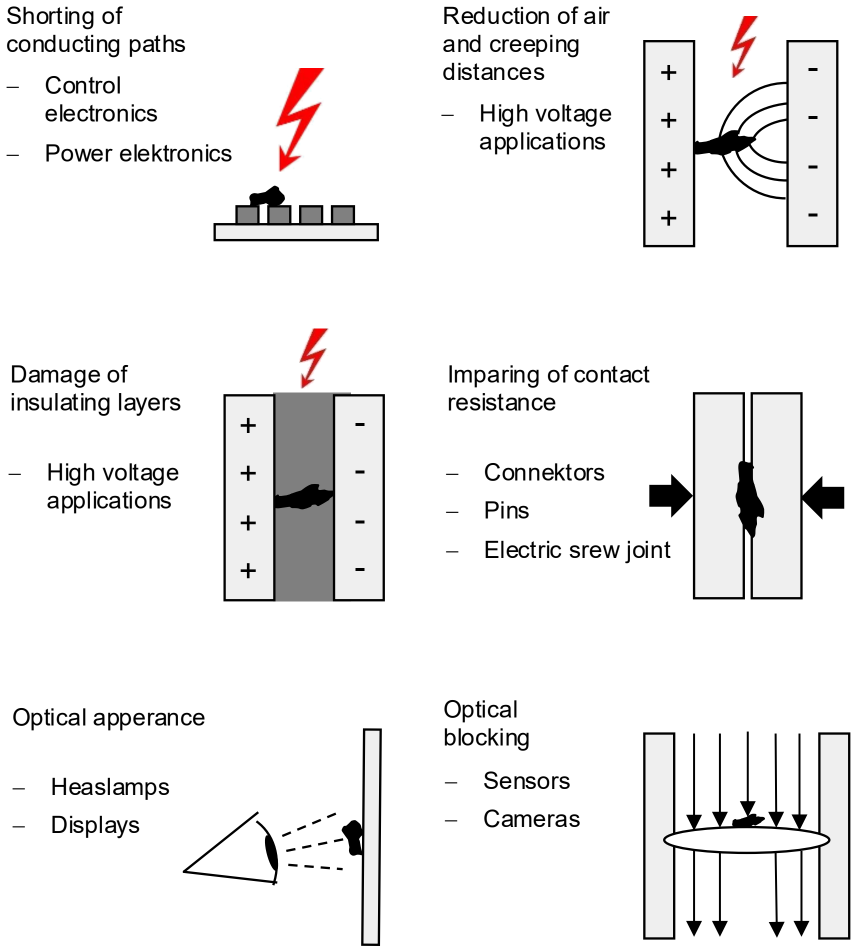


Figure 2-3: Examples of damaging mechanisms

A 2.2 Rise in cleaning costs as cleanliness limit values become tighter

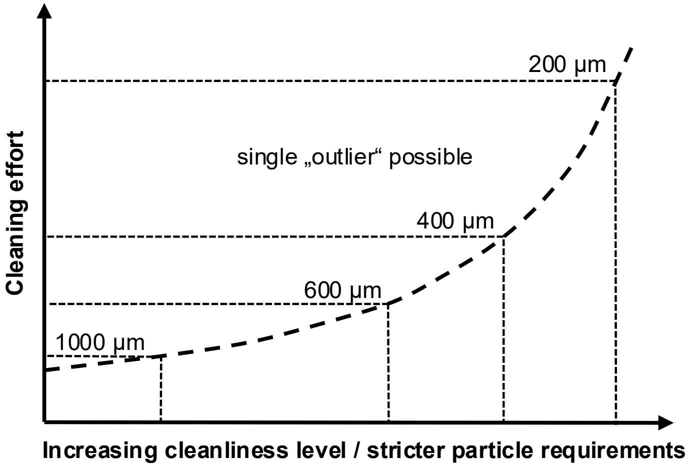


Figure 2-4: Rise in cleaning costs as cleanliness limit values become tighter

In mass manufacture, the cost of part cleaning typically rises exponentially when greater cleanliness levels, i.e. smaller permissible particle sizes, must be achieved. The reason is that higher costs do not just arise from individual points. In fact, there is a whole list of aspects that can affect the cleaning results, e.g.:

- higher new investments
- bath care/filtration
- longer cleaning times
- lower filling quantities
- better quality washing frames/baskets
- maintenance
- environment

This is only an example of cleaning. Stricter cleanliness requirements can lead to significant costs throughout the process chain – both in the production of individual parts and in subsequent assembly processes, in logistics, in the production environment and staff qualification.

Note: As of 2025, the committee for the revision of VDA 19.1 – which comprises more than 40 companies – is not aware of any mass-produced automotive components that can be manufactured reliably to a cleanliness standard of < 100 µm.

A 2.3 Recommendations for defining and dealing with cleanliness specifications

Cleanliness specifications are often defined as reasonably as possible based on the information available in order to ensure the operational reliability of a component or system. Avoiding certain pitfalls in this process facilitates the inspection of technical cleanliness and, in some cases, also the achievability of the limit values in the process chain. The following issues can lead to problems:

- Residue weights of < 1 mg are specified which are below the detection limit of most analysis scales (see Chapter 8.2.1.4), or require high investments (air conditioning, vibration damping, high-resolution scales) without providing any significant insight into the damage potential of the contaminants.

- Gravimetric cleanliness limit values and particle size distributions are specified simultaneously. Either gravimetric analysis then no longer makes sense for clean components (see preceding item) or the particles are already so densely packed on the analysis filters that, even though gravimetric assessment works well, the particles cannot be properly counted and measured.

- If only the largest permissible particle is specified, this can be a good starting point for determining a damage potential, but when evaluating cleanliness inspection results, it should be kept in mind that the largest particle or its length can be subject to large (process-related) variations. Accordingly, it is not possible to monitor a process based solely on the evaluation of the largest particle.

- Fibers are specified according to quantity and/or size without knowledge of the pervasiveness of textile fibers in production (including in class 1 and class 2 clean rooms) and in cleanliness laboratories and inspection facilities and without certainty as to the effort and expense required in order to avoid fibers, assuming it can even be accomplished.

- The metallic shine of particles is often a good indicator that particles are of metallic origin. However, it is a purely optical and optional typification that should be checked in the manual follow-up check. If too many (small) particles with a metallic shine are specified, this follow-up check can no longer be performed.

- In many cases, cleanliness inspections according to VDA 19.1 provide an initial indicator of particle damage potential in the automated analysis. An actual evaluation often requires additional inspections like the ones shown in the following examples:

    - Metallic particles are often evaluated as functionally critical, which is accurate in many cases, since they can potentially be conductive and hard. However, the precise characteristics and whether they result in a functional risk often depend on the exact material and the specific application. For example, an aluminum particle, which is potentially conductive, can be non-critical in an electronic low-voltage application due to its natural oxide layer, since it does not cause any short circuits. Furthermore, the hardness of aluminum is below that of many other metals and does not necessarily have to be functionally critical.

    - Particles that are classified as mineral in automated SEM/EDX analysis are potentially hard. The hardness cannot be reliably determined based on the elemental composition alone, however. For example, a particle detected as aluminum oxide could consist of very hard and abrasive corundum or oxidized aluminum with completely different properties.

- Cleanliness specifications per 1000 cm² of component surface area could facilitate the specification or the comparison of variously sized components with regard to cleanliness, but in certain constellations, they could also lead to problems with the cleanliness inspection or the evaluation of results. For example, if only one particle of a certain size is permitted per 1000 cm², in the case of a component with an area of 500 cm², it is impossible to say whether or not the component is within the specification if a particle of the specified size is found in the inspection. However, it is not possible to always inspect enough components to cover the specified area of 1000 cm². This issue should be accounted for when defining the unit of reference.

As these examples demonstrate, it is very important that the creation of cleanliness specifications or limit values, the development of inspection procedures and the evaluation of cleanliness inspection results be conducted by specialists or a team of specialists.

The following table shows, as an example, a purely fictitious cleanliness specification, and the text that follows explains the factors that went into it:

Table 2-1: example cleanliness specification for a component (limit value per component)

Particle size class	**All particles (excluding fibers)**	**Particles with metallic shine**
100 ≤ x < 150 µm	80	not specified
150 ≤ x < 200 µm	40	not specified
200 ≤ x < 400 µm	20	8
400 ≤ x < 600 µm	6	2
600 ≤ x < 1000 µm	2	0
x ≥ 1000 µm	0	0

Explanation of cleanliness specification:

- Textile fibers not regulated because they are not functionally critical. However, they have to be identified in the analysis in order to separate them from other particles.

- Particle characteristics and typifications that can be inspected by light-optical standard analysis are used. The smallest specified particle of 100 µm can be inspected by standard analysis, which detects particles of 50 µm and greater.

- Particle size classes with smaller particle sizes (< 200 µm) can be used for early detection of fluctuations in the manufacturing process (e.g. in cleaning) that cannot be detected due to the small particle sizes.

- Both particles with a metallic shine and non-shiny particles are specified, the ones with a metallic shine being regulated more strictly.

- For the particles with a metallic shine, only very few particles in the two largest permissible classes are specified, because it is then relatively easy to manually double-check if this typification was correctly picked up by the automatic microscope.

3 SELECTING THE INSPECTION METHOD

A cleanliness inspection method, especially one for confirming cleanliness limit values, typically comprises three steps:

- Particle extraction: In a cleaning step, the particles are detached from the component by means of a liquid or gaseous test medium or an adhesive carrier (e.g. stamp). The extraction method depends on the properties of the inspected object (component), such as size, shape, accessibility of the inspected surfaces, component material and type and adhesion of the contamination to be removed.

- Particle separation: Particles with a size relevant to the analysis are deposited on an analysis filter (or a particle trap). The type of analysis filter is selected primarily based on the size of the particles requiring analysis according to the cleanliness specification.

- Particle analysis: The particles are analyzed with regard to the relevant characteristics that are defined, for example, in the cleanliness specification. Depending on the requirement, these could be size, quantity, material or other characteristics of the particles.

Note 1: In individual cases, direct analysis of particles on an inspected object is also possible, as long as the nature of the inspected object permits this. The particle extraction and separation steps are then omitted (see Chapter 8.2.2.3.4).

Note 2: In the stamping test, the particle “separation” element is omitted or performed in the same step as the extraction.

The inspection purpose should be considered when selecting the individual elements of the inspection method (see also Figure 3-3 in the Annex). The following cases are possible:

- **Verification of cleanliness limit values:** For the verification of cleanliness limit values, reliable verification of the particle load on the inspected object required according to the specifications is of primary importance when selecting the inspection method. The inspection method to be used is subject to certain requirements, e.g. proof of adequate extraction efficiency according to a declining test, consideration of the entire relevant surface area of the inspected object as well as use of standard analysis for evaluation. It is also necessary to factor in other parameters defined in the customer-supplier relationship, which meet certain requirements from VDA 19.1, however, e.g. pixel resolution or the filter (pore size) to be used.

- **Monitoring (for process control):** Inspection methods that can provide a lot of meaningful results within a short time and indicate process changes are particularly suitable for process control monitoring. Methods that are not mentioned in VDA 19.1 can also be considered.

- **Cause research: Cause research** typically requires more specific information on particles, e.g. the material, and the methods used can sometimes be more time-consuming and costly. The appropriate inspection method to use can sometimes depend in part on whether it is necessary to obtain information on the total particle amount or on individual large particles. In line with cause research, it is generally also possible to use methods that are not mentioned in VDA 19.1, as long as they provide the necessary information.

The rest of this section focuses on the verification of cleanliness limit values.

Note 3: With certain component types, such as adhesive pads or tapes as well as permanent magnets, extraction according to VDA 19.1 may not be effective and therefore may not make sense, because the particles are stuck fast to the surface of the parts (or sometimes in case of ferromagnetic particles and magnets). In this case, it is possible to check whether there might be alternative cleaning methods not described in VDA 19.1 (e.g. wiping with a fiber-free washing medium in the case of magnets) that can be used, whether the components are suitable for direct inspection (e.g. for adhesive pads, see also Chapter 8.2.2.3.4) or whether technical cleanliness can be ensured some other way (see also Chapter 2.6).

3.1 Selecting the extraction method

The purpose of selecting an extraction method, deriving parameters for it and subsequently validating the method is to adapt and optimize a cleaning task. According to Sinner’s Circle (Figure 3-1), the following parameters influence the extraction result:

- Inspection medium (chemical cleaning component)

- Temperature

- Cleaning mechanism (extraction method with parameters)

- Time (time the component surface is exposed to the extraction method)

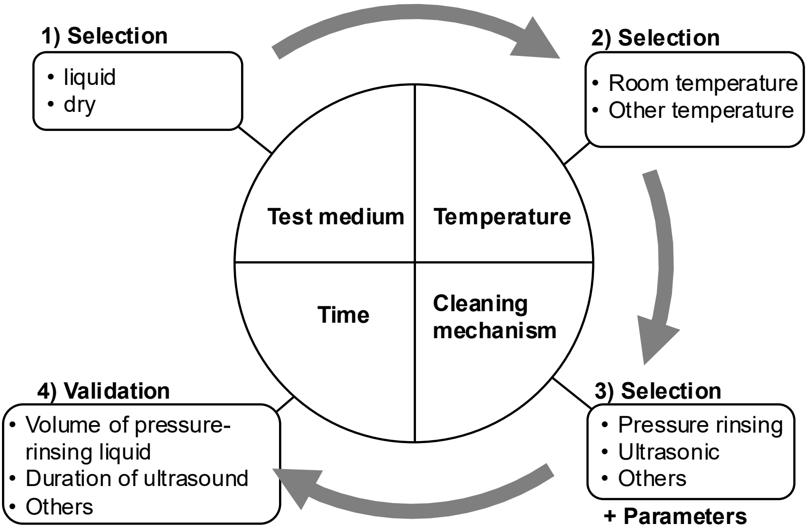


Figure 3-1: Procedure for selecting the extraction method

Note: Note that, during the extraction procedure, burrs can detach from the component. These burrs may then be detected in the component cleanliness inspection. To prevent this, only use carefully deburred components in a cleanliness inspection. If this is not possible, determine how the detached burrs should be evaluated and documented.

3.1.1 Inspection medium

3.1.1.1 Principles

A particle bonded to a component surface by forces of adhesion serves as a model for the cleaning task to be solved. The purpose of the extraction method is to overcome these forces and detach the particles.

If the particles are bound to the surface by manufacturing auxiliary materials, these materials must be removed before the cleanliness inspection. This is best done by liquid extraction. Particles with very weak adhesion or dry contact can be removed either by liquid extraction or by dry extraction (see Figure 3-2).

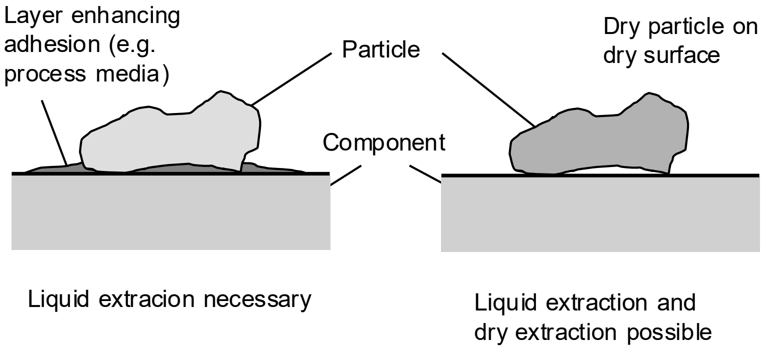


Figure 3-2: Particles bound to the component surface by forces of adhesion

Due to the different solvent effects and the cleaning forces of liquids and air transferred in a flow, there is a different basic suitability for dry and liquid extraction techniques:

- Liquid extraction: basic suitability for particles ≥ 5 µm
- Dry extraction: Particle size range ≥ 25 - 50 µm

Note 1: In the stamping test, which is a dry extraction method, the suitability ≥ 25 - 50 µm is determined by the evenness of the adhesive faces and the achievable initial cleanliness.

Note 2: The above-mentioned suitability for a particle size range is a basic suitability as far as the extraction effectiveness of the method. Factors such as the blank values achievable with the utilized extraction equipment also have to be considered when evaluating the actual suitability.

Note 3: Note that, during the extraction procedure, burrs can detach from the component. These burrs may then be detected in the component cleanliness analysis. This should be considered when selecting the extraction method if necessary.

3.1.1.2 Liquid extraction (liquid as extraction medium)

During manufacture or in operation, many functionally-relevant automotive components come into contact with fluids that can attach or remove particles, e.g.:

- Cooling lubricants

- Preservatives
- Cleaning agents
- Joining aids
- Operating fluids

For all these components, it is recommended to use liquid extraction. Tests have to be performed to determine which liquid is best suited for detaching the contaminants without corroding the component surface. For a basic overview, refer to Table 6-1 Table 6-2 in the annex. Table 6-1 shows that most process fluids used in production can be removed by means of two groups of cleaning liquids: surfactant-containing, aqueous, neutral cleaning media and non-polar solvents. In the case of the latter, particular care must be taken with regard to work safety and environmental protection.

Recommendation for extraction liquid selection:

1. Check whether aqueous, surfactant-containing, non-foaming, neutral cleaning media are suitable: These can generally be used to remove co-contaminants such as aqueous emulsions of cooling lubricants, animal and vegetable greases and oils and also amine-based anti-corrosives.

2. If they cannot be used, in the next step, check whether non-polar solvents (degreasers) such as those described above can be utilized. Non-polar solvents are often required when there are mineral oil-based lubricants or anti-corrosives present.

   Note 1: In order to ensure good solubility with the highest possible degree of occupational health and safety, it is typical to use degreasers with ISO-alkane mixtures of the chain length C10-C13 and an aroma content of < 2%, a flash point of > 60°C, a boiling range of 180 – 220 °C and a kinematic viscosity of ≈ 2 mm^2/s at 20°C for liquid extraction with solvents. They are available from various suppliers and can be considered equivalent with regard to their solvent properties in line with the indicated parameters.

3. If neither of the first two cleaner groups can be used, check if a polar solvent (e.g. ethanol) or other kind of cleaner might be suitable. This needs to be agreed in the customer-supplier relationship, and the suitability of the utilized inspection set-up must be checked.

When making this selection, always consider the compatibility of the extraction liquid and the construction material (see Table 6-2).

Note 2: In cases where steel components are returned to the production line after a cleanliness inspection, they generally need to be treated with an anti-corrosive (applied with cleaning medium or separately after extraction).

3.1.1.3 Dry extraction

Some components requiring a cleanliness inspection do not come into contact with fluids during their manufacture or subsequent operation (e.g. engine air intake components or control and power electronics). Also, some materials are damaged if they come into contact with liquids, such as air filters or paper and cardboard used in packaging materials, which may also affect cleanliness. If particles can be removed from such components without the need for a chemical solvent, it is possible to use a dry extraction method without liquids. The components must also be dried after extraction, and some components can then be returned to the production process.

3.1.2 Temperature

The inspection medium should be used at room temperature in order to minimize inspection costs and efforts (safety, comfort, heating times, energy costs, etc.). In exceptional cases, a different temperature may be required.

3.1.3 Mechanisms

3.1.3.1 Selection and adjustment of cleaning mechanisms

The cleaning mechanisms used for extraction are mostly selected based on the size and geometry of the component as well as the position of the inspection surfaces (interior or exterior or partial area). In case of components with multiple functional areas that also might have different cleanliness specifications, multiple extraction methods can also be used to inspect one component (see also Table 3-4).

With particle contamination in particular, mechanical forces can significantly improve cleaning performance. The cleaning mechanism typically performs two tasks:

- The actual cleaning task: Detaching firmly-adhering contaminants by means of strong mechanical forces.

- Final rinsing: Removal of the detached particles that may have started to re-sediment and are now adhering only slightly (to the surface of the component or extraction equipment) by means of relatively weak mechanical forces.

This third step in the Sinner's circle for selecting the extraction method (see Figure 3-1) is made up of two sub-points: "selecting cleaning mechanisms", i.e. the extraction method itself, and "cleaning mechanism parameters", i.e. defining the parameters (volume flow, ultrasound output, etc.) for the extraction. These determine the strength of the extraction performance up to the point of potential damage to the component surface. It depends greatly on the parameters with which the extraction methods mechanically influence the component (impulses, forces, etc.).

Selecting suitable parameters can require thorough knowledge of the inspected object, its production process and its subsequent use. However, if there are no well-founded specifications or empirical information available that would stipulate the use of certain extraction parameters, then it is advisable to use the recommended start parameters that are suggested for the given extraction method (see Chapter 6).

3.1.3.2 Liquid extraction

Liquid extraction can be done by four different extraction methods – pressure-rinsing, ultrasonics, internal rinsing and agitation (see also Table 3-4 in the annex).

Pressure-rinsing/low-pressure rinsing: Pressure-rinsing with spray nozzles is suitable for directly accessible surfaces with large areas that can be cleaned with parallel jet nozzles or fan nozzles. Internal surfaces or external areas that are difficult to access can only be cleaned to a certain extent with nozzles. For such areas as cannot be accessed directly with a spray jet, spray lances with a small diameter may be useful, e.g. inserted into blind holes.

Advantages: The pressure-rinsing method of extraction is very universally applicable and can be adapted to many extraction tasks.

Disadvantages: Detached particles are distributed over a large area, so that a costly final rinsing step required. The large wetted surface areas of the extraction equipment make it more difficult to attain low blank values. In addition, there is a strong operator influence, given that the procedure is typically manual.

Note 1: Spray nozzles can also be used for internal extraction by inserting them directly into tubing or bores and pipe apertures with small diameters, for example. However, this only applies for the extraction method “internal rinsing”, where the spray nozzle merely functions as an adapter to connect the rinsing line to the component.

The pressure-rinsing method of extraction comprises two areas: **low-pressure rinsing**, in which extraction is mostly determined by the cleaning effect of the liquid running over the surface, and **pressure-rinsing**, in which the impulse of the jet hitting the surface provides an additional cleaning effect. Table 3-1 describes selection criteria for the different areas of the extraction method “pressure-rinsing”.

Table 3-1: Selection criteria for extraction by pressure-rinsing and low-pressure rinsing

Low-pressure rinsing Flow rate < 1 l/min with 2.5 mm round nozzle	**Pressure-rinsing** Flow rate ≥ 1 l/min with 2.5 mm round nozzle
Contaminants for which the detaching and washing effect of the extraction medium is sufficient	Contaminants that require an additional impulse of the jet hitting the surface
Smaller parts that are not fixed and could be “sprayed away” by a stronger jet	Fixed or larger parts that cannot be “sprayed away”

Note 2: Enclosed extraction equipment can be used both for the low-pressure rinsing range and for pressure-rinsing. When open pressure-rinsing equipment or glassware is used, using the parameters for the pressure-rinsing range leads to the risk of particle loss and/or health or safety risks due to the extraction liquid spraying out. For this reason, this extraction equipment is typically only suitable for the low-pressure rinsing range.

Ultrasonics: Ultrasound baths, into which components are completely immersed, are used to clean objects with simple external geometries. With this extraction method, which is especially suitable for small bulk goods, components are either placed in ultrasound-permeable baskets (see Chapter 6.4.3.2 Note 2) in baths specially constructed for cleanliness analysis with an outlet to analysis filtration, or in beakers that are placed in standard laboratory ultrasound baths.

Where ultrasound baths are utilized to clean the inner surfaces of components, it must be verified that the cleaning effect in the interior is adequate. In general, this becomes more and more difficult the smaller the aperture becomes for the ultrasound waves to enter, the deeper the internal geometry to be cleaned penetrates into the component, and the broader the dimensions are of the cavity concerned.

Advantages: Ultrasonic cleaning is easy to perform, reliably reproducible and only marginally influenced by inspection staff. The inspection set-up for small parts can be achieved relatively cheaply. Moreover, the smaller wetted surface areas allow for lower blank values.

Disadvantages: If inappropriate parameters are set, cavitation effects may cause material to detach from the inspected objects (e.g. in very small particle size ranges), which is then falsely recognized in the analysis as particulate contamination. Extraction-related parameters in the ultrasonic bath can be determined without inspected objects, but if the bath or tank is loaded with inspected objects, the actual cavitation effect on and between the inspected objects is difficult to test.

Internal rinsing: Internal rinsing is suitable for extracting particles from the inner surfaces of many components, e.g. for:

- Active sub-assemblies (e.g. pumps, injectors), inspected in internal rinsing systems while activating the components concerned.
- Pipe-shaped passive components that are much longer than the size of the inlet/outlet and whose internal cross-section is similar to the diameter of the inlet and outlet.

With internal rinsing, the extraction liquid is fed into the component via adapters, and the complete inner geometry of the component to be sampled is always wetted.

After flowing through the interior of the component, via an adapter and tubing or piping, the liquid is then advanced to the filtration unit, or drains off the component directly into an extraction bath (liquids may not come into contact with the exterior of components). In order for the internal rinsing step to be effective, a turbulent flow through the interior of the component is required.

Advantages: By adapting rinsing lines, it is possible to easily separate the inspection surface from non-relevant surfaces. Since the wetted surface areas are limited, and the influence by inspection staff is marginal, a low blank value level is achieved. For many fluid-conducting components this is the best extraction method, because it simulates real vehicle conditions.

Disadvantages: Inspection set-ups/internal rinsing systems may be highly complex where high flow rates (components with large internal cross-sections) or active components (e.g. switched, powered or driven) are concerned. By adapting rinsing lines to the inspected objects, abrasion from joining processes (screwing, pushing, pressing, etc.) may occur, which could be falsely recognized as contamination originating from the component.

Agitation: Agitation is a suitable method for extracting particles from simply-shaped, spacious inner areas of components without narrow cross-sections or apertures that are difficult to seal. It is not suitable for narrow pipes or capillaries, because the extraction medium cannot be sufficiently agitated to remove particles effectively.

Advantages: This method is simple and allows for low blank values since the wetted surface areas are small. It can often be implemented with very little equipment.

Disadvantages: The method is only suitable for use on a very small spectrum of components. Cannot be performed manually on large inspected objects (weight of inspected object + extraction liquid).

Note 3: The term “agitation” always refers to extraction from inner surfaces. A procedure for extracting particles from the outer surfaces of components (one or several) by immersing them in a receptacle filled with liquid and subsequently carrying out an agitation or swilling step is not foreseen in VDA 19.1 (risk of component abrasion).

3.1.3.3 Dry extraction

There are four different methods of dry extraction – air jet extraction, which corresponds to the pressure-rinsing process in liquid extraction, or flow-through extraction of the inspected object, similar to rinsing extraction with liquid, (brush nozzle) suction and the stamping test (see also Table 3-5).

Air jet extraction: With this extraction method, particles are removed from the inspected object by a jet of clean, oil-free compressed air. The method is suitable for external surfaces, or for inner component surfaces that can be easily accessed by the jet of compressed air. It is used for electronic components, components forming part of engine air intake systems where the throughflow method cannot be applied, or for logistics packaging such as blister packs, small load carriers or cardboard.

Advantages: This extraction method can also be applied to components that would be damaged if they came into contact with a liquid. Furthermore, there is no need to dry the components, and the extraction equipment can also be used for liquid extraction.

Disadvantages: A complex enclosed extraction set-up with compressed air and liquid medium supply is required. The extraction is only effective in locations that are reached by the compressed air jet (no rinsing effect as with liquid extraction).

Air throughflow extraction: With this type of extraction, air is usually guided through the inspected object in a specially-constructed inspection apparatus. The method is suitable for evaluating the cleanliness of inner surfaces of air conducting components (e.g. of engine air intake systems) or components that cannot be sampled with liquid. With this procedure, large volumes of air are guided through component cross-sections several centimeters in diameter.

Advantages: Using adapters connected to piping systems makes it easy to separate the inspection area from non-relevant component surfaces. For air intake components, this is a particularly good extraction method, since it simulates real vehicle conditions. This method can also be used to inspect air filters, which are not compatible with liquids. Another advantage is that the inspection medium leaves no residues in the inspected object.

Disadvantages: Complex inspection apparatus and the production of component-specific adapters are necessary. Moreover the implementation is time-consuming due to the preparation of primary analysis filters for air which then have to be manually re-prepared as secondary analysis filters for liquid.

(Brush nozzle) suction: In this extraction method, particles are removed from the surface of the inspected object by suction. In suction extraction, a suction nozzle is passed over the surface of the inspected object at a defined distance. The extraction effect can be enhanced by using a brush attachment on the suction nozzle which is attached with contact but without pressure. Note that the component surface can be damaged if it is touched by the bristles (e.g. abrasion, charging effects).

Advantages: The inspected objects do not need to be placed in a chamber or tank for extraction. So extraction can also be performed in production areas outside of a cleanliness inspection laboratory and on large and unwieldly components. Since air is used as an extraction medium, the inspected objects do not need to be dried.

Disadvantages: The suction effect only works if the suction nozzle can be held very close to the inspection surface. The cleanliness of the ambient air that is used as an extraction medium largely determines the achievable blank values and thus has an influence on the result of the component.

Stamping test: With this method, an adhesive surface (adhesive pad) is pressed onto the surface of the inspected object by a stamp, and the particles are transferred onto the adhesive pad as the stamp is lifted off. Therefore, particles are extracted and deposited onto a surface for later analysis in a single step.

Advantages: The stamping test is easy to implement and can be used directly in production, so there is no need to transport components to the laboratory. The precisely delineated extraction area makes this method especially suitable for inspecting part surfaces with cleanliness specifications.

Disadvantages: Disadvantages: The stamping test can only be used for accessible, even or convex surfaces, not for concave surfaces, recesses or narrow inner spaces. It is also not suitable for rough surfaces and large component areas.

3.1.4 Time

The suitable extraction time is determined for each component and not derived based on the component geometry or type of contamination as with the other parameters. This is done by repeating individual extraction steps and determining the decline in the extracted particle load, which is called the “declining test” (see Chapter 5). Even though the volume of inspection liquid is used for qualification in some methods, the actual parameter that is qualified is the extraction method’s contact time on the component surface.

3.1.5 Final rinsing

The final rinsing procedure is done after the actual extraction step but can (partially) take place at the same time, depending on the technical design of the inspection set-up (e.g. with internal rinsing). The final rinsing procedure has the following tasks:

1. In the final rinsing procedure, the particles removed from the inspected objects in the extraction process are entirely rinsed or transported onto the analysis filter (or another carrier that undergoes analysis).

2. If multiple inspections/extractions are performed in a row (same or different inspected objects), the final rinsing procedure of the current extraction is the conditioning of the extraction apparatus for the following extraction.

The final rinsing procedure can be performed with the same and/or other tools and parameters as the extraction.

The necessary final rinsing time and quantity depends on the extraction apparatus, the auxiliary materials and equipment used and, under certain circumstances, the quantity and type of the particles and substances brought into the inspection equipment during extraction. The strictly applicable minimum final rinsing time and quantity (minimum final rinsing procedure) is the amount required in order to carefully and thoroughly cover all the relevant areas with extraction medium or another final rinsing medium without having to remove large amounts of firmly adhered particles or difficult-to-remove substances. The effectiveness of the final rinsing procedure is verified in the process of qualifying the extraction and developing the routine inspection (see Chapter 5).

3.1.6 Start parameters

After selecting the extraction method (cleaning mechanism), which is essentially determined by the size, shape, material and location of the component surfaces requiring inspection, there is considerable leeway regarding the specific parameters that can be chosen (e.g. diameter of the spray nozzle, volume flow, ultrasound frequency, etc.). In order to obtain maximally comparable extraction results (and thus also analysis results), it is best to start qualification tests using the start parameters recommended in Chapter 6.

Note: To optimize an extraction procedure for a specific component with regard to particle detachment (without damaging the component surfaces concerned) or extraction time, start parameters may be modified provided they are checked and documented appropriately.

3.2 Selecting the filtration method

Through the increasing use of optical analysis, in which particles are counted and measured on analysis filters, the careful selection and execution of the filtration procedure are crucial to the quality of the later analysis step. Analysis filters are chosen according to their compatibility with the extraction liquid and their capacity to retain particles. To ensure that the correct particles are retained by the analysis filter, the particle sizes stated in the cleanliness specification are of the utmost importance. Another aspect is the kind of particles (materials, colors, etc.) that are relevant and should be detected in the analysis (contrast between particles and filter background for detection with image processing).

3.3 Selecting the analysis method

The analysis method is selected according to the particle characteristics indicated in the cleanliness specification for the inspected object and according to the purpose of the analysis.

3.3.1 Verifying cleanliness limit values

The cleanliness limit values must be reviewed in the customer-supplier relationship. VDA 19.1 describes possible analysis methods and the particle characteristics that can potentially be analyzed. It also sets minimum requirements (e.g. optical resolution). There are two equally effective ways to perform this limit value inspection:

1. One is “standard analysis”, in which additional parameters are defined for implementing the analysis methods, so they can be used

with no need for further arrangements in the customer-supplier relationship. These standard analyses cover a wide range of cleanliness specifications and issues.

2. A free analysis in line with the minimum requirements that can be adapted to the specific issues under investigation or particles to be verified. The technology and analysis parameters used must be arranged and documented in the customer-supplier relationship.

Cleanliness limit values can be checked using the following analysis methods:

- Gravimetry:

  Gravimetry is used to determine the total mass of all particles extracted from the component and deposited on the analysis filter.

- Light-optical analysis:

  With light-optical standard analysis, microscopes, flatbed scanners, light-optical measuring cells, measuring heads or camera systems are used to determine particle size distributions for particles of ≥ 5 µm, as long as the measuring system can meet the prerequisites for the pixel criterion, even for the smallest particle size. (Otherwise, the particle size distribution is only possible for larger particles). It is possible to measure the length and/or width of particles and determine their level of (metallic) shine.

  The use of light-optical analysis methods requires trained staff that not only know how to operate the systems but also need to be able to double-check the measurements and typifications to an extent.

  Light-optical standard analysis was developed in order to accurately detect dark and metallic particles ≥ 50 µm on white analysis filters (**standard filters** also defined) with incident illumination in microscopes and scanners. Parameters such as image brightness and threshold values for image processing are defined in order to make analysis results more comparable.

  In **free light-optical analysis**, the illumination and evaluation over image processing but also the selection of analysis filters can be adapted to suit the inspection task (smaller particles, low-contrast particles, etc.). If the minimum requirements with regard to pixel resolution and pore size of the analysis filters are met and the methods are agreed in the customer-supplier relationship, then specially optimized cleanliness limit value inspections can be performed.

- Automatic SEM/EDX analysis:

  In this type of analysis, automatic SEM/EDX systems can be used to determine particle size distributions for particles ≥ 5 µm based on length and/or width and assign particles to their material classes based on their elemental composition, as determined by X-ray spectroscopy.

  Due to the different contrast mechanisms with light-optical and scanning electron microscopy systems, the particle counter results of the different analysis methods are not comparable.

  SEM/EDX standard analysis was developed to accurately detect particles larger than 50 µm comprising elements with atomic weights heavier than that of carbon on carbon-based filter membranes (**standard filter** also defined) with backscattered electron detectors. The percentage by weight of the elements that make up the particles is determined by X-ray spectroscopy (EDX). In order to make analysis results more comparable, parameters such as image brightness and threshold values for particle detection image processing are defined, as well as consistent material classes in which the particles are grouped based on their elemental composition.

  In **free SEM/EDX analysis**, the settings and parameters for image formation, particle detection and X-ray analysis can be adapted to the inspection issues that are cannot be covered by standard analysis. Different material classes can also be defined. To the extent that the methods are agreed in the customer-supplier relationship, specially optimized cleanliness limit value inspections can be performed.

3.3.2 (Process) monitoring

For (process) monitoring, it is possible to use simplified or differently parameterized analyses according to VDA 19.1 or other methods not covered in VDA 19.1 at regular intervals during production. The results of these analyses should be available early enough to allow for effective process monitoring and control.

Note: Standard or extended analysis methods can also be used for process monitoring if they are used on a regular basis.

There are two different approaches to (process) monitoring:

- Inspections on components: Regular cleanliness inspections can be performed, using limit value inspection methods as described in VDA 19.1 (with standardized parameters or modified parameters). In order to obtain faster results and thus more data for process monitoring, the methods can also be simplified, e.g. only proportionate, non-full-surface extraction of the inspected objects or evaluation of analysis filters. But it is also possible, for example, to use optical particle counters with which the particle dimensions cannot be determined precisely but which do not require analysis filtration. Moreover, there are many other methods outside of VDA 19.1 that could be considered and that could provide information on the cleanliness state of a component and its change over time.

- Inspections of cleanliness-related influencing variables: This includes influencing variables as described in 19.2, e.g. joining processes, assembly environment, packing or operating fluids that can affect the cleanliness of components or assemblies. Corresponding monitoring methods are also described in VDA 19.2. The cleanliness and quality of process auxiliary materials such as cooling lubricants or cleaning media is also included in this point but is not further discussed in VDA 19.1.

3.3.3 Extended analysis

If any further questions arise from the limit value inspection results, monitoring data or damage cases, extended analysis methods can be used for more detailed characterization.

They provide information on the type and, accordingly, the potential origin of particles and are used:

- for process optimization,
- to search for causes (sources of damaging particles),
- in conjunction with the response to limit value exceedances,
- and if the cleanliness specification includes requirements in the form of certain characteristics (e.g. particle height) which could not be determined using the methods designated for the verification of cleanliness limit values (see Table 3-2).

The application of extended analyses can require a lot of effort and higher costs.

Extended analyses are used when the following additional information on the contaminant particles is needed:

- geometric characteristics of particles other than length and width, e.g. the third dimension
- material identification

The following tables (see Table 3-2 and Table 3-3) present an overview of the described analysis methods and their areas of application.

Table 3-2: Analysis methods and possible applications

Analysis method		**Purpose of analysis**			
		Validation of cleanliness specification		**(Process) monitoring**	**Extended analysis**
		Standard analysis[1]	**Free analysis[2]**		
Gravimetry		+	+	+	-
Scanner 2D		+	(+)	+	-
Light microscope	2D	+	+	+	+
	3D	-	-	-	+
Additional light-optical measuring cells, probes, camera systems		(+)	+	+	+
SEM/EDX		+	+	-	+
Computer tomography		-		-	+
LiBS		-		-	+
Raman		-		-	+
Infrared		-		-	+
Optical particle counter		-		+	-

1 Without arrangement with customer, comparable but with limited range of application

2 After arrangement with customer but without additional restrictions (except minimum requirements), the comparability of the results can be limited

+	suitable
(+)	essentially suitable, if measurement system requirements met
-	not suitable or not designated by VDA 19.1

Table 3-3: Analysis methods, significance and limits

Procedures	**Information**						**Limitations**
	Total residue weight	**Particle size**			**Other characteristics**		
		Length	**Width**	**Height**	**Metallic shine**	**Material**	
Gravimetry	x						No information on single particles or material-/size-specific differentiation
Scanner		x	x		(x)[2]		Can only be verified on the image, greater optical magnification or other contrast methods not possible
Light microscope		x	x	(x)[1]	(x)[2]		Potentially not all options usable with one lens
Additional light-optical measuring cells, probes, camera systems		x	x		(x)		system-specific
Computer tomography		x	x	x[5]			Prolonged analysis times
SEM/EDX		x	x			x	No differentiation of organic particles
LiBS		x[3]	x[3]			x	No differentiation of organic particles
Raman		x[3]	x[3]			x	Metals not detected, limitations with fluorescing and black particles
Infrared		x[3]	x[3]			x	Only organic particles, no fully-automated analysis
Optical particle counter		x[4]					Sensitive to interference from air bubbles

() Depending on lenses and model

[1] Possible with material microscopes with small depth of field

[2] Prerequisite: manual follow-up check

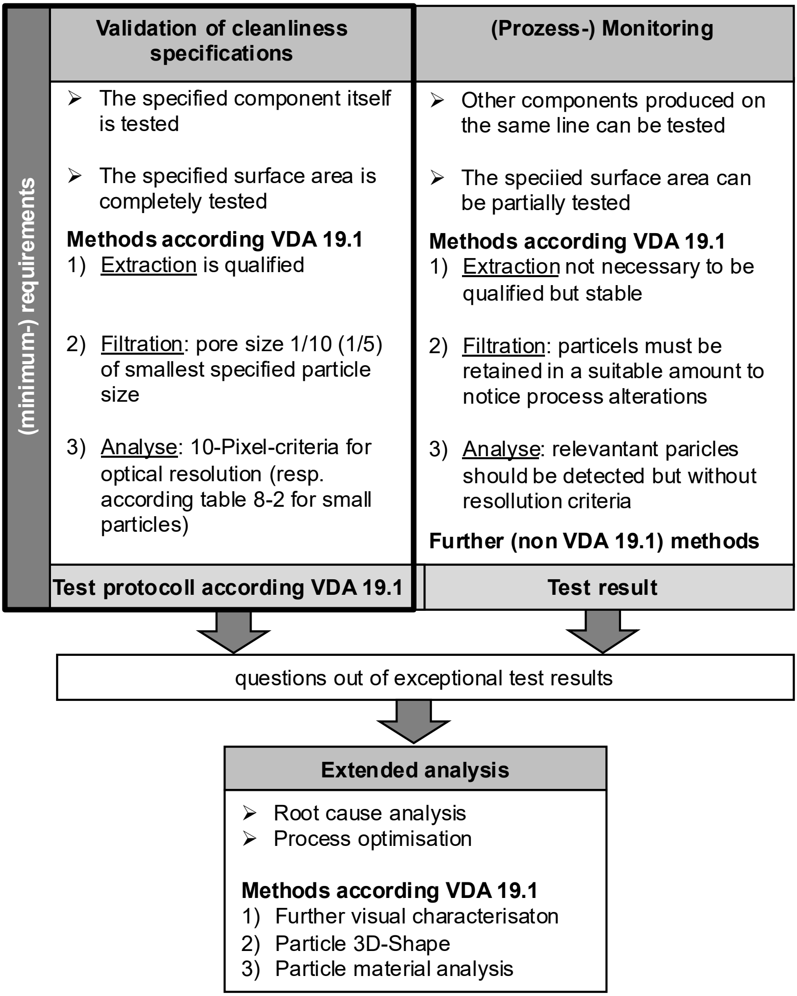
[3] Material analysis coupled with automated light-optical particle detection

[4] Size often determined by the diameter of a circle with an equivalent surface area

[5] Here, all size information can be determined (volume, thickness, cross-section, etc.)

Annex 3 Selecting the inspection method

A 3.1 Purpose of analysis



Validation of cleanliness specifications

- The specified component itself is tested
- The specified surface area is completely tested

Methods according VDA 19.1

1) Extraction is qualified
2) Filtration: pore size 1/10 (1/5) of smallest specified particle size
3) Analyse: 10-Pixel-criteria for optical resolution (resp. according table 8-2 for small particles)

Test protocoll according VDA 19.1

(Prozess-) Monitoring

- Other components produced on the same line can be tested
- The speciied surface area can be partially tested

Methods according VDA 19.1

1) Extraction not necessary to be qualified but stable
2) Filtration: particels must be retained in a suitable amount to notice process alterations
3) Analyse: relevantant paricles should be detected but without resollution criteria

Further (non VDA 19.1) methods

Test result

questions out of exceptional test results

Extended analysis

- Root cause analysis
- Process optimisation

Methods according VDA 19.1

1) Further visual characterisaton
2) Particle 3D-Shape
3) Particle material analysis

Figure 3-3: Purpose of analysis

Note: For information on qualification tests, refer to Chapter 5; for information on selecting a suitable filter pore size, refer to Figure 7-3, and for information on a suitable optical resolution, refer to Table 8-4.

A 3.2 Examples of component characteristics and suitable extraction methods

Table 3-4: Liquid extraction: Examples of component characteristics and suitable extraction methods

Extraction method	**Component characteristics**	**Examples**
Pressure-rinsing <u>or</u> ultrasonics	Small components, several millimeters to a few centimeters in size, difficult to handle individually, for extraction in bulk (total component surface area)	Ball bearings, gaskets, screws, springs, O-rings, etc.
Pressure-rinsing	Small to large components, a few centimeters to over one meter in size (total component surface area)	Conrods, pistons, gears, housing parts, camshafts, rotors, stators, etc.
ultrasonics	Small to medium-sized components, a few centimeters to a few decimeters (total component surface area) limited by size of US tank	Rotor shaft, stator assembly, etc.
Internal rinsing	Component areas with good throughflow properties, with connector cross-sections and interior cross-sections sized between a few millimeters and several centimeters (inner area)	Tubing, piping, filter housings, heat exchangers, cooling channel of power electronics, etc.
Internal rinsing <u>or</u> pressure-rinsing	Inner component surfaces with connector cross-sections and interior cross-sections in the centimeter range; can be inspected by internal rinsing and also accessible for pressure-rinsing	Hydraulic valve blocks, pipe or tube connections, turbo-charger housing, rails, etc.
Internal rinsing <u>and</u> pressure-rinsing	Components with separate functional areas, of which some are suitable for extraction by pressure-rinsing (exterior) and others by internal rinsing (interior), (one after the other on different analysis filters)	Cylinder crank housing, crankshafts, etc.
Agitation	Geometrically simple inner surfaces of components without narrow cross-sections and with few easy-to-seal openings (handling limit with manual extraction: weight of component + extraction liquid)	Compressed air tanks, coolant containers, etc.
Agitation <u>or</u> Internal rinsing	Inner surfaces of components with good throughflow properties and few easy-to-seal openings (cross-sections of apertures and inner areas in lower centimeter range)	Piping, simple heat exchangers (with cross-sections that are not too narrow,) etc.
Agitation <u>or</u> Pressure-rinsing	Geometrically simple inner surfaces of components without narrow cross-sections, with few easy-to-seal openings and apertures with large cross-sections	Tanks, short fat pipes, etc.

Table 3-5: Dry extraction: examples of components and suitable extraction methods

Extraction method	Component characteristics	Examples
Air jet extraction	**External areas or inner surfaces of components accessible by a jet of compressed air**, which do not come into direct contact with liquid during their manufacture or operation and which would be damaged if they came into contact with liquid	Electronic printed circuits, multi-layer electronics, electric motors, (optical) sensors, single components of air intake tracts not suitable for air throughflow extraction, packaging (SLC, blisters, cardboard,) etc.
Air throughflow extraction	**Inner component surfaces with good throughflow properties** which do not come into direct contact with liquid during their manufacture or operation and which would be damaged if they came into contact with liquid	Tubing, housing, filters, manifolds, bellows in air intake tract, etc.
(Brush nozzle) suction	**Outer and inner component surfaces accessible for the suction nozzle**, which do not come into direct contact with liquid during their manufacture or operation and are free of adhesion-strengthening residues and which would be damaged if they came into contact with liquid; components that can only be inspected in production due to their size or weight	Electronic printed circuits, cable harnesses, battery trays, housing, packaging (SLC, blisters, cardboard, paper), film, insulation, etc.
Stamping test	**Accessible, even surfaces**, dry without adhesion-strengthening residues, not too rough (no rough cast surfaces)	Adhesive and sealing faces, permanent magnets, etc.

Note: The component characteristics listed in Table 3-4 and Table 3-5 for the extraction methods are examples that cover a variety of application examples. Under certain circumstances, it may be possible to use one of the aforementioned extraction methods to inspect components with characteristics that differ from this description, e.g. if a suitable extraction apparatus is available.

4 HANDLING COMPONENTS CLEANLY

4.1 Principles

Technical cleanliness is not a constant feature of a component but rather a temporary condition that is influenced by external factors. It should therefore be stipulated in the customer-supplier relationship when and where a cleanliness specification is to be performed (for example, after cleaning, on arrival at the assembly line or at another point in time).

In order for inspected objects to be received in a representative state, sequences and conditions have to be rigidly upheld from the point of removal up to the point of arrival at the inspection facility. This also applies to deviations from serial conditions when transporting an inspected object to the inspection location (such as the use of different packaging or a different transport pathway). As it is essential that inspected objects are handled in a clean manner, workers performing such inspections must be appropriately trained and instructed.

The following factors may influence the state of cleanliness of the inspected object on its removal from the process chain:

- Handling
- Packaging
- Transport
- Environmental conditions
- Warehouse
- Preparatory steps before the inspection (e.g. inserting plugs, disassembly or affixing mounts).

In cases where inspected objects are returned to the production line or reused, appropriate cleanliness regulations may be required, e.g. treatment with an anti-corrosive or the use of an unused plastic bag.

Detailed assistance on evaluating influencing factors and maintaining the cleanliness state of components is provided in **VDA 19 Part 2.** To evaluate a cleanliness laboratory, refer to the annex for a recommendation for a questionnaire (see Table 4-1).

4.2 Selected measures and recommendations

4.2.1 Staff

Responsibilities regarding the complete inspection process, from removal of the inspected object until its return, must be defined.

Staff must meet the prerequisites and have the necessary skills to perform work in a cleanliness laboratory. These can include aspects of a chemical/material laboratory as well as aspects of a measuring room. Members of staff involved in the inspection must be made aware and instructed on how to handle inspected objects cleanly.

Depending on the job performed by a staff member in a cleanliness laboratory (e.g. extraction, analysis, documentation, interpretation of cleanliness inspection results, etc.) different training topics could be required, e.g.:

- Understanding the meaning of cleanliness as a quality criterion as well as how it differs from other specified quality parameters and their measurement/detection without extensive sample preparation, e.g. of a dimensional accuracy

- Knowledge of the current version of VDA 19.1

- Understanding and interpreting cleanliness specifications

- How to unpack, handle, prepare and store inspected objects while preventing the loss or addition of particles

- Understanding the meaning of the blank value and the criteria (blank value criterion) to be met as well as how the blank value is determined

- Information on the conditioning of extraction equipment in preparation for extraction procedures, verifiable with repeated blank value inspections

- Selecting suitable extraction methods and parameters based on the size, morphology and materials of the inspected objects as well as evaluating their suitability based on declining curves

- Interpreting declining curves in order to assess the suitability of extraction methods
- Selecting the appropriate extraction method based on the type of contamination as well as the material, size and geometry of the inspected object
- Performing the extraction and final rinsing steps without particle loss, verifiable with recovery tests
- Selecting the right filter pore size and the appropriate filter material
- Determining the right temperature and drying duration as well as the cooling time in the desiccator for gravimetric analysis
- Information on the handling, preparation and storage of filters while preventing the loss, addition and damage of particles
- Information on the functionality of image acquisition systems (microscope, scanner, etc.)
- Information on image analysis (pixel size, gray value, etc.)
- Information on the functionality of scanning electron microscopes for particle analysis
- Information on conducting SEM-EDX inspections/
- Information on double-checking and interpreting the results
- Information on the maintenance and calibration of the equipment

4.2.2 Packaging

The packaging selected for delivering the inspected object to the cleanliness laboratory depends on the purpose of the inspection and the validity of the cleanliness specification. There are two basic questions to consider:

- The cleanliness of the inspected object should be checked in a defined delivery state as specified in the customer-supplier relationship. In this case, if possible, it is best to use the **standard transport packaging** or **series packaging** which is also used for delivery to the cleanliness inspection location. This way, the influence of the packaging on the cleanliness state of the inspected object is accounted for.

- The cleanliness of the inspected object should be checked after a certain process step, e.g. after a cleaning or assembly process. The cleanliness state of the inspected object should be maintained and not affected or not significantly affected by the packaging. In such cases, a **test packaging** is used which, if possible, should meet the following requirements:

    - no generation of particles (e.g. due to abrasion during transport)

    - no loss of particles

    - no damage to inspected objects

    - no packaging residue left on the component or transferred inside the component

    - no contamination from the environment (sealed packaging)

    - no surface changes to the component due to corrosion

These requirements for the test packaging apply throughout the entire transport process, the handling and the storage as well as under the given environmental conditions (including climatic variations).

Foils and bags that are in direct contact with the inspected object must be clean and unused (disposable packaging). Cardboard is not suitable as a direct means of packaging for inspected objects because it generates large quantities of particles.

Reusable packaging, which objects are placed into directly, must be cleaned before use.

The same applies for closures: They may not cause any mechanical damage to the inspected object during assembly and disassembly. Self-cutting closures may not be utilized.

If multiple components are placed together loose in a packaging unit, there is a risk of them striking/rubbing against each other during transport (material abrasion), causing particles to detach.

Note 1: The packaging should be appropriately labelled so that inspected objects can be clearly identified.

Note 2: If the cleanliness of the test packaging is subject to a similar criterion as that applied to the blank value, the influence of the packaging on the cleanliness value of the inspected object(s) is very low. Attention: This cannot be applied to the series (reusable) packaging, since this can result in a very high packaging cost and is technically unfeasible.

Note 3: During the transport of inspected objects to the cleanliness inspection location, particles can fall or detach from the inspected object and then collect in the transport packaging. If the component-facing interior of the packaging is also inspected for cleanliness, these particles can be accounted for. This must be documented in the inspection specification.

4.2.3 Storage and transport

So as not to impact the cleanliness state of inspected objects, the following conditions must be met:

- shortest routes possible
- fastest times possible
- minimal vibration
- protection against damage inside the packaging
- safe from damage to the packaging
- where applicable, additional protection from wetness, humidity and temperature fluctuations

It is recommended that outer packaging and storage areas intended for inspected objects be specially marked.

4.2.4 Facilities for inspecting cleanliness

The necessary inspection environment is always indicated in the cleanliness specification of the inspected object. It is recommended that the area be physically separated from other areas (e.g. clean room). The suitability of an inspection environment can be confirmed by means of a blank value determination.

The suitability of the inspection environment does not necessarily depend on a (specific) clean room class. The installation of clean air technology to create a defined air cleanliness class according to ISO 14644 may not be required. It is only important that the blank value is reliably attained because this may also reflect possible environmental influences.

Where required by the inspection (blank value), create separate clean areas (e.g. clean tool bench).

The handling and potential disassembly of inspected objects should also take place under environmental conditions that comply with the cleanliness requirements.

The methods and frequency of cleaning of floors, equipment, devices and workspaces depend on the contamination level and cleanliness requirements of the inspected objects.

Note: Even in a high-quality inspection environment such as a clean room, inspected objects can be contaminated due to particles generated from assembly/disassembly processes or cross-contamination, etc. Cross-contamination can occur due to particles being carried over from various sources, e.g. due to contaminated exteriors of test packaging or other contaminated surfaces or objects.

4.3 Exclusion from an inspection – invalid inspection

4.3.1 Deviations from required state on delivery

In case of issues with the inspected object or its packaging which may have affected its state of cleanliness, the inspection may not be performed.

Recommended further action:

- Document the discrepancy or deviation from the means of packaging specified
- Inform all people involved before or after the inspection
- Label the component and proceed with relevant instructions, e.g. return or destroy it

Typical exclusion criteria include missing or damaged inner packaging, unsuitable packaging materials, moisture, corrosion, component damage, visible foreign contamination, e.g. splinters, etc.

If a component is inspected despite such issues, this must be documented in the inspection report.

4.3.2 Deviations and errors in the inspection procedure

Any deviations to or incidents occurring during the actual cleanliness inspection must be documented in the inspection report. If there is a possibility that they may have falsified results, the determination of cleanliness values is meaningless and their documentation in the report not permitted.

Annex 4 Clean handling

A 4.1 (Self-) audit questionnaire

The questionnaire presented below contains a selection of questions that can be used for a cleanliness laboratory self-audit and should be adapted to the conditions of the space, staff and equipment.

Table 4-1: (Self-) audit questionnaire

1	**Testing environment**
1.1	Is there a suitable inspectoin environment (recommended: at least a class 2 clean room)?
1.2	Is the inspection environment marked and clearly delineated so as to exclude the possibility of impermissible particle carry-over into the inspection environment?
1.3	Is there a cleaning plan?
2	**Staff**
2.1	Is the staff trained?
2.2	Is there a clothing concept?
2.3	Does the staff have awareness of cleanliness-conscious handling practices?
3	**Extraction**
3.1	Is a blank value determination performed regularly?
3.2	Is the extraction performed according to a qualified inspection specification (declining test, final rinsing procedure review)?
3.3	Is adequate particle recovery (min. 90%) ensured on the utilized extraction apparatuses?
3.4	Are declining tests performed with the start parameters or, in case of differing parameters, with appropriate justification?
4	**Filtration**
4.1	Is a 5 micron sieve cloth filter used for the standard analysis?
4.2	Is a suitable filter used for the free analysis to determine specified particle counts/sizes?
5	**Gravimetry**
5.1	Are gravimetric tests performed?
5.2	Is at least a four-digit scale (readable to 0.1 mg) available?
5.3	Is the scale calibrated regularly?
5.4	Are filters pre-conditioned for the gravimetric analysis?
6	**Light microscopy**
6.1	Are appropriate settings used for evaluation (e.g. brightness, threshold, pixel resolution)?
6.2	Is the microscope regularly checked with a particle standard?
6.3	Are at least the 10 largest particles checked in line with the follow-up check?
7	**Documentation**
7.1	Is there a work instruction for all the steps of the cleanliness inspection?
7.2	Is a qualification reference indicated in the inspection report?
7.3	Does the inspection report include all the necessary information?
7.4	Are filters archived according to the requirements?
7.5	Are raw data and inspection reports stored/archived in accordance with the requirements?

5 QUALIFICATION TESTS AND BLANK VALUE

5.1 Principles

The **qualification test** is used in order to develop the extraction procedure (routine inspection) and constitutes the final step of the procedure that was started with the selection of the extraction method in Chapter 3.1.

The main element of the qualification procedure is the determination of the extraction duration and thus the fourth segment (time) of the Sinner's circle presented in Figure 3-1. This is done experimentally as what is known as a **declining test** as shown in the schematic diagram in Figure 5-1.

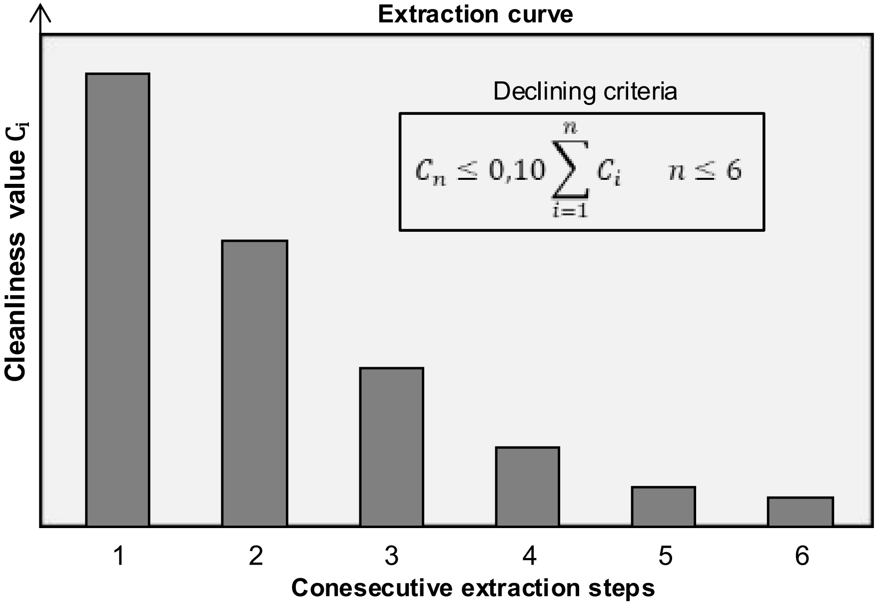


Figure 5-1: Cleanliness value determined based on repeated extraction of a component ("declining behavior")

As part of a cleanliness inspection, it must also be ensured that the analysis result cannot be skewed by contaminants that do not come from the inspected object making their way into the inspection procedure.

The determination of the **blank value** and compliance with a permissible limit help to ensure that the cleanliness inspection is performed under sufficiently clean inspection and environmental conditions.

In order to verify that the processes of extraction, final rinsing of the extraction apparatus, analysis filter handling and drying as well as analysis do not result in the loss of any particles which would then be missing from the analysis result, the **recovery of test particles** can be determined.

In the last step, the effectiveness of the completed final rinsing procedure plays a role after the extraction. For evaluation purposes, a **review of the final rinsing procedure** is performed.

Note 1: When checking cleanliness specifications in the customer-supplier relationship, the qualification of the extraction conditions according to VDA 19.1 is a prerequisite.

Note 2: The requirements listed for the qualification must be reasonably applied to the dry extraction procedure to the extent possible. For the stamping test, the review of the final rinsing procedure, for example, is not required, while the system can be applied to the final suctioning as part of the method (brush) suctioning.

5.2 Qualification tests

5.2.1 Principle

The cleaning effect of the extraction method determines whether or not the cleanliness of a component can be correctly assessed. In a cleanliness inspection, it is therefore necessary to demonstrate that detachable contaminant particles can be extracted from the inspected object as thoroughly as possible.

Since there is no way to absolutely determine the particle load actually present and also no defined contaminated “standard contamination parts” that cover the full spectrum of automotive parts with regard to geometry, materials, particle content and adhesion of contaminants, we instead perform declining tests.

The declining behavior of the cleanliness values must be tested in order to develop appropriate sampling conditions for a component or a group of similar components (component family) and describe them as the “inspection specification”.

Note 1: Components can be grouped as a component family if they have similar design characteristics, are produced using the same or a similar manufacturing process and have similar material and surface characteristics. They differ only in size, and it needs to be assessed/checked if they behave similarly (except for the size factor) in a declining curve with the solvent properties. Examples of a component family include camshafts for four- and six-cylinder in-line engines that are manufactured identically and differ only in their length and number of cams. Pipes of different diameters, however, require different flow rates for internal rinsing and therefore cannot be grouped in one component family.

Repeated extraction of a component is used to determine whether or not the removed particle load is declining and the extraction method is therefore appropriate.

The “declining criterion” is used to determine that the analyzed contaminants are removed sufficiently completely (see Figure 5-1). This is used to determine the point along the declining curve at which the last particle contamination value is under 10% of the previously extracted total contamination amount. This point is used in order to develop the routine inspection procedure.

At the same time, the creation of declining tests can also be used to evaluate whether or not the extraction method potentially corrodes the component and releases particles from the component surface that are not considered contaminants (see Figure 5-7 in the annex).

Note 2: The qualification and creation of the routine inspection procedure are performed at least once for a component or component family. In case of (structural) changes to the component or its production process due to which the existing extraction procedure potentially can no longer be used to detach contaminants from the component to the same extent (different part geometry or changes to the type, amount or adhesion of contaminant particles), the qualification procedure should be repeated. This is the responsibility of the manufacturer of the inspected object. Component changes or relevant process changes must be reported to the inspection laboratory.

The qualification procedure includes the steps listed in Table 5-1.

Table 5-1: Steps of the qualification procedure

Step		Comment
1	Determine the blank value (Chapter 5.3)	component-specific
2	Declining test (Chapter 5.2.3.1)	component-specific
3	Develop the routine inspection procedure (Chapter 5.2.3.2,) i.e. determine the final extraction duration	component-specific
(4)	(Review of the derived routine inspection parameters by means of double inspection, Chapter 5.2.3.3)	optional, component-specific
5	Test the recovery of test particles (Chapter 5.4)	(optional see note 4), equipment-specific
6	Checking the final rinsing procedure	component-specific (and equipment-specific)

Note 3: The final rinsing procedure should also be checked if different extraction apparatuses (different design, size, etc.) are used for the extraction of a component.

Note 4: The recovery of test particles should be checked in line with the qualification test according to the specific equipment. This does not have to be done at the same time as the declining test for a component. Rather, it should be done upstream for every utilized extraction apparatus.

Once the blank value, the declining behavior and the final rinsing procedure have been successfully checked and, independently of this (not necessarily at the same time) appropriate recovery has been ensured for the utilized inspection equipment, the resulting inspection procedure can be established as a qualified inspection specification for routine inspection.

Chapter 12 describes the development of routine inspection procedures based on various examples of inspected objects.

5.2.2 Materials and equipment

The extraction parameters inspection medium, temperature and cleaning mechanism for the extraction, the filtration and the analysis method are defined as described in Chapter 3.

A stock of identical components (same type, same production batch) should be provided in case the declining test needs to be repeated.

5.2.3 Procedure

5.2.3.1 Declining test

Figure 5-1 (see Chapter 5.1) shows an example of a declining curve as it appears under appropriate sampling conditions. The procedure is performed essentially as follows:

1. Define a presumably suitable inspection lot size (e.g. sampled surface of at least 200 cm² for small parts or the surface to be inspected as per the specification).

2. The inspection equipment should be conditioned to the point that it reaches an adequate cleanliness state. The adequate cleanliness state should also be verified with a blank value determination.

   Note 1: As a parameter for the blank value inspection after the conditioning of the extraction apparatus, the same procedure as for a declining step can be used (but at least the final rinsing procedure, see Chapter 5.3.4). The final rinsing procedure can be established for the specific equipment based on established values.

3. The extraction procedure with the start parameters is carefully applied to the exact same component and inspection lot six times in a row. After every extraction step, the inspection equipment must be rinsed using an effective final rinsing procedure. The cleanliness value C is determined for each of the six individual extraction steps (see explanation after list).

4. Afterwards, the relationship between the observed cleanliness value and the sum of all cleanliness values obtained until the extraction step in question is calculated:

$$\frac{C_n}{\sum_{i=1}^{n} C_i} = Declining\ value, Step n of\ the declining\ test$$

C_n: Cleanliness value currently under consideration

C_i: Cleanliness value of the extraction step

5. If the declining value ≤ 0.10, the declining criterion has been reached.

$$C_n \leq 0.10 \sum_{i=1}^{n} C_i\, n \leq 6$$

6. Once the declining criterion is reached, the parameters for the routine inspection procedure are derived (see following Chapter 5.2.3.2,) and these parameters are then recorded in the inspection specification.

7. If the declining criterion cannot be reached within six extraction steps, the extraction parameters and possibly also the inspection lot size have to be adjusted appropriately, or a different extraction method must be selected, and the declining test must be repeated with **a new component or** inspection lot. Refer to the annex for help adjusting the procedure (see Figure 5-7).

8. If the declining criterion cannot be reached despite repeated optimization of the extraction parameters, this is a special case with regard to inspection technology (see Chapter 5.5)

Note 2: The six cleanliness values Ci for the respective individual extraction steps can be represented graphically as a declining curve, e.g. as in Figure 5-1. Refer to the annex (see Figure 5-7) to see some of the different curve forms that can result from declining tests, along with their potential interpretations.

The declining values and the declining criterion (Items 4. and 5.) are determined using the cleanliness values C_i.

The C_i cleanliness values refer to the same measurements as the limit values in the cleanliness specification of the component. These include:

- **for gravimetric information:** the residue weight.

- **for light-optical or other methods of determining the particle size distribution:** the particle counts in the individual particle size classes. At least all specified particle sizes and particle types should be accounted for. If there are not enough counter events in the specified particle sizes, smaller particle size classes can also be included in the declining test, provided they can be reliably detected (i.e. the requirements for the filter pore size and the pixel criterion for the analysis are met). To simplify the determination and presentation of the declining behavior, it is possible to add up all the particle size classes. However, be sure that a decline is observed in all particle size classes.

- It is recommended to **leave fibers out** of the calculation of the declining values, since they are ubiquitous and can potentially get into the inspection, even under cleanliness conditions, thus skewing the result. If fibers do need to be included, however, then the corresponding prerequisites for minimizing fibers in the inspection environment (appropriate clean room environment, clothing concept, etc.) must be applied.

- If there is no cleanliness specification, or if only a maximum permissible particle size (e.g. no particles > X µm allowed) is specified, then the declining test includes all the particle size classes (totaled) that can reasonably be measured at the selected magnification and pixel resolution of the light-optical analysis method (see Chapter 8.2.2 Light-optical analysis) and can reliably be retained by the selected analysis filter (see Chapter 7 ANALYSIS FILTRATION AND SEPARATION

Note 4: To obtain more information, the declining behavior can be evaluated in several particle size classes without adding them up.

An exception for determining the declining values can result in the following cases:

- If the declining test produces residue weights so low that they are below the detection limit of the scale, making it impossible to perform a valid declining criterion calculation, it is possible to instead use the particle size distribution (light-optical analysis) to perform the declining value calculation or to use it on its own.

- If, in a specified particle size distribution and a light-optical evaluation (e.g. in the standard analysis), so few counter events occur (or are expected) that it is not possible to represent an effective extraction and obtain a declining curve, then a filter membrane with a smaller pore size can be used and an analysis of smaller particles than specified can be performed (with the corresponding optical resolution).

- In case of additional requirements in certain material classes which can only be verified, for example, with an SEM/EDX analysis, the effectiveness of the extraction can be based on all the particles detected in the SEM/EDX (not only the specified material classes) or on the light-optical analysis. For example, in the specification of functionally-critical materials, these particles only occur in very small numbers or ideally not at all. Accordingly, the prerequisite of an adequate number of counter events to calculate the declining values is not met.

5.2.3.2 Obtaining the parameters for the routine inspection parameters

The data in Chapter 5.2.3.1 is used to derive the appropriate parameters for the routine inspection, i.e. the final extraction times (see Table 5-2) and recorded in the inspection specification.

Table 5-2: Obtaining the extraction times and/or number of stamps for the routine inspection

Extraction method	Obtaining the appropriate extraction parameters from the declining test
Pressure-rinsing and low-pressure rinsing	Total rinsing duration that is equivalent to the total volume at the given flow rate of the sprayed liquid
Ultrasonics	Total duration in the ultrasound bath (+ duration for degassing)
Internal rinsing	Total rinsing time that is equivalent to the total volume at the given flow rate of the rinsing liquid
Agitation	Total agitation time that is equivalent to the number of agitation strokes at the given agitation frequency
Air jet extraction	Total air jet extraction time
Air throughflow extraction	Total time that the liquid flows through the component
(Brush nozzle) suction	Total time that the component is vacuumed
Stamping test	Number of stamps with which the component surface is stamped

The objective of a qualified routine inspection procedure is to extract at least 90% of the detachable contaminants with the utilized extraction method. If **n individual extraction steps** are required in order to reach the declining criterion (10%), the routine inspection procedure is performed at least for **(n-1) times the total extraction time**.

The amount of liquid or the duration of the final rinsing procedure to remove the particles from the extraction apparatus is not multiplied by (n-1) (for final rinsing procedure verification, see Chapter 5.2.3.4).

The routine inspection procedure thus developed and qualified is used to extract particles when verifying cleanliness specifications in the customer-supplier relationship (see Figure 5-8 in the annex).

Note 1: It may happen that, contrary to the described procedure, only one component or inspection lot is available for a qualification procedure to develop the extraction procedure and subsequent routine procedure for determining the cleanliness value. In such an exceptional case, the cleanliness value of the component or inspection lot can be estimated based on the values obtained in the declining test (sum of all cleanliness values up to the value at which the declining criterion is reached).

Note 2: Right from the evaluation of the declining test, it is already apparent, for example, whether or not particles are present which are not permissible in accordance with the cleanliness specification (e.g. based on their size, type or material class).

Note 3: In the ultrasonic extraction method, the total duration is derived from the declining test and is extended by the length of time required for degassing (see Chapter 6.4.3.1).

If the qualification of a cleanliness inspection procedure for a component family is performed based on a declining test, surface deviations with differently sized components can be dealt with as follows:

- The declining test is performed with the largest component in the component family, and the extraction time obtained for the routine inspection is applied to all other components of the component family, or

- a surface-specific adjustment is made for the duration of the inspection $(t_2 = \frac{A_2}{A_1} \times t_1)$ and a double inspection is performed for verification.

  t_1/t_2: Total time for component 1/component 2

  A_1/A_2: Area of component 1/component 2

5.2.3.3 Verification of the derived routine inspection parameters/double inspection (optional)

As an optional verification of the derived routine inspection parameters, a “double inspection” can be performed (see Figure 5-6):

- The routine inspection procedure developed in the preceding section is performed twice on another not yet sampled inspection lot, and the cleanliness values C_1 and C_2 are determined.

- If the second cleanliness value ≤ 30% of the sum of the two cleanliness values, the developed routine inspection parameters are suitable and can be established as an inspection specification.

$$C_2 \leq 0.30(C_1 + C_2)$$

– If the criterion is not met, it must be checked if the sampling conditions/extraction parameters can be appropriately adjusted.

Note: The double inspection can also be used when copying an inspection procedure from another laboratory, for example, or in order to verify extraction parameters within a component family.

5.2.3.4 Checking the final rinsing procedure

The final rinsing procedure (see also Chapter 3.1.5) is an important step in the extraction, since all the particles that were detached from the inspected objects in the extraction process need to be transferred to an analysis filter (or another carrier). The cost and effort of a final rinsing procedure depends greatly on the extraction apparatus (size, complexity) and the contaminants (type and amount) brought in during extraction.

The verification of the final rinsing procedure is also performed as part of the qualification test for the inspected object. For this purpose, in the first routine inspection following the declining test, a blank value (see Chapter 5.3) is determined once before and once after the routine inspection, and compliance with the blank value criterion is checked. If the blank value is observed before and after the routine inspection, the final rinsing procedure is appropriate and can be applied in the extraction procedure. If the blank value is not observed after the routine inspection, the final rinsing procedure is not adequate and must be optimized, e.g. with a declining test for final rinsing (see also Figure 5-4 in the annex).

Note: To demonstrate the effectiveness of the final rinsing procedure, the blank value that can be derived from the determined cleanliness value is relevant (goal: no particle loss). In case of very clean components, it can happen that the required blank value criterion cannot be observed either before or after the routine inspection (see Information on non-compliance with blank values in Chapter 5.3.5). In this case, the final rinsing procedure cannot be reasonably verified using the described procedure, and this must be documented accordingly. If the applied final rinsing procedure has already been successfully checked for several other components, it can be assumed in this case that the final rinsing procedure can also be used for the current component.

5.3 Blank value

5.3.1 Principle

Component cleanliness inspection by extraction carries the risk that not only particles from the inspected object but also particles additionally brought into the inspection set-up will end up in the analysis result.

If this proportion of foreign particles (“blank value”) is too high, the results of the component cleanliness assessment can be skewed. The blank value represents the total value for contaminants that do not originate from the component.

The causes of such foreign particles can be:

- Extraction liquid and final rinsing liquids
- Extraction equipment (trays, basins, tubing, etc.)
- Handling during extraction and analysis as well as actuation of pumps or valves
- Environment and personnel
- All items that come into contact with the component and the extraction liquid (holders, plugs, etc.)

The cleanliness of the inspection environment must be adapted to the required cleanliness state of the components. In order to ensure that the blank value has no significant influence on the inspection result,

- it must be appropriately determined, and
- it may not exceed a certain maximum ratio to the required or determined component cleanliness state.

The determined blank value may not be subtracted from the cleanliness value of the inspected object – that is, the result of a component cleanliness inspection. A high blank value increases the risk that an inspected object might exceed the permissible cleanliness limit value.

Note 2: If the required blank value is not reached, the cause must be localized among the aforementioned influence factors.

Note 3: For advice on cleanliness-based optimization that can also be applied to a cleanliness laboratory, refer to VDA 19 Part 2 - Technical Cleanliness in Assembly.

Blank value determinations can be omitted if a comparable inspection was performed immediately prior. A blank value determination should be performed, however, if there is a risk that the cleanliness state of the extraction apparatuses is not appropriate or is unknown, for example:

- after prolonged disuse of the extraction apparatuses, overnight shutdown, after a weekend or an extended period of time.
- if switching from a component inspection with a high particle content to one with a low particle content, because there is a very high risk of carrying over an amount of contaminants that is impermissible for the clean component.

5.3.2 Deriving blank values

As part of cleanliness inspections for determining a particle count or a residue weight, the permissible blank value is derived from the cleanliness values of the component. If no specification is provided, the permissible blank value is calculated based on the required cleanliness values. In this case, the following blank value criteria must be observed (see Table 5-3):

- 10% of the required cleanliness value or
- 10% of the determined cleanliness value

If only one maximum permissible particle is specified, in order to derive the blank value criterion, the maximum permissible particle size is divided by the factor two, and particles in the size class into which this value falls or larger are not permissible (see Table 5-3). This requirement does not apply or apply additionally if a specification in the form of a particle size distribution is available.

Note 1: If the cleanliness values for a component are not known and there is no cleanliness specification for the component – e.g. in the case of an initial sampling – then the basis for calculating the blank value is only obtained in the qualification test.

Note 2: If individual fibers are specified in a cleanliness specification by number and/or length, then problems can arise when applying the blank value system to this particle type, because fibers can be expected even in clean rooms that are also used as cleanliness inspection laboratories, and these fibers can show up in the blank values. In this case, the customer-supplier relationship must include relevant terms that can also be implemented in the laboratory.

The blank value always refers to the specific component inspection. To be able to calculate permissible blank values, for cleanliness data per area or wetted volume or for coded cleanliness data, it is always necessary to first calculate the permissible contamination amount for the analyzed inspection lot (one or more components) (see Figure 5-10 in the annex).

If a cleanliness specification includes a combination of different cleanliness characteristics, e.g. residue weight and particle size distribution, the blank value for all the specified characteristics must be calculated and observed. However, in case of low gravimetric cleanliness limit values, the blank value can be below the detection limit of the scale. In this case, the blank value is considered observed if it can be detected with the likewise completed optical analysis and the corresponding blank value.

Table 5-3: Blank value criterion and examples

Cleanliness specification	**Blank value criterion**	**Example**			
		Cleanliness specification		Derived blank value	
Gravimetric	10% of the required or determined residue weight*)	7 mg		0.7 mg	
Particle size distribution	10% of the number of required or determined particles in every size class (decimal places are always rounded)	Size class in µm	Permissible number	Size class in µm	Permissible number in the blank value
		100 ≤ x < 150	90	100 ≤ x < 150	9
		150 ≤ x < 200	28	150 ≤ x < 200	2
		200 ≤ x < 400	12	200 ≤ x < 400	1
		400 ≤ x < 600	0	400 ≤ x < 600	0
Largest permissible particle	Maximum permissible particle size is cut in half; particles of this size class or larger are not permissible**)	no particles > 500 µm permissible		500 µm/2 = 250 µm, is in size class H 200 µm ≤ x < 400 µm therefore: no particles ≥ 200 µm allowed in the blank value	
none	no particles > 100 µm allowed ***)	-		no particles > 100 µm allowed	

*) Note the resolution of the scale, see Chapter 8.2.1

) This should only be used if the largest permissible particle is **explicitly specified. This derivation rule should not be applied in case of a specified particle size distribution for size classes in which no particles are permitted.

***) Only applies if there is no information available, no cleanliness specification, no analysis result from these components, no experience with similar components.

5.3.3 Materials and equipment

For determining the blank value (blank value procedure), the exact same equipment, materials, settings and inspection parameters should be used both for the extraction and for the filtration and analysis.

5.3.4 Procedure

1. Calculate the permissible blank value, either based on the cleanliness specification or based on the cleanliness values determined in Section 5.2.3

2. Precisely perform the routine inspection devised in Section 5.2.3 without a component and determination of the cleanliness value (=blank value)

3. Inspection to see if the determined blank value falls within the permissible range

Note: If the blank value procedure is performed just like the actual component inspection (duration, extraction medium volume, procedure), then all the influences on the blank value are covered by the blank value procedure. With adequately filtered extraction media and a suitable inspection environment, the blank value is often determined by the residual particles in the extraction apparatuses. If this is the case (inspections, experience, recommendations of the manufacturer of the extraction apparatuses, etc.,) the blank value verification procedure can be shortened. Make sure, however, that all the relevant surfaces of the inspection equipment are still adequately rinsed with extraction medium. The shortest possible blank value procedure corresponds to the minimum final rinsing procedure that is performed following an extraction.

If blank value criteria are not met, then some of the inspection equipment or its condition or environment are not suitable and must be optimized. An inadequate final rinsing procedure can also lead to the blank value criteria being exceeded if particles remain in the extraction apparatus.

For the consequences of non-compliance with blank values, see also next Chapter 5.3.5.

5.3.5 Non-compliance with blank value criteria

Particularly in case of very clean inspected objects, the problem can arise that the required blank value criterion (10% with regard to the particle count or residue weight) is impossible or difficult to reach despite the very costly and complex equipment, inspection environments and conditioning of the extraction apparatus.

Note 1: Be aware that the surfaces of an extraction apparatus are typically much larger than those of the inspected objects, but the influence on the inspection result should only be a fraction. This means that the surfaces of the extraction apparatuses in relation to the area unit may sometimes have to be several orders of magnitude cleaner than even very clean inspected objects. In some situations, this can be very difficult or even impossible to achieve.

Figure 5-2 shows examples to illustrate how the results of a cleanliness inspection are evaluated. The following cases are possible:

1. In the cleanliness inspection, the blank value criterion derived from the determined cleanliness value is observed, which allows for a reliable cleanliness value to be determined for the inspected objects.

2. In the cleanliness inspection, the blank value criterion derived from the determined cleanliness value is not observed, which does not allow for a reliable cleanliness value to be determined for the inspected object. It is possible to gauge, however, whether or not a certain upper limit is exceeded.

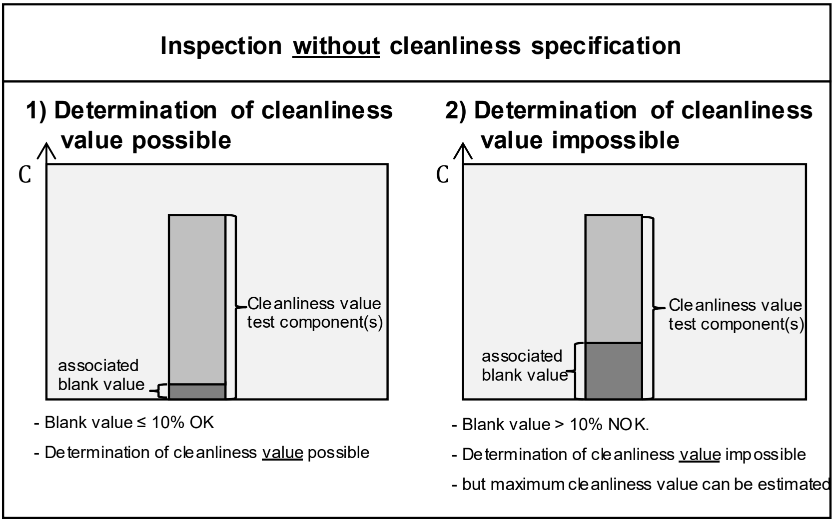


Figure 5-2: Influence of the blank value on a cleanliness inspection result (without cleanliness specification)

Figure 5-3 shows examples to illustrate how the results of a cleanliness inspection are evaluated with this cleanliness specification. The following overarching cases are possible:

- Compliance with a specification can be demonstrated.

    a) In Example 1, the blank value criterion derived from the cleanliness specification is met, and the cleanliness value of the inspected object is below the limit value. The completed cleanliness inspection can thus be used to clearly demonstrate compliance with the cleanliness specification. In the provided example, the blank value portion of the determined cleanliness value is also not greater than 10%, making it possible to determine a reliable cleanliness value for the inspected object.

    b) In Example 2, the blank value criterion derived from the cleanliness specification is not met, but the cleanliness value of the inspected object, which the blank value portion falls within, is below the limit value. The completed cleanliness inspection can thus be used in this case to demonstrate compliance with the cleanliness specification.

- Compliance with a specification cannot be demonstrated.

    a) In Example 3, the blank value criterion derived from the cleanliness specification is met, and the cleanliness value of the inspected object is also above the limit value. So the completed cleanliness inspection clearly indicates that the cleanliness specification is not met. In the provided example, the blank value portion of the determined cleanliness value is also not greater than 10%, making it possible to determine a reliable cleanliness value for the inspected object.

    b) In Example 4, the blank value criterion derived from the cleanliness specification is not met, and the cleanliness value of the inspected object is also above the limit value. In addition, the blank value portion of the determined cleanliness value for the inspected object is greater than 10%, making it impossible to determine a reliable cleanliness value for the inspected object. In this case, it is not possible to definitely evaluate compliance with the cleanliness specification, since the exceeding of the limit value could also be attributed to the blank value criterion not being met. Since the VDA 19.1 requirements for the blank value criterion are not met, the cleanliness inspection should be considered invalid in this case, and compliance with the specification has failed for now. To verify compliance with the specification, in this case, it is necessary to perform another component cleanliness inspection. First, this inspection has to be optimized with regard to compliance with the blank value criterion, however.

    c) In Example 5, the blank value criterion derived from the cleanliness specification is not met, and the cleanliness value of the inspected object is clearly above the limit value. The blank value portion of the determined cleanliness value for the inspected object is lesser than 10%, thus making it possible to determine a reliable cleanliness value for the inspected object. In this case, despite non-compliance with the blank value criterion (derived from the cleanliness specification) due to the reliably determinable cleanliness value for the inspected object (blank value criterion derived from the cleanliness value observed) we can definitively state that the specification has not been observed.

Note 2: If the cleanliness specification of the inspected object is observed, the evaluation of the blank value filter can be omitted, or the blank value filter can also be evaluated after analysis of the inspection lot.

If the blank value criterion is not met in the completed cleanliness inspection, then this should be evaluated according to the provided examples and noted in the inspection report.

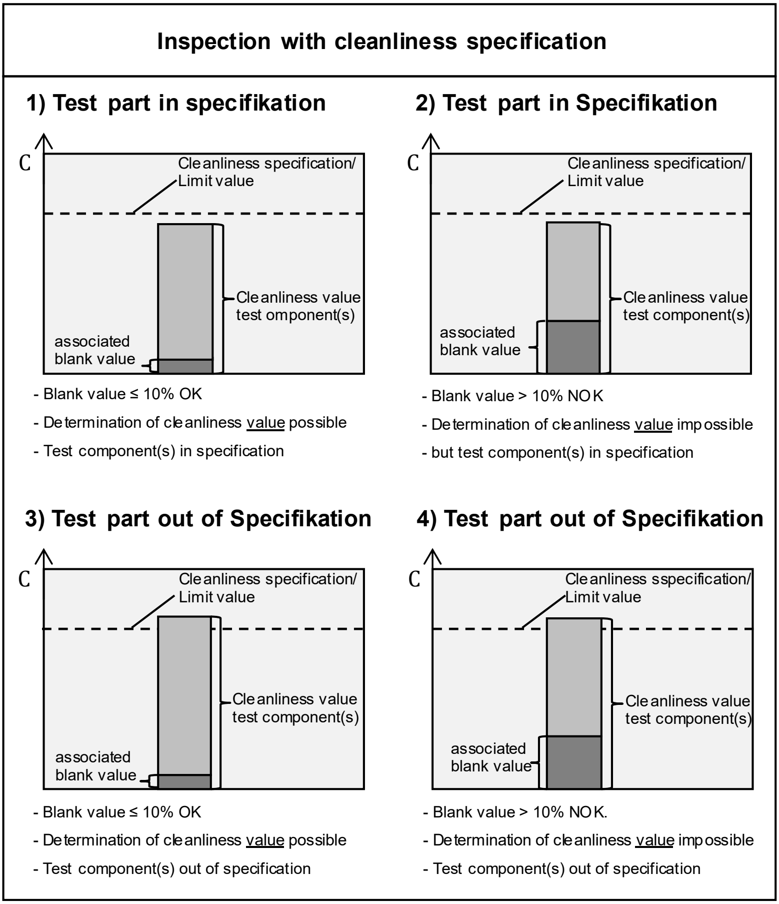


Figure 5-3: Influence of the blank value on a cleanliness inspection result (with cleanliness specification)

5.4 Recovery of test particles

5.4.1 Principle

The blank value determination can be used to ensure that the amount of foreign particles that makes its way into the extraction, final rinsing, filtration, analysis filter handling and analysis chain is not critical for the result of a certain cleanliness inspection.

Another important aspect is that no relevant particles are lost in this chain. A check for possible particle loss can be performed through the inspection with test particles. In this process, particles of a known size, number or mass are placed in the extraction apparatus. The final rinsing procedure and all the other steps are performed, and, in the analysis, it is checked whether or not these particles are recovered. This method can be used, for example, to check and optimize:

- final rinsing procedures,
- design characteristics of extraction and filtration units,
- analysis filter handling during removal, transport and drying or
- for training the inspection staff.

5.4.2 Material and equipment

In addition to all the materials and equipment that are used to check the blank value or for a routine inspection, we also need particles of a known number and size or total mass which are within the relevant particle size range that is usually tested with the extraction apparatus. The amount should be selected so that a percentage can also be determined for recovery. (If there are only a few particles, the percentage can vary drastically if individual particles are not recovered). These particles should be prepared such that they can be placed in the extraction apparatus without any loss but also without any additional particle carry-over. The analysis method utilized must be compatible with the selected type, size and amount of test particles. Different types of particles can be used:

1. Specially manufactured test particles that produce a specific measurement value in the analysis. As a prerequisite for this, e.g. in light-optical analyses, the particles must be deposited reproducibly on an analysis filter, so that the same projection surface is always measured in a light-optical analysis. Moreover, the particle sizes should not be too close to a particle size class limit, so as to avoid “class jumpers” (particles that are sometimes sorted into one particle size class and sometimes into another).

Note 1: Be aware that very smooth and flat test particles can potentially adhere strongly to the walls of the extraction apparatuses, making them difficult to recover. Spherical particles, on the other hand, have very little adhesive power and therefore comparably easy to remove from surfaces. Using these particles therefore cannot provide representative recovery results.

2. In-house “company particles” (for example, particles that come from a backflushed sieve cloth filter used in a component cleanliness inspection and therefore do not correspond to any actually occurring particles) that should also be recovered in routine analysis in daily laboratory operations. The analysis filter from which the backflushed particles originate should also be analyzed after the backflushing in order to determine which particles were not removed in the backflushing and so cannot be put back into the recovery procedure.

3. Particles without a precisely measured particle spectrum but with a known total mass for a gravimetric determination of recovery. The particle size spectrum, even if it is not precisely known, should be selected so that it can be reliably held back from the utilized analysis filter. This can be done, for example, using blast particles of a specific grain size.

Note 2: The utilized test particles should be used in sufficient amounts. Otherwise, a single particle not being found will appear to indicate a relatively high rate of particle loss.

The particles can be prepared loose, fixed on a substrate but detachable with the extraction medium or suspended in a liquid that can be mixed with the extraction medium.

5.4.3 Procedure

The recovery test can be performed according to the specifications of the extraction apparatus manufacturer or as described below:

1. Obtain known test particles,

2. introduce the test particles into the extraction apparatus,

3. perform final rinsing of the extraction apparatus according to specified procedure,

4. perform analysis filtration, filter removal, filter drying and filter analysis, and

5. determine the recovery rate, and compare with a target value:

    a) As a rule, a recovery rate of ≥ 90% should be reached for test particles (relative to the particle count or the utilized particle mass); however, additional other requirements can be defined (for certain particle sizes or types).

    b) With in-house “company particles” the recovery rate that is possible and achievable depends greatly on number, size and geometry as well as the extraction and filtration equipment utilized and should be established on a case-by-case basis.

6. If the targeted recovery rate is not reached, the “final rinsing, filtration, filter handling and analysis” chain should be optimized with regard to the procedure and/or equipment, and the tests should be repeated with test particles.

The particle recovery check should initially be performed by the manufacturer of the extraction apparatus and then regularly performed by the user (e.g. once a year or according to the manufacturer’s specifications).

5.5 Special cases

If the qualification criteria “decline” and/or “blank value” cannot be demonstrably met after repeated optimization of the sampling conditions, the most suitable inspection procedure can be established as a routine inspection in the customer-supplier relationship.

Note 1: Before a component cleanliness inspection is designated as a special case, it is necessary to first carefully consider and eliminate all the possible errors, e.g. improper handling, particle carry-over from non-relevant component surfaces, etc.

Potential special cases include:

- Active assemblies that have to be operated during extraction (e.g. valves, pumps, injectors, etc.). The removed contaminant particles and particles generated by the run-in behavior overlap one another, so that the declining curve of the contaminant particles cannot be observed separately.

- Components that emit particles, e.g. from the component material or the (sacrificial) coatings.

- Components that are extremely clean and for which no qualification can be achieved despite increasing the inspection lot size and optimizing the blank values.

Note 2: When test parameters are defined for the special case, as an initial reference value, it is possible to select, for example, the start parameters of the best-suited extraction method and five times the starting extraction time.

5.6 Capability of inspection procedures

If different extraction methods (different extraction methods, media or parameters) were qualified, for example, by different laboratories, and these methods reached the declining criterion in the declining tests, the resulting routine inspection procedures can, under certain circumstances, lead to different inspection results. This can, in turn, result in different inspection findings (specification met or not met). To help resolve the issue of which inspection procedure is best-suited and which inspection result is valid, the following questions can be asked:

- Is the utilized extraction method compatible with the extraction parameters used for the component?

- Does the comparison of the declining tests indicate that material corrosion may have occurred?

- Can the extraction parameters used be assumed to provide sufficient cleaning action?

- Is the utilized inspection medium capable of effectively removing contaminants?

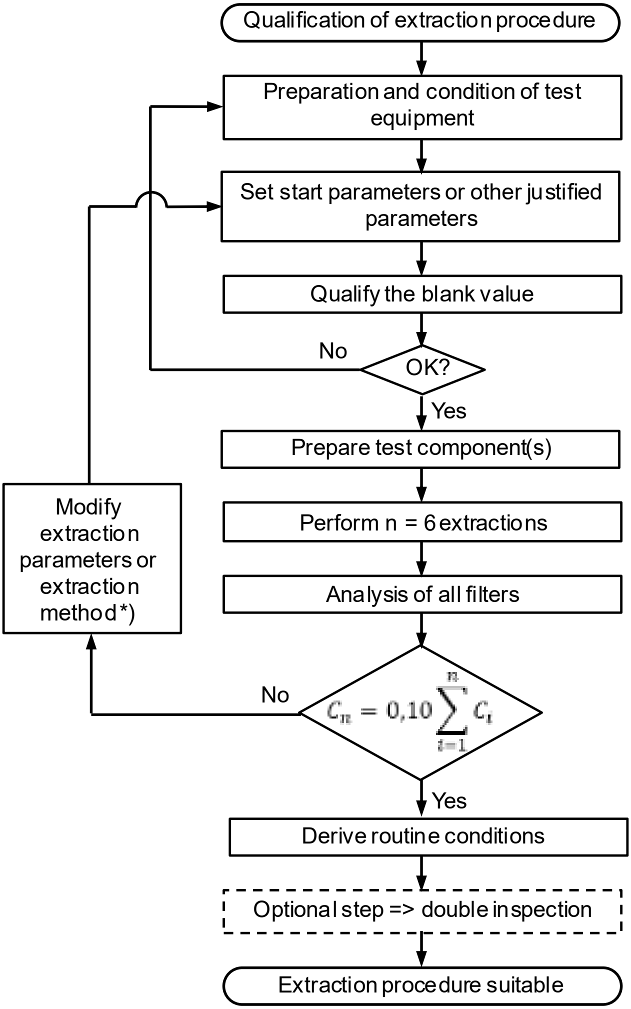
- If the start parameters were modified, what were the reasons?

In case of doubt, the parties involved should agree on an inspection procedure with the goal of comparability. The procedure should be documented in sufficient detail.

Note: Often, the causes can be traced to non-comparable analysis results but also to an inadequate description of the inspection procedure, e.g. precisely which inspection areas of a component should be sampled (interior, exterior, both) or whether or not certain areas should be excluded from the inspection (e.g. threads), which analysis filter should be used, etc. These questions should be clarified as well, first with a comparison and an evaluation of inspection procedures.

Annex 5 Qualification inspections and blank value

A 5.1 Declining test process diagram



*) see also Annex A5.4, Figure 5-7: Declining curves of a different form (interpreting the different declining curves)

Figure 5-4: Declining test process diagram

A 5.2 Final rinsing procedure check process diagram

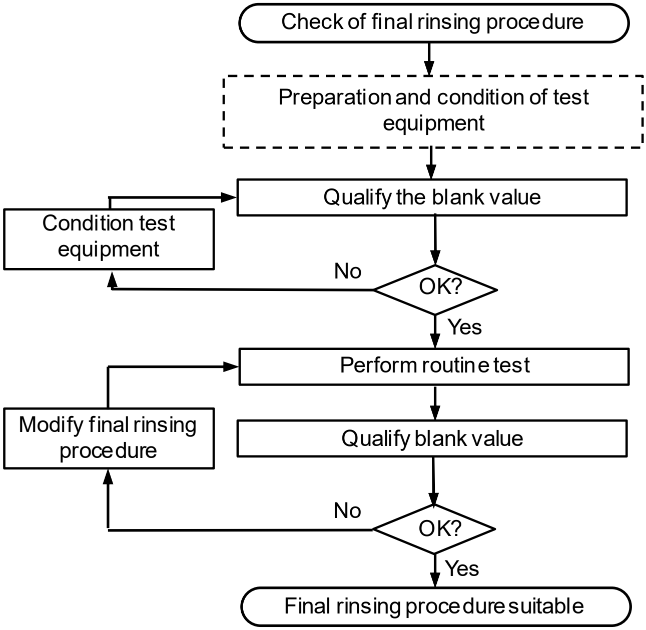


Figure 5-5: Final rinsing procedure check process diagram

A 5.3 Double inspection process diagram

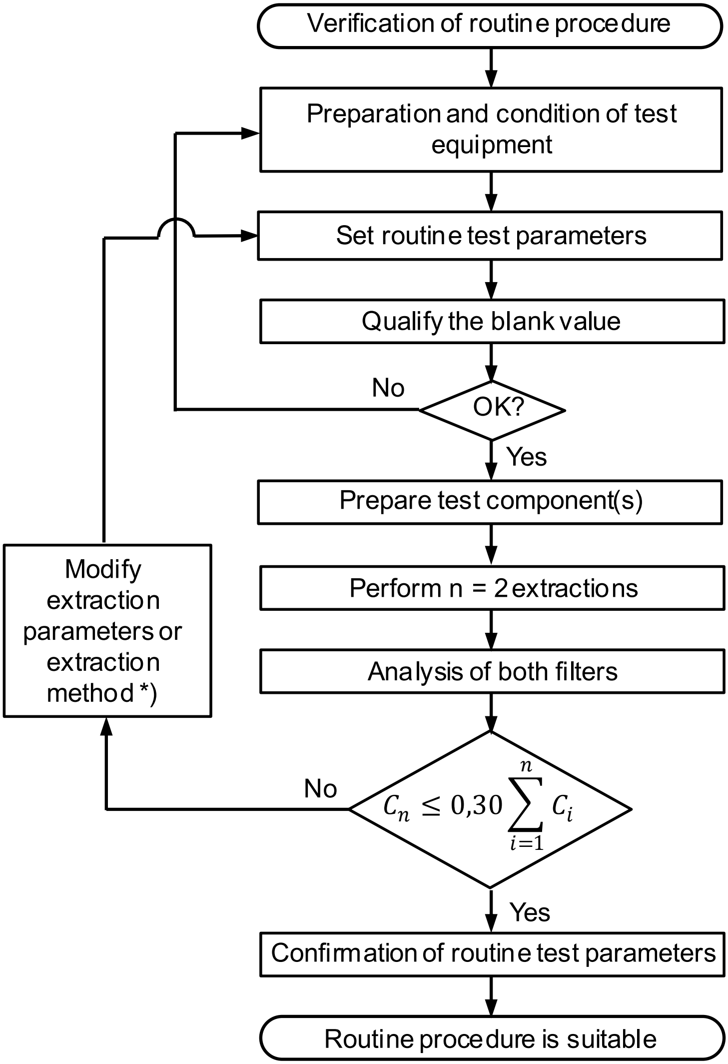


Figure 5-6: Double inspection process diagram

A 5.4 Declining curves of a different form (interpreting the different declining curves)

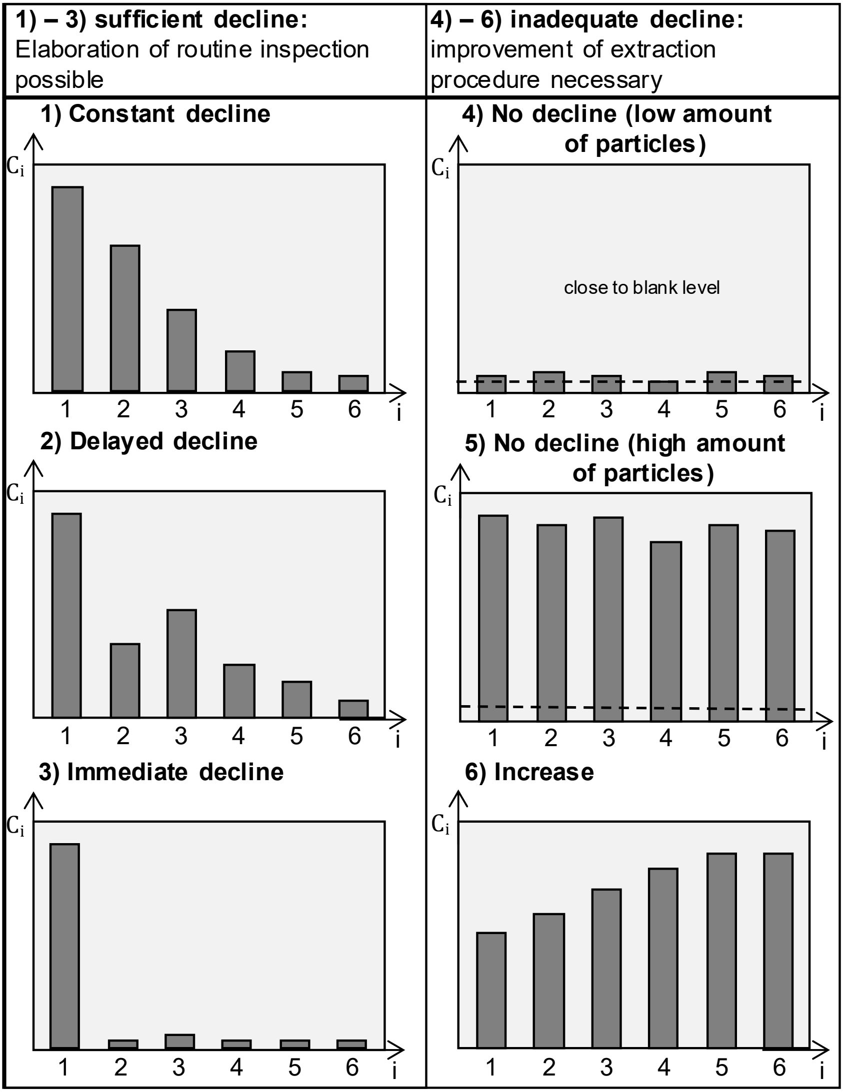


Figure 5-7: Declining curves of a different form (interpreting the different declining curves)

Adequate decline (routine procedure can be developed)

for 1) steady decline: Even removal of the contaminants; no further interpretation necessary; the routine inspection procedure can be derived.

for 2) delayed decline or "hump curve": The cleaning is not even due to the delayed release of contaminants or manufacturing adjuvants such as preservatives by the extraction medium.

If the declining criterion is reached after a maximum of six declining steps, the routine inspection procedure can be created as with 1).

If a declining criterion cannot be reached due to greatly delayed particle detachment, **dissolving** can be performed as an individual, separate step before the actual extraction (see also Chapter 6.4.6). In this process, the inspected object is first immersed in a suitable solvent (e.g. the extraction medium) for an appropriate length of time. Alternatively, components can also be completely filled and sealed if the inspection surfaces are on the interior.

The volume of liquid used in the dissolving step as well as the final rinsing liquid for the vessel in which the dissolving step is carried out forms part of the analysis liquid and must first be filtered and analyzed accordingly.

The dissolving step can be speeded up during the extraction process by using an extraction liquid with a stronger chemical solvent action. In such cases, the respective safety regulations apply.

for 3) immediate decline: In the first declining step, the entire detachable particle load is extracted from the inspected object. The other declining steps only show particle quantities that are near the blank value.

- It is possible to use the same parameters and extraction amounts and times for the routine inspection as for the individual steps of the declining test.

- There may be an "overextraction," i.e. in the first step, the extraction goes on much longer than is necessary in order to detach the particle load. In this case, the declining test is repeated with lesser quantities/times for the individual extraction step in order to record a declining curve and determine the extraction amount and time actually necessary.

Insufficient decline (routine procedure cannot be developed, extraction needs to be optimized)

for 4) no decline (few particles): In every individual extraction, approximately the same amount of contaminant particles is found but on a very low level. There are several possible causes for this:

- The contaminant amount found in each individual extraction is in the order of magnitude of the blank value. In this case, an extraction procedure with low component particle emission/low blank value should be established. If the blank value is already very low, however, the component might already be so clean that it is no longer to perform a particle load decline, since the extraction would only yield a few individual particles here and there. If this is the case, it should be documented.

- Increasing the size of the inspection lot can also be an effective method of clearly setting the tested particle load apart from the blank value portion of the inspection and thus obtain a declining measurement.

- The declining test can be performed using a finer filter and an analysis method with higher optical resolution. Under certain circumstances, an effective and sufficient extraction can thus be demonstrated based on smaller particles.

- In addition, testing can be done to check if the effectiveness of the extraction can be increased by a dissolving step or by strengthening the cleaning mechanism (see Chapter 6.4.6).

- One possible reason for the lack of a decline could be residual magnetism in ferromagnetic components. In this case, the components should be demagnetized before the extraction.

for 5) no decline (many particles): In every individual extraction, approximately the same amount of contaminant particles is found. There are several possible causes for this:

- The extraction effect (chemical dissolving or mechanical action) is so high that it extracts particles which are not considered adhering contaminants but which come directly from the component (material). These could be particles detached by ultrasound in cast materials, chipped off coatings, detached burrs or welding beads that are permanently stuck to the surface, etc. In this case, the extraction parameters must be modified in order to prevent “**component corrosion**,” or a different extraction method must be selected. However, such a declining behavior could also indicate that a component cannot achieve the required cleanliness values due to its properties or processing and is not suitable for use in cleanliness-sensitive areas in this condition.

- “Component corrosion” can also occur through the use of an unsuitable extraction medium.

- Another possible reason for the lack of a decline could be an inadequate final rinsing procedure, i.e. particles that were extracted from the inspected object are not completely removed from the inspection equipment and are carried over into the downstream extraction steps.

for 6) increase: The contaminant amount found in each individual extraction goes up. This also has several possible causes:

- As with 5), severe “component corrosion” is taking place.

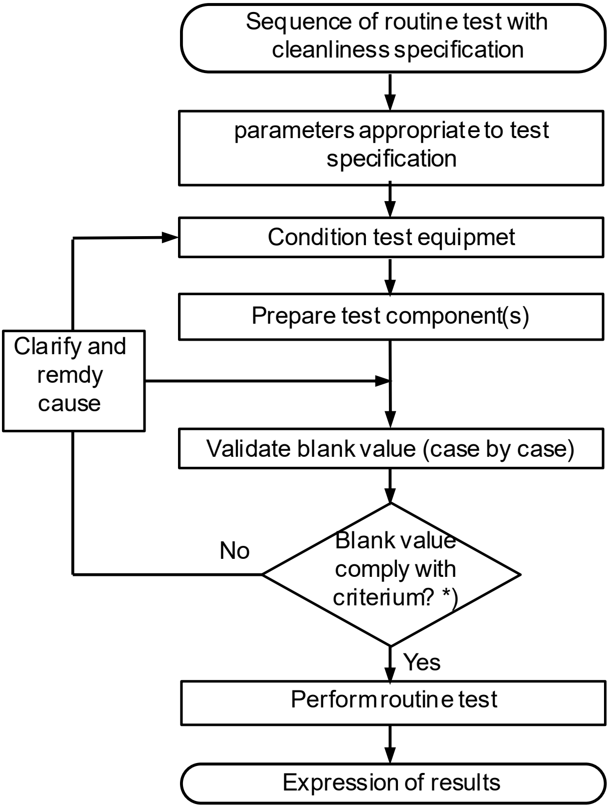
- The effect of the extraction is so weak that the adhering particles are only released after intensive dissolving, as with 2). This can be the case with old dried-on or gummed up preservatives and a weakly dissolving cleaner.

- Concentration can occur due to insufficient final rinsing of the component or extraction apparatus or improper handling.

Note: Any deviations in the form of declining curves can also be due to incorrect handling, inappropriate inspection set-ups, etc.

A 5.5 Routine inspection procedure

1. Cleanliness specification available:

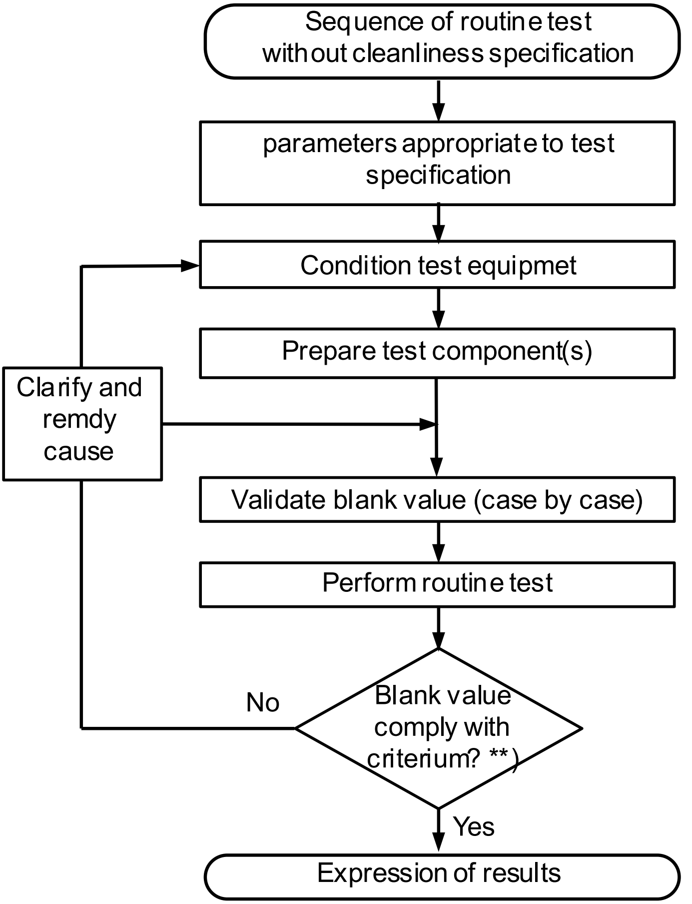


*) Blank value ≤ 10% of cleanliness limit value in cleanliness specification

Note: The preparation of the inspected objects can also be done immediately preceding the routine inspection.

Figure 5-8: Routine inspection procedure (cleanliness specification available)

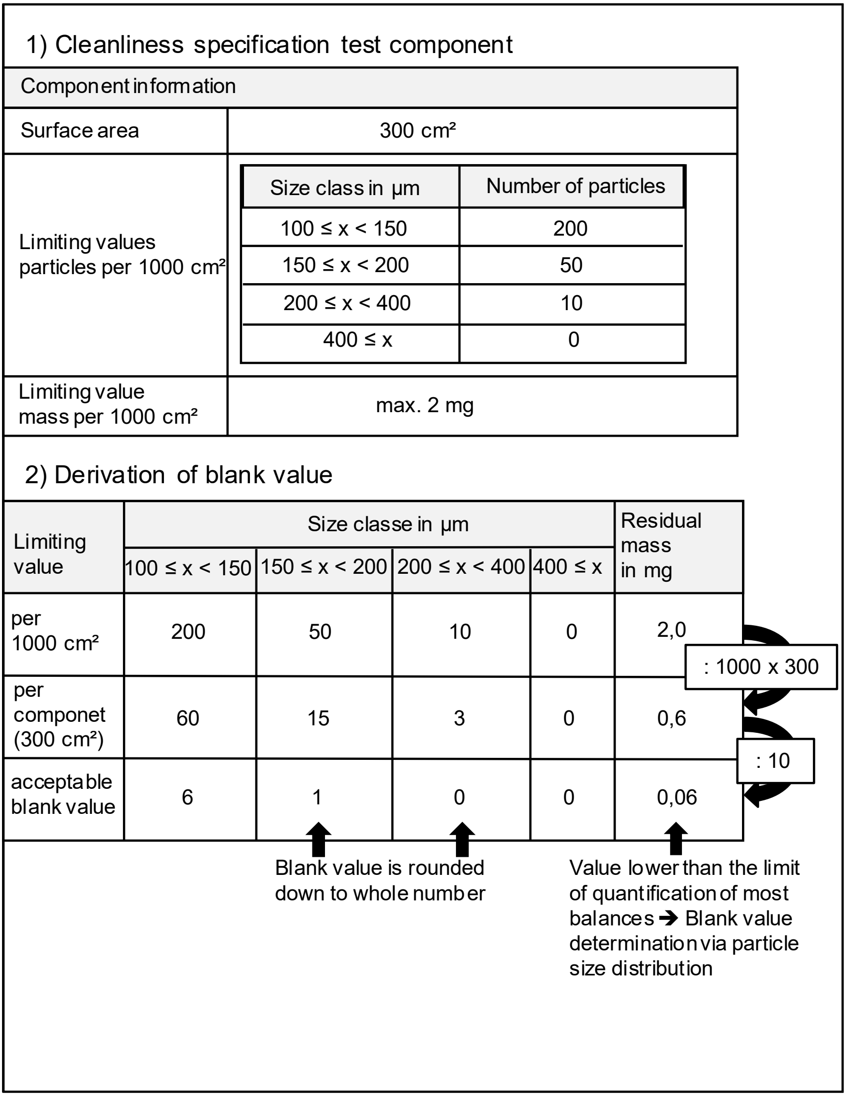
2. without cleanliness specification:



**) Blank value ≤ 10% of cleanliness value measured in routine test

Figure 5-9: Routine inspection procedure (without cleanliness specification)

A 5.6 Example of blank value criterion being derived from a surface-related component cleanliness specification



1) Cleanliness specification test component

Component information	
Surface area	300 cm²
Limiting values particles per 1000 cm²	
Limiting value mass per 1000 cm²	max. 2 mg

Size class in µm	Number of particles
100 ≤ x < 150	200
150 ≤ x < 200	50
200 ≤ x < 400	10
400 ≤ x	0

2) Derivation of blank value

Limiting value	Size classe in µm				Residual mass in mg
	100 ≤ x < 150	150 ≤ x < 200	200 ≤ x < 400	400 ≤ x	
per 1000 cm²	200	50	10	0	2,0
per componet (300 cm²)	60	15	3	0	0,6
acceptable blank value	6	1	0	0	0,06

Blank value is rounded down to whole number

Value lower than the limit of quantification of most balances ➔ Blank value determination via particle size distribution

Figure 5-10: Example of blank value criterion being derived from a surface-related component cleanliness specification

6 EXTRACTION METHOD

6.1 Principles

Due to the geometry and surface characteristics, function-related components in automotive fluid or electronic systems in particular are typically not suitable for a complete, direct inspection of particles (e.g. with direct optical or microscopic methods). For this reason, we will look at the process of dissolving particles out of or from components by means of “extraction” or sampling.

The goal is not only for a representative number of particles to be found but for the detachable particles to be detected as fully as possible and also for individual, critical particles to be reliably removed. This requirement is proven and checked as described in Chapter 5.

Depending on the inspected object, it may be necessary to use multiple extraction methods. It can also be necessary to mechanically actuate elements of the inspected object in order to sample the affected inspection surfaces.

If the customer and the supplier have a corresponding agreement, then the packaging directly in contact with the component should be included in the cleanliness inspection. This can make sense if there is a risk of particles that are categorized as relevant falling off of the component as it is transported to the inspection laboratory.

A component can have multiple inspection surfaces that are subject to different cleanliness specifications and should therefore be sampled separately.

Note: Different inspeection surfaces of a component can only be regarded as separate to the extent that they can be extracted separately from one another (e.g. interior and exterior of a component).

After the particles are detached from the inspection surfaces, which is done by means of a liquid or dry extraction (see also Chapter 3), they are separated onto an analysis filter membrane (see Chapter 7), which is then put through a standard and/or extended analysis. In line with process monitoring, other extraction methods or extraction methods not qualified according to Chapter 5 can be used as well as other analysis methods which do not meet the limit value inspection criteria described in Chapter 8. Particles can also be detected directly in the extraction medium, for example, without them being separated out onto a filter or a particle trap.

Since the result of a cleanliness inspection depends, to a significant degree, on the meticulous, usually manual implementation of the extraction procedure, the use of qualified and motivated inspection staff (see also Chapter 4.2.1) is crucial. The details of the extraction procedure must be provided in the inspection specification.

6.2 General requirements of extraction equipment

All items of the extraction apparatus coming into contact with the inspection medium, and all surfaces thereof whose cleanliness could affect the result of the component cleanliness inspection, must be constructed and kept clean in such a way as to ensure that the permissible blank value is not exceeded. The following points must be taken into account in their design and operation:

- low degree of surface roughness
- chemical and mechanical resistance
- no particle traps, such as dead zones or undercuts
- easy to clean
- non-magnetic
- not electrostatically chargeable
- tilted collection vessels and angled piping (as short as possible) from collection vessel to analysis filtration
- no particles emitted from the component itself (or only particles which are not relevant to the component inspection), also when components are activated, moved or driven
- It should be possible to effectively transfer particles to the filter (see Chapter 5.4)

Note The requirements should also include work safety requirements (see Chapter 11).

To facilitate the attainment of and compliance with blank values, the surfaces of the extraction apparatus that are in contact with media and that are located between the purification filter of the inspection medium and the analysis filtration unit should be kept as small and as geometrically simple as possible.

There are also influencing variables that cannot be tested for using the blank value or particle recovery, e.g. the way the inspected object is held in a fixture or the way piping/tubing is attached for internal rinsing or throughflow extraction. Such factors may also have to be examined separately.

With extraction by (brush) suction, the extraction apparatuses do not come into contact with liquids, i.e. chemical resistance as mentioned above plays a less important role. In particular, the electrostatic properties of the suction lines and the other system components are important. The extraction medium is the ambient air, which is usually not specially conditioned. Its cleanliness with regard to airborne particles such as textile fibers has an influence on the analysis result and is factored into the blank value determination. If necessary, the suction extraction procedure should be performed in a suitable clean air environment (e.g. laminar flow box).

6.3 Preparatory steps and post-treatment of inspected objects

Although the preparation step should be performed near the inspection environment, if there is a risk of particles being generated or released when preparing components for a cleanliness inspection, it should be carried out at different suitable workplace.

6.3.1 Unpacking

Inspected objects that are not delivered in the series packaging should be delivered for inspection in a way that complies with cleanliness requirements. In many cases, this requires a suitable test packaging. The purpose of the test packaging is to protect the inspected object from recontamination during storage or transport on its way to the cleanliness inspection, after it is removed in the relevant manufacturing step.

When opening packaging and removing inspected objects, take care to ensure that contaminants on the outside of the packaging cannot get onto the inspection surfaces of components. Examples of appropriate action include:

- Cleaning packaging exterior before opening
- Changing gloves between opening packaging and removing inspected objects
- Packaging is opened by one person and inspected objects are removed by another

- Onion skin principle (two layers of packaging and lock concept)

6.3.2 Clarifying which surfaces require inspection

It is not always the entire surface of a component that is relevant for cleanliness or subject to a cleanliness specification. In many cases, only part of the surface area of a component is relevant to cleanliness or has been designated a cleanliness specification (e.g. only the interior of the casing for an electronic device), or a component has multiple cleanliness-related areas that are subject to different cleanliness requirements (e.g. refined oil inlet and outlet). Two details need to be clarified:

- The exact location of the inspection surface(s) to derive further steps, e.g. possible disassembly or other preparatory steps, and plan the extraction strategy (e.g. sequence of the various extraction steps, pressure-rinsing procedure, etc.).

- The exact size of the inspection surface(s). This is especially important if the cleanliness specification is normed or coded, e.g. per 1000 cm^2 or 100 cm^3. In such cases, the permissible quantity of contamination for the inspected object is calculated using the real size of the inspection surface, and subsequently used to derive the permissible blank value for the inspection. Additionally, when developing a declining test, the required quantity of extraction liquid can be determined on the basis of the start parameters.

6.3.3 Preparatory steps

Where inspection surfaces are not the full size of the component, or where a component possesses several relevant inspection surfaces with different cleanliness specifications (see also 6.3.2), it may be necessary to isolate the various component areas from one another. In this way, extraction liquid cannot inadvertently come into contact with another inspection surface during the procedure and transfer particles to it that are not relevant.

Areas not requiring inspection must be isolated, for example by plugging, coating, masking, sealing or marking. Isolation measures must be carried out in an appropriately clean manner.

If non-relevant areas of an inspected object require pre-cleaning, care must be taken to ensure that no particles or other substances are transferred to the relevant inspection surfaces or removed from them.

For the extraction, it may still be necessary to fix the inspected object in mounting, lifting or sampling devices or to use adapters for items such as rinsing lines, drives or electrical connections. This may also cause particles to be generated or released. Consequently, the same recommendations apply as those mentioned in Chapter 6.3.4 Disassembly.

Note: In some cases, it may make sense to design adapters for components in bright colors. If particles of this color then appear in the analysis, the particles originate from the adapter and are not due to an inadequate level of cleanliness of the inspected object.

6.3.4 Disassembly

In some cases, it may be necessary to partially or fully dismantle the inspected object before the cleanliness inspection in order to gain access to the functional surfaces relevant to the extraction.

During disassembly, there is a high risk that particles will be generated and released, e.g. from joints. To prevent disassembly particles from reaching component inspection surfaces, disassembly tasks must be carefully planned and performed in an appropriately clean manner. Particles originating from disassembly steps must be removed (e.g. by suction cleaning or wiping) as soon as they are generated/released or immediately afterwards. All tools and auxiliary equipment must be kept clean and designed with low abrasion levels.

There is also a risk during disassembly that particles from external surfaces that are not relevant to the inspection may be transferred to internal surfaces that are relevant to component cleanliness. This can essentially be avoided by cleaning external surfaces before carrying out the disassembly process.

Due to the risk of the cleanliness state of inspection surfaces being impacted by disassembly processes, disassembly steps must be carefully documented, and precise instructions for disassembly must be provided. If particle generation during disassembly processes must be considered highly probable despite compliance with the aforementioned instructions, a note to this effect should be made in the inspection report.

6.3.5 Demagnetization

Magnetism causes magnetizable particles to adhere more strongly to the inspected object. Therefore, inspected objects that are ferromagnetic should be checked for residual magnetism in case they need to be demagnetized before extraction.

Example: The non-critical residual magnetism value of components of diesel injection systems in contact with media: 2.5 Gauss or 200 A/m

Machining steps during a component’s manufacture may cause it to become magnetized. If a product requires demagnetization, this must be documented. Functionally-relevant features of a component may be destroyed by demagnetization processes.

Components which cannot be demagnetized for technical reasons are usually exceptional cases; these must be specified in the customer-supplier relationship. If only non-magnetic and detachable particles need to be removed by extraction, then conventional extraction methods with liquid or air can be used. If there are also magnetized particles to remove, then particle stamps can be used, provided that the geometry and accessibility of the inspected objects allows this. Sometimes, however, it may be necessary to use very component-specific methods of particle removal that are not covered in VDA 19.1.

6.3.6 Post-treatment

It must be documented whether an inspected object must be scrapped or returned to the production line after inspection. Any post-treatment steps, such as removing residual extraction liquid, drying the component or applying a preservative must be specified.

6.4 Liquid extraction

As described in Chapter 3.1.1 Selecting the extraction method, liquid extraction is suitable for the majority of functionally-relevant components encountered in the automotive industry.

6.4.1 Extraction liquid

The extraction liquid (and final rinsing liquid) has to be compatible with the component as well as with the extraction and filtration equipment, including all seals and filters used.

As far as the cleaning effect is concerned, the extraction liquid is mainly selected based on the component material and the characteristics of the expected contaminants. These factors depend on, among other things, the previous history of the component and its manufacturing process (see also Table 6-1 and Table 6-2 in the annex). Particles relevant to the inspection may, for example, be bound in assembly greases or preservatives.

If the extraction liquid and final rinsing liquid are not adequately clean, purification filters must be used.

Note 1: Purification filters must reliably retain particles of a size that is maximum 10% of the smallest particle size specified for a component. If the smallest size to be assessed is, e.g. 100 µm, the purification filter must at least be capable of reliably retaining particles ≥10 µm (minimum deposition rate of 99%). An alternative to this is to filter liquids repeatedly.

Attention: With aqueous cleaning media, for example, active cleansing substances present in the extraction liquid could be removed by the filter.

Note 2: If reusing an extraction liquid, note that the filters used in conventional extraction set-ups only remove particulate contaminants. This can result in chemical contaminants (e.g. oil) accumulating in the extraction liquid. Any corresponding extraction liquid replacement should be adapted to the circumstances.

All the liquid quantities used for extraction, final rinsing and potentially also for dissolving must be included in the analysis.

For reuse (e.g. in circulation systems), the extraction liquid must be conditioned so that the quality of the inspection result is not impacted. Ensure that:

- the physical/chemical cleaning effect of the liquid cannot be affected, e.g. by the depletion of detergents or the consumption of active chemical ingredients,

- no substances (e.g. greases or preservatives) can be added which could skew the inspection results, and

- no substances can be added which could damage the inspection equipment or component; e.g. water, acids, alkalis.

Annex 6.4.1 Extraction liquid

A 6.4.1.1 Suitability and compatibility of extraction liquids

The following tables only give a simplified overview of extraction liquids. Individual applications still require technical clarification. The tables do not include special cleaning media that are not grouped into the categories mentioned.

Table 6-1 describes the ability of extraction liquids to dissolve accompanying contaminants from components that have a potential to bind particles.

Table 6-1: Dissolving ability of extraction liquids

Substance (contaminant)	**Extraction liquid**		
	aqueous tensidic neutral	**Polar solvents[1]**	**Non-polar solvents[2]**
Salts (water-soluble)	+	-	-
Mineral oil-based lubricants (MBS)	-	+	+
Coolants/lubricants – aqueous emulsions (aqueous CLB)	+	+	O
Brake fluids (glycols, higher alcohols)	+	+	+
Animal and vegetable greases and oils (AV-GO)	O	+	+
Silicon oil	-	-	+
Anti-corrosives, amine-based	+	+	O
Anti-corrosives, other	O/+	+	+
Wax	O Only above melting point	O	+

+ suitable, O partially suitable, - unsuitable

[1] polar solvents, e.g. alcohols

[2] non-polar solvents, e.g. cold cleaners or benzene

In Table 6-2 describes the compatibility of extraction liquids with materials.

Table 6-2: Material compatibility of extraction liquids

Material **(inspected object and inspection equipment)**	**Extraction liquid**		
	aqueous tensidic neutral	**Polar solvents**	**Non-polar solvents**
Plastics[3]	+	O	O
Elastomers	+	O	O
Coated surfaces[3]	O	O	O
Magnesium and magnesium alloys	O With inhibitors	+	+
Aluminum, Al-alloys and cast aluminum, chromated aluminum	+	+	+
Zinc, zinc alloys and cast zinc	+	+	+
High-grade steel	+	+	+
Steel and cast iron	+	+	+
Hot-dip galvanized iron, electroplated and chromated	+	+	+
Non-ferrous metals (copper, brass, bronze, etc.)	+	+	+
Glass	+	+	+

+ suitable, O partially suitable, - unsuitable

[3] Many of the plastics and paints used with functionally-relevant automotive parts are resistant to fuel and oil. In this case, solvents can also be used for extraction. In case of doubt, check the compatibility.

6.4.2 Pressure-rinsing

6.4.2.1 Principle

Pressure-rinsing refers to the application of extraction liquid to a component via an open jet. In addition to the dissolving effect of the extraction liquid itself, the cleaning effect is also due to the momentum of the jet impacting the inspected object, and there is a rinsing effect as the extraction liquid runs off the component. In extraction, we differentiate between low-pressure rinsing with a flow rate of < 1 l/min. and pressure-rinsing with a flow rate of ≥ 1 l/min. Pressure-rinsing produces a stronger cleaning mechanism than does low-pressure rinsing. The 1 l/min threshold between these two ranges pertains to a round jet nozzle with a 2.5 mm outlet diameter and a resulting extraction liquid discharge speed of 3.4 m/s.

The method is suitable for cleaning external geometries and easily accessible inner geometries. If coarse-meshed baskets or sieves are used, small components with simple geometries can also be extracted one at a time or in bulk (see also Figure 6-4 in the annex).

With most applications, a full-jet nozzle with a round cross-section is utilized. However, depending on the geometry of the component requiring extraction, it may be more practical to use different-shaped nozzles (see Figure 6-3 in the annex).

Note 1: Pressure-rinsing tools (nozzles) can also be implemented to clean the inner surfaces of components when fitted onto a bore or hose. Care must be taken to ensure that the complete internal area is filled and wetted with extraction liquid. The extraction effect in this case is no longer a pressure-rinsing effect but an internal rinsing effect, because the surface is not exposed to an open jet (see Chapter 6.4.4).

Essential influencing parameters of the pressure-rinsing method:

- Characteristics of the extraction liquid
- Volume flow combined with nozzle cross-section
- Geometry of nozzles and lances
- Distance and angle to inspected object
- Sequence of extraction of surfaces

- Time per surface or forward feed
- Repetitions per surface

Note 2: The pressure of the jet can only be used to characterize its cleaning effect to a limited extent. Although the volume flow of a nozzle with a given nozzle diameter is proportional to the pressure at the nozzle, it is often difficult to measure the pressure directly at nozzle level. Liquid feed pressures measured in other areas of the system (e.g. in a pressure tank or behind a pump), may vary significantly from the actual pressure at nozzle level and are therefore unsuitable as parameters. On the other hand, the volume flow remains constant regardless of where it is measured. Even if the volume flow is not measured via a sensor in the liquid feeding system, it can be simply calculated by means of volumetric measurement (e.g. filling rate of a beaker into which the pressure-rinsing jet is directed) and is thus suitable as a parameter.

In the cases of nozzles with round outlet cross-sections and a non-widened cylindrical jet (or several such nozzles in a pressure-rinsing tool), the efficacy of the pressure-rinsing jet is much less dependent on its distance away from the component as would be the case with a widening flat-jet nozzle (fan nozzle). This makes it easier to perform a defined extraction on the inspected object (see also Figure 6-3 in annex: Diagrams 1), 4) and 6)).

The efficacy of the pressure-rinsing method is very dependent on the individual extraction steps, which are generally carried out manually. The pressure-rinsing procedure suitable for the respective inspected object must be documented in the inspection specification.

If the pressure-rinsing method is implemented using a solvent as an extraction liquid, aerosols could be generated. These aerosols may form a combustible mixture even in cases where the flashpoint of the extraction liquid is much higher than the inspection temperature/room temperature. If there is a risk of aerosol formation, the extraction should be performed in a suitable extraction chamber which does not contain any potential ignition sources (see also Figure 6-6 in the annex). The graph contained therein can be used as a guide to determine the combinations of nozzle diameter and volume flow which may lead to aerosol formation. The graph was developed for round full-jet nozzles. The use of flat-jet nozzles (fan nozzles) or other nozzles that widen and mist the pressure-rinsing jet generally causes aerosol formation and requires explosion protection measures (see also Chapter 11 WORK SAFETY AND THE ENVIRONMENT).

6.4.2.2 Start parameters

Criteria for deciding between low-pressure rinsing and pressure-rinsing as the most suitable extraction method can be found in Chapter 3: SELECTING

THE INSPECTION METHOD. The start parameters for both ranges can be found in the following tables (Table 6-3 and Table 6-4) and Figure 6-1.

Table 6-3: Start parameters for **pressure-rinsing**

Parameter	Start value for pressure-rinsing
Nozzle shape	Round full-jet nozzle
Nozzle diameter	2.5 mm
Volume flow	1.5 l/min
Distance from component	max. 15 cm
Pressure-rinsing volume/ component surface area	see Figure 6-1 and Figure 6-2 as well as Table 6-5 and Table 6-6

Table 6-4: Start parameters for **low-pressure rinsing**

Parameter	Start value for low-pressure rinsing
Nozzle shape	Round full-jet nozzle
Nozzle diameter	2.5 mm
Volume flow	0.5 l/min
Distance from component	max. 10 cm
Pressure-rinsing volume/ component surface area	see Figure 6-1 and Figure 6-2 as well as Table 6-5 and Table 6-6

Note 1: When sampling larger surfaces, several nozzles (e.g. combined in a pressure-rinsing tool) can be used together to reduce the extraction time. However, care must be taken to ensure that the above-mentioned parameters apply for each nozzle aperture.

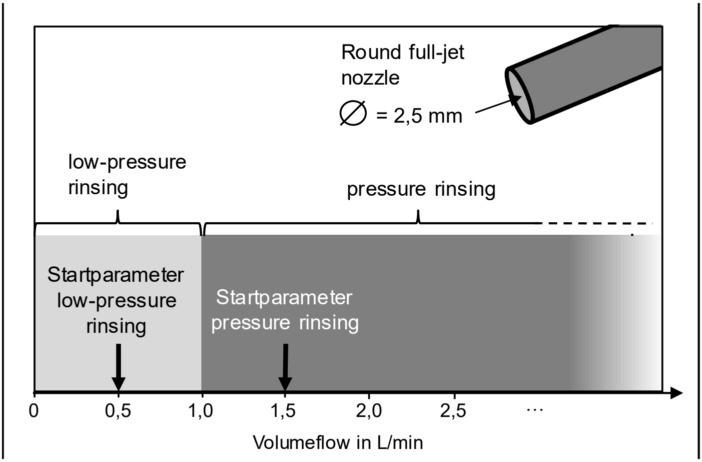


Figure 6-1: Start parameters for the low-pressure rinsing and pressure-rinsing areas

The volume of extraction liquid used per square centimeter of component surface area in order to create the declining curve depends on the size of the component. In order to rinse smaller components carefully, more liquid is needed in relation to the size of the component than is needed for large components. Moreover, with pressure-rinsing, the action of the medium running off the component already provides an extraction effect in the area that has not yet been extracted by the jet. As a reference point for determining the pressure-rinsing volume per square centimeter of component surface area, the following formula can be used:

$$V_{St/A} = 5\frac{mL}{cm^2} \times \sqrt{\frac{200\ cm^2}{A_{cp}}}$$

$V_{St/A}$: Area-specific start volume in mL/cm²
A_{cp}: Sampled area of the inspected object in cm²

The start pressure-rinsing volume per component is obtained using the following formula:

$$V_{St} = 5\frac{mL}{cm^2} \times \sqrt{200cm^2 \times A_{cp}}$$

V_{St}: Start volume in mL

This recommendation applies to components that are rinsed individually, whether they are single parts or multiple parts in an inspection lot, and are individually sampled one by one. Individual values of this formula can also be found in Table 6-5 and Table 6-6.

Small inspected objects tend to involve fewer contaminants, such that it can often be difficult to extract enough particles to stand out from the blank value. This can be avoided by extracting a larger number of components at the same time in an inspection lot.

As an approximate reference value, when using pressure-rinsing for small components, the inspection lot should contain at least enough components to comprise a **sampled surface area of 200 cm²** or more.

If small components are extracted by pressure-rinsing as bulk goods, the individual parts are not extracted individually from all sides. Rather, they go through one shared extraction. For the start quantity per cm², the value of the minimum inspection lot of 200 cm² is used:

$$V_{St/A} = 5\frac{mL}{cm^2}$$

The annex (see Figure 6-7 and Figure 6-8) contains graphics representing the size-dependent starting pressure-rinsing volume.

Figure 6-2 shows the three scenarios:

- Single component ≥ 200 cm² extracted individually,
- Single component < 200 cm² extracted individually but multiple parts in an inspection lot of ≥ 200 cm² and
- single component < 200 cm² extracted as bulk goods in an inspection lot of ≥ 200 cm² and added up.

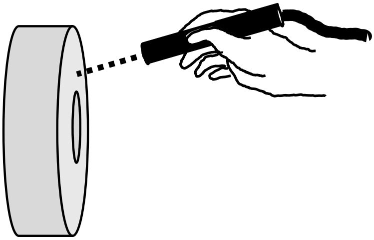
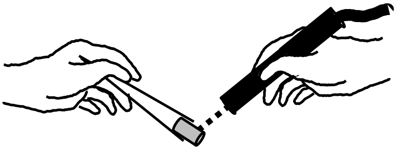
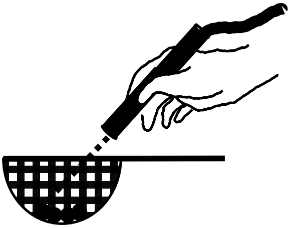
1 Pressure rinsing individual Component test surface **≥ 200 cm²** Startparameter pressure rinsing volume V per cm² component area A_c: $V_{St/A} = 5\frac{mL}{cm^2} \times \sqrt{\frac{200\ cm^2}{A_{cp}}}$ Test lot size: min one component	
2 Pressure rinsing individual Component test surface **< 200 cm²** Startparameter pressure rinsing volume V per cm² component area A_c: $V_{St/A} = 5\frac{mL}{cm^2} \times \sqrt{\frac{200\ cm^2}{A_{cp}}}$ Test lot size: number of components, that a minum surface area of 200 cm² results	
3 Pressure rinsing bulk good Component test surface **< 200 cm²** Startparameter pressure rinsing volume V per cm² component area A_c: $V_{St/A} = 5\frac{mL}{cm^2}$ Test lot size: number of components, that a minum surface area of 200 cm² results	

Figure 6-2: Rinsing start quantity per surface in mL/cm² and inspection lot size depending on the component area in cm²

During the qualification test/declining tests (see Chapter 5), the required rinsing volume per component surface is determined for the routine inspection depending on after which extraction step the declining criterion is attained. If the declining criterion cannot be achieved with these start parameters or if more suitable parameters are justified and documented, the recommended start parameters may be modified.

Table 6-5: Start quantity for pressure-rinsing single parts (for start parameter set)

Components sampled by pressure-rinsing individually				
Inspected object area in cm²	Start pressure-rinsing volume/inspected object area in mL/cm²	Resulting start pressure-rinsing volume per inspected object in mL	Minimum inspection lot size (number of components per inspection lot)	Total pressure-rinsing volume per inspection lot in mL
10	22.4	224	20	4480
50	10.0	500	4	2000
100	7.1	710	2	1420
200	5.0	1000	1	1000
400	3.5	1400	1	1400
500	3.2	1600	1	1600
1000	2.2	2200	1	2200
1500	1.8	2700	1	2700
2000	1.6	3200	1	3200
5000	1.0	5000	1	5000
10.000	0.7	7100	1	7100
20.000	0.5	10.000	1	10.000

Table 6-6: Start quantity for pressure-rinsing bulk goods (for start parameter set)

Components sampled by pressure-rinsing as bulk goods				
Inspected object area in cm²	Start pressure-rinsing volume/inspected object area in mL/cm²	Resulting start pressure-rinsing volume per inspected object in mL	Minimum inspection lot size (number of components per inspection lot)	Total pressure-rinsing volume per inspection lot in mL
1	5.0	-	200	1000
2	5.0	-	100	1000
5	5.0	-	40	1000
10	5.0	-	20	1000
20	5.0	-	10	1000
50	5.0	-	4	1000

Note 2: The formulas and tables are general recommendations for deriving the rinsing start volume per component surface for a declining test. It may make sense to increase this starting value if, for example, the component is very complex or the contaminants adhere very firmly. In the opposite case, the rinsing start volume per component surface can also be reduced. Note that a reduction carries the risk

of an unsuccessful declining test, which may then have to be repeated with a higher rinsing volume per component surface.

Note 3: The annex (see Figure 6-6) contains information on the use of alternative nozzle cross-sections with equivalent mechanical cleaning effects.

6.4.2.3 Materials and equipment

The materials and equipment used in the extraction step must comply with the general requirements of extraction equipment described in Chapter 6.2:

1. Extraction liquid
2. Recipient for component: e.g. rest, forceps or mount for single objects; coarse-meshed basket for small components; manipulators for large components
3. Pressure-rinsing device consisting of (see also Figure 6-5 in the annex):
    a) Pressure-rinsing tool(s): e.g. “nozzle stylus,” which can be controlled manually during the component extraction process and final rinsing of the extraction apparatus, lances for component inner surfaces, or similar.
    b) ability to release fluid (finger switch or foot switch)
    c) media supply with container for extraction liquid, purification filter, pump or pressure supply
    d) Container for filtering the analysis liquid (integrated or separate)
4. Extraction container: e.g. pressure-rinsing chamber, funnel or sampling vessel to collect analysis liquid
5. Suction unit (optional): to remove residual liquid from component cavities
6. Where required, graduated vessel to measure volumes: e.g. beaker or measuring cylinder and stopwatch to control extraction times or calculate the flow rate if volumetric measurement is used for the pressure-rinsing step

Note: Using laboratory wash bottles for component extraction by pressure-rinsing is not recommended, because it is not possible to attain a defined and stable pressure-rinsing parameter and is thus not a reproducible extraction step. However, in many cases, laboratory wash bottles are suitable for the final rinsing of extraction or filtration equipment.

6.4.2.4 Procedure

The following procedure must be adapted to the features of the inspected object and/or inspection equipment. The extraction must be performed in accordance with applicable work safety rules.

1. Procure all resources required for the inspection

2. Pre-clean all surfaces of the extraction apparatus in contact with media (manually or using automatic chamber rinsing); where appropriate, determine pre-cleaning blank value

3. Prepare the inspected objects in accordance with Chapter 6.3

4. If necessary, release particles (see Chapter 6.4.6)

5. Place the inspected object in the extraction container/extraction chamber; if necessary, position the inspected object in such a way so as to enable the liquid to flow easily into the sampling container or collecting vessel

6. Execute the pressure-rinsing extraction procedure carefully and in compliance with all parameters, times and the precise pressure-rinsing sequence without loss of liquid and without wetting component areas that are not relevant to the inspection

7. Remove residual liquid (if required, repeatedly) from all areas of the component where liquid can accumulate; use suction apparatus to remove liquid from objects with cavities that are difficult to access (this liquid must be included in the analysis)

8. Where applicable: extract the inner surfaces of packaging (this liquid is also included in the analysis)

9. Carry out a final rinse on all areas of the extraction equipment (chambers, fixtures for components, gloves, auxiliary materials

such as plugs, etc.; manually or with automatic chamber rinsing) including surfaces that come into contact with the extraction medium in the next step during filtration on the inflow side of the filter. A suitable procedure should be elaborated, tested and defined for this final rinsing step (the resulting liquid forms part of the analysis liquid)

10. Transfer all the liquid for filtration and analysis

11. Fill out the inspection report

6.4.2.5 Documentation

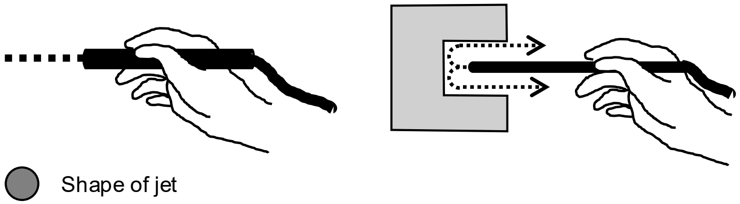
see Chapter 9 DOCUMENTATION as well as Chapter 12 CASE EXAMPLES

Annex 6.4.2 Pressure-rinsing

A 6.4.2.1 Examples of pressure-rinsing techniques

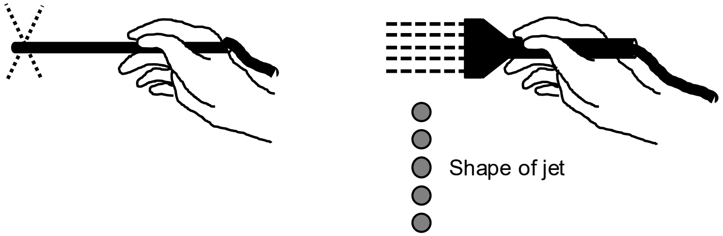
1) Round full-jet nozzle for localized extraction

2) Pressure rinsing lance for extracting particles from blind holes



3) „Spiked lance“ for extracting particles from internal component areas

4) Parallel-jet nozzle for extracting particles from larger surface areas



5) Flat-jet nozzle (fan nozzle) for extraction of larger surface areas (care with aerosol formation)

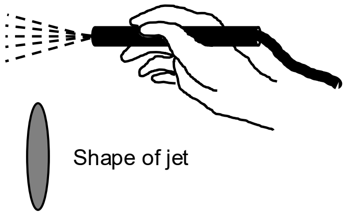


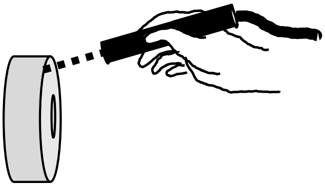
Figure 6-3: Examples of pressure-rinsing techniques

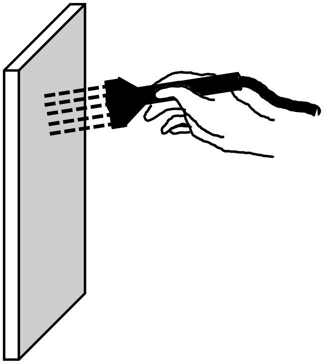
Note: Not all nozzle types shown can be used with the start parameters.

A 6.4.2.2 Examples of use of pressure-rinsing

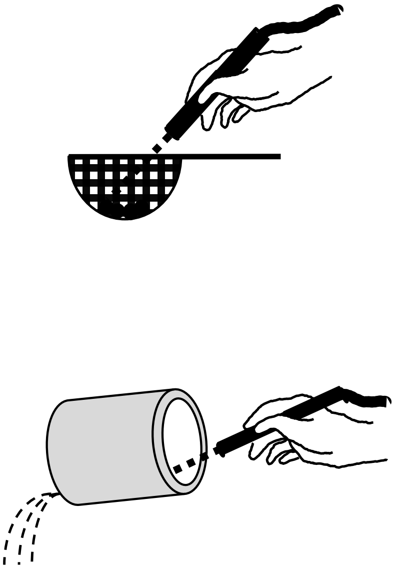
1) Pressure rinsing single component

2) Pressure rinsing large surfaces





3) Pressure rinsing small components
(bulk goods)



4) Pressure rinsing accessible
internal areas of components

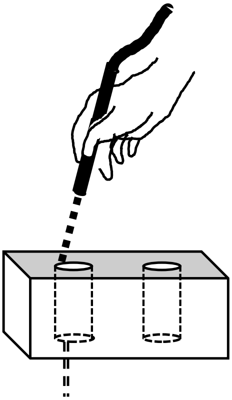


Figure 6-4: Examples of use of pressure-rinsing

A 6.4.2.3 Example of pressure-rinsing apparatus

1) Pressure-rinsing chamber (clean air area)
2) Manual pressure-rinsing tools
3) Collecting basin
4) Stopcock
5) Analysis filter
6) Media supply with
   - Container for test liquid
   - Purification filter
   - Pump or pressure supply
7) Control unit for pressure-rinsing programs
8) Foot switch

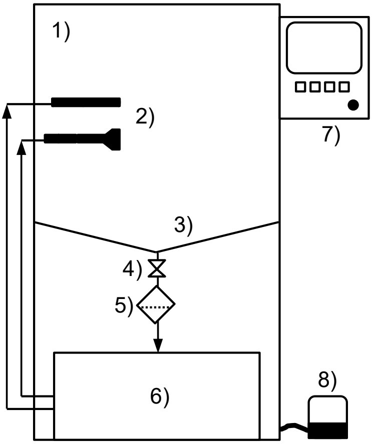


Figure 6-5: example pressure-rinsing apparatus

A 6.4.2.4 Nozzle diameter and flow rate

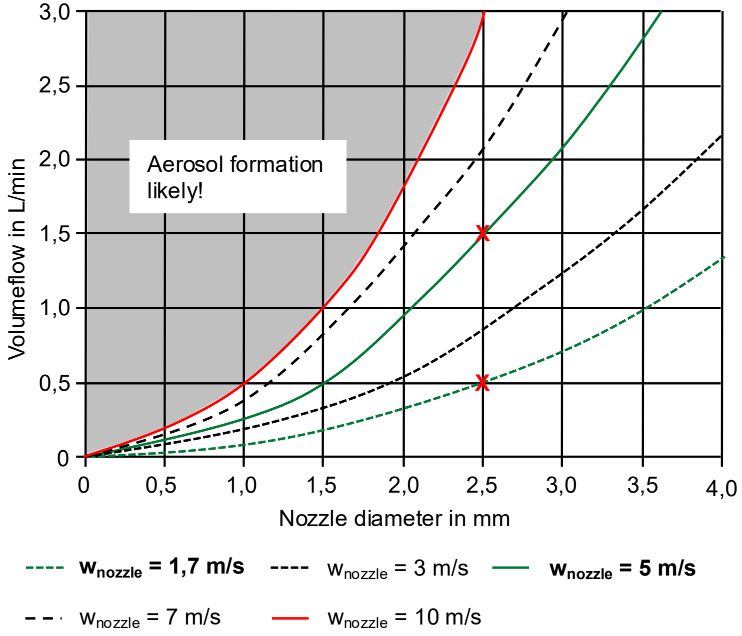


Figure 6-6: Nozzle diameter and flow rate

The figure shows the curves for various nozzle exit velocities based on the nozzle diameter and flow rate. This exit velocity characterizes the impulse of the fluid and thus its mechanical cleaning effect. The points marked X indicate the start parameters for low-pressure rinsing and pressure-rinsing. By following the lines at constant exit velocities, it is possible to determine the flow rate that corresponds to the equivalent mechanical cleaning effect for other nozzle diameters. Based on

- Leaflet M 043 02/2007 published by BG Chemie
- EN 12921-3:2005+A1:2008 (international C-norm ISO 12921-3)

the area in dark gray can be expected to have aerosol formation at the nozzle outlet, such that even liquids that are not flammable at room temperature can create potentially explosive mixtures. The consequences should be considered on a case-by-case basis.

A 6.4.2.5 Rinsing start volumes

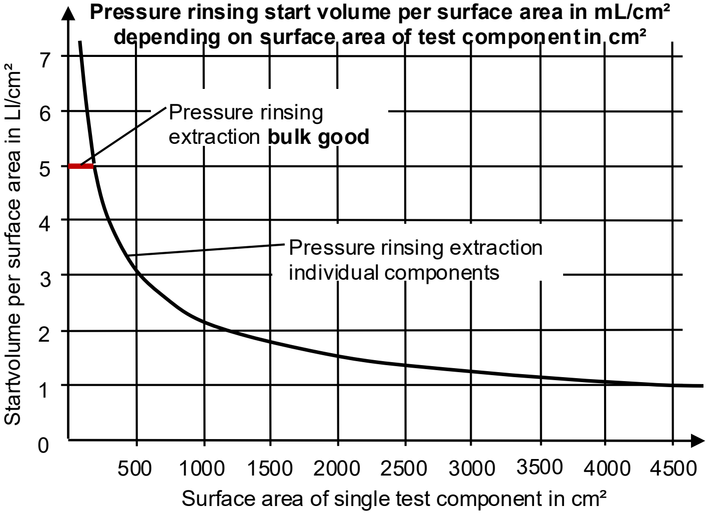


Figure 6-7: Rinsing start quantity per surface in mL/cm² size depending on the component area in cm² (for start parameter set)

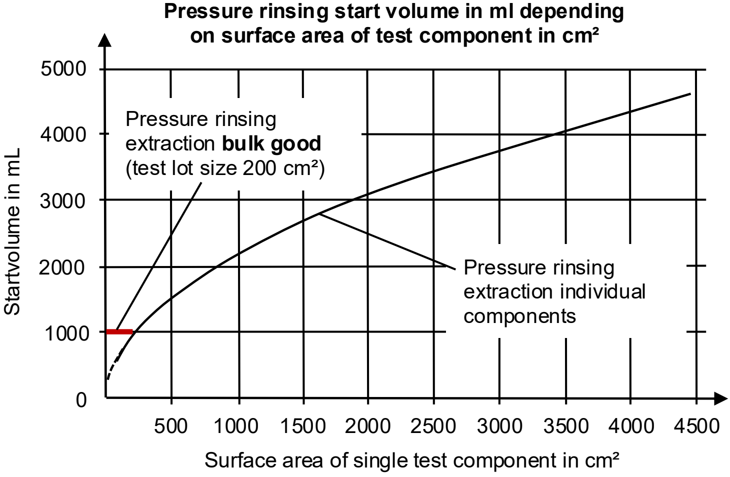


Figure 6-8: Rinsing start quantity in mL size depending on the component area in cm² (for start parameter set)

6.4.3 Ultrasonics

6.4.3.1 Principle

Extraction by ultrasound describes the action of mechanical oscillations ranging between 20 and 400 kHz exerted on the surface of an inspected object via a liquid. The cleaning procedure is performed in immersion baths fitted with ultrasonic oscillating elements.

The particle-detaching effect of extraction by ultrasonics is caused by high pressure peaks that form when cavitation bubbles implode.

The ability of ultrasonics to detach contaminants is due mainly to the ultrasound frequency and changes in ultrasound pressure, which are influenced by the ultrasonic output and geometric features. As a rule, the higher the ultrasound output and the lower the ultrasound frequency, the stronger the physical cleaning forces become.

Note 1: In the event that inappropriate ultrasound parameters cause too much material to be removed from the component surface, thus skewing the result, this can be corrected by setting a higher frequency or lower output. Special care must be taken with cast iron, because graphite may be released. Care is also required with cast aluminum surfaces, painted or coated surfaces and sintered materials, as the selection of unsuitable ultrasound parameters may cause material damage with the result that non-relevant particles are released from the component surface.

Ultrasound baths are suitable for sampling external geometries as well as internal surfaces, provided the sound waves can penetrate component apertures with sufficient intensity. The smaller the openings for the sound waves and the larger the inner cavities become in proportion, the poorer the cleaning effect inside a component. Therefore, when extracting contaminants from the interior and exterior of a component at the same time, the cavitation threshold inside the component must be exceeded without the component material on the outside being attacked.

Ultrasound baths are especially suitable for extracting contamination from small components that are difficult to handle individually because they can be sampled in bulk. The use of small ultrasound extraction baths or beakers reduces the total surface area wetted during the extraction step, which has a positive impact on achievable blank values.

Ultrasonics can also be used to enhance internal rinsing procedures. Here, the interior of the inspected object, which is generally tube-shaped (no sound-absorbing materials), is subjected to a stream of extraction liquid and additionally immersed in an ultrasound bath and sonicated externally.

There are two types of ultrasound extraction:

- **Direct sonication**: The inspected object(s) (e.g. small parts in the sieve basket as bulk goods) are located directly in the ultrasound tank. The ultrasonic transmission medium is the same as the extraction medium (aqueous cleaner). The sonicated volume is the same as the volume of the extraction liquid. The tank is typically emptied through a floor drain. The filtration unit is connected directly to the discharge outlet (see Figure 6-9 in the annex, cases 1) and 2)).

- **Indirect sonication**: The inspected object(s) are located in an additional container (e.g. beaker or stainless steel tray), that is submerged in the ultrasound tank. The ultrasonic transmission medium in the tank (DI water) is separate from the extraction medium (aqueous cleaner or solvent). The filtration of the extraction medium is typically separate (e.g. suction filter), and only the contents of the submerged container are filtered, not those of the ultrasound tank (see Figure 6-9 in the annex, cases 3) and 4).

Note 2: If multiple components are extracted in the ultrasound bath at the same time, there is a risk of abrasion particles forming when the components touch one another during sonication.

The main parameters influencing extraction by ultrasound are:

- characteristics and temperature of the extraction liquid
- ultrasound frequency
- ultrasound power density
- cavitation noise level
- arrangement of ultrasonic oscillators in the bath
- orientation of the component in relation to the ultrasound source
- extraction time

6.4.3.2 Start parameters

The start parameters for extraction by ultrasonics are carefully selected in order to avoid highly-aggressive low ultrasound frequencies, and the cavitation noise level is selected so as to achieve a good cleaning effect. The criterion for effective cleaning and thus extraction effect is what's called "transient cavitation". It can be determined based on the cavitation noise level, which must reach a minimum of 206 dB (IEC TS 63001:2024 Annex A, B).

This value, which can be ascertained with hydrophones and corresponding data processing, is either determined by the design of the ultrasound tank or can be adjusted to a certain degree in case of power-adjustable devices.

Table 6-7: Start parameters for ultrasonics

Parameter	Start value
Ultrasonic frequence	35-40 kHz
cavitation noise level (IEC TS 63001:2024 Annex A, B)	≥ 206 dB
Time	30-60 s

Note 1: The power density in W/l, i.e. the power received by the sound transducers and emitted into the volume of the tank, is not an adequate measure on its own for the occurrence of transient cavitation, which is necessary for effective cleaning. Small ultrasound tanks need a much greater power density compared to larger tanks.

Note 2: The initial or regular review of the cavitation noise level is performed regardless of whether the extraction was performed with aqueous cleaner directly or indirectly or in the cold-cleaner-filled beaker, stainless steel tray, etc. with water as the transmission medium. In both cases, the cavitation noise level is checked in the empty tank (without basket, etc.), with demineralized/DI water, in laboratory ultrasonic baths at the standard fill level, at room temperature and after degassing. To check utilized baskets etc. monitoring can be performed, e.g. according to Annex A 6.4.3.2.

Note 3: A cavitation noise level measurement can be used to check whether utilized baskets, etc. are permeable enough for the ultrasound.

Note 4: IEC TS 63001:2024 (Measurement of cavitation noise in ultrasonic baths and ultrasonic reactors) describes the currently valid version for the measurement of cavitation noise levels in ultrasonic baths. Since the unit of reference for the preceding version of the standard or DIN Spec 40170 has changed, see Table 6-8 for a corresponding conversion tool.

Note 5: Even if the ultrasound does not show any transient cavitation when used directly in cold cleaners and the extraction effect is thus not in the same order of magnitude as in aqueous applications, it can still be used, e.g. to assist with dissolving, thanks to its fine-rinsing effect. This method is not equivalent to an ultrasound extraction with transient cavitation, however.

Table 6-8: Cavitation noise level conversion (different version of standard)

DIN Spec 40170*	IEC TS 63001:2019*	IEC TS 63001:2024 (Annex A, B)
x	x+117	x+177
29	146	206

* no longer valid

When using ultrasonic testing for small components that are inspected in bulk, it is recommended that the inspection lot should contain at least enough components to comprise a **sampled surface area of 200 cm²** or more. For an explanation of this recommendation, see also 6.4.2.

During the qualification test/declining tests (see Chapter 5,) the required duration in the ultrasound bath is determined for the routine inspection depending on after which extraction step the declining criterion is attained. If the declining criterion cannot be achieved with these start parameters or if more suitable parameters are justified and documented, the recommended start parameters may be modified.

6.4.3.3 Materials and equipment

The materials and equipment used in the extraction step must comply with the general requirements of extraction equipment described in Chapter 6.2.

1. Extraction liquid/extraction medium and, if necessary, transmission liquid for indirect sonication

2. Ultrasound bath: Ultrasound bath of suitable size for the inspected object with a cavitation noise level of ≥ 206 dB (IEC TS 63001:2024 (Annex A, B)) and an ultrasound frequency of 35-40 kHz. In addition:

    a) Mounting device to secure the inspected objects in the bath (no contact with the base or walls); materials must be permeable to ultrasound waves (e.g. baskets with very coarse mesh, no mounting devices made from compact absorbent plastics)

b) Where appropriate: beaker for holding small components and corresponding mounting device for beaker

Note 1: In the routine inspection, all the attachments (holders, tubs, beakers, etc.) used in ultrasonic tanks should correspond to those used in the development and qualification of the extraction procedure.

Note 2: If small parts are sonicated as bulk goods and are so small that they require a very fine basket, it may be advisable to use a beaker or stainless steel tray (indirect sonication) instead of a basket, since this has less of an effect on the ultrasound.

3. Where appropriate: additional containers (funnels, beakers) to collect the extraction liquid

4. Pressure-rinsing inspection set-up for the final rinsing of components and equipment (see Chapter 6.4.2)

5. Graduated vessel to measure volumes, e.g. beaker or measuring cylinder

6. If necessary, container for filtering the analysis liquid

7. If necessary, suction unit for removing residual liquid from component cavities

Attention: In addition to the general safety requirements applicable to all extraction methods (see Chapter 11), two further points must be considered when using ultrasound baths:

- Due to the coupling of ultrasonics in the extraction liquid and the resulting energy input, liquids may heat up if subjected to ultrasonic waves for an extended period of time. It is especially important to consider and check this if using combustible liquids. The liquid must be kept 20° below the flashpoint.
- In conventional laboratory ultrasound baths, it is not permissible to add solvents for direct sonication. This is only allowed for approved extraction apparatuses, provided that the solvent is used for dissolving (see also Chapter 6.4.6).
- When using solvents (direct or indirect sonication), ensure that the corresponding workplace limit values are not exceeded through vaporization of solvents. It may be necessary to use an exhaust/suctioning device.
- During the application of ultrasound, do not place hands or any other part of the body in the extraction liquid (risk of embolus or destruction of skin cells).

6.4.3.4 Procedure

The following procedure must be adapted to the features of the inspected object and/or inspection equipment. The extraction must be performed in accordance with applicable work safety rules.

1. Procure all resources required for the inspection

2. Pre-clean all surfaces of the extraction apparatus in contact with media; where required, determine blank values

3. Prepare the inspected objects in accordance with Chapter 6.3

4. Fill the extraction apparatus with clean extraction liquid:

    a) For inspection directly in the ultrasound bath, direct sonication: Fill the bath and set the output to achieve the required cavitation noise level. (For ultrasound baths with non-adjustable power, this typically corresponds to the designated standard fill level of the tank).

    b) In a beaker or stainless steel tub, indirect sonication: Fill the bath with water (optional: add a small amount of cleaning medium/tensides to improve the wetting capacity). The water only serves to transmit the ultrasound waves to the beaker and is not later analyzed. As with direct sonication, if necessary, adjust the power to correspond to the necessary cavitation noise level. Fill the beaker or stainless steel tub. The level of fluid in the beaker or stainless steel tub should be approximately at the level of the fluid in the ultrasound basin or slightly higher

5. Degas the transmission and inspection medium (30 s usually enough). For extraction procedure qualification, degas before introducing the inspected object; for routine inspection, degas the introduced inspected object directly in combination with extraction (and adjust the extraction time by the degassing time)

6. Place the inspected object(s) (in a single layer to prevent shadowing) in the ultrasound bath in recipients such as baskets or in the filled beaker, which is secured in the ultrasound bath by a mounting device (see Table 6-10)

7. Start the ultrasound extraction with the parameters, frequency and time stated in the inspection specification

   Note 1: If the component will be sonicated from several sides or several positions, take care when changing its position (turning over, rotating, etc.) to avoid additional particles from being generated by this handling step.

8. Remove the inspected object(s), and carefully rinse over the ultrasound tank or beaker with clean extraction liquid

9. If necessary, drain the inspected object to remove any residual liquid and collect the particles it contains

10. If necessary, extract the inner surfaces of packaging (low-pressure-rinsing); any liquid also counts as analysis liquid

11. With indirect sonication, empty the beaker; alternatively, if technically feasible, drain the analysis liquid from the tank with direct sonication

    Note 2: If using laboratory ultrasound tanks for direct sonication, ensure that no particles that have detached from the component remain in the tank. There is often the risk of a “particle sink” at the tank drain, which typically has a gap or step to it for manufacturing reasons. If the ultrasound tank has taps or similar for drainage, check if operating the taps causes them to drop particles that could overlap with the analysis result (blank value).

12. Carry out a final rinse on all surfaces wetted with extraction liquid (e.g. beaker and/or tank, holders, baskets, etc.) with a sufficient amount of extraction liquid. This includes surfaces that come into contact with the extraction medium in the next step during filtration on the inflow side of the filter. Any resulting liquid forms part of the analysis liquid.

13. Transfer all the liquid for filtration and analysis

14. Fill out the inspection report

6.4.3.5 Documentation

see Chapter 9 DOCUMENTATION as well as Chapter 12 CASE EXAMPLES

Annex 6.4.3 Ultrasound

A 6.4.3.1 Examples of use of extraction by ultrasound

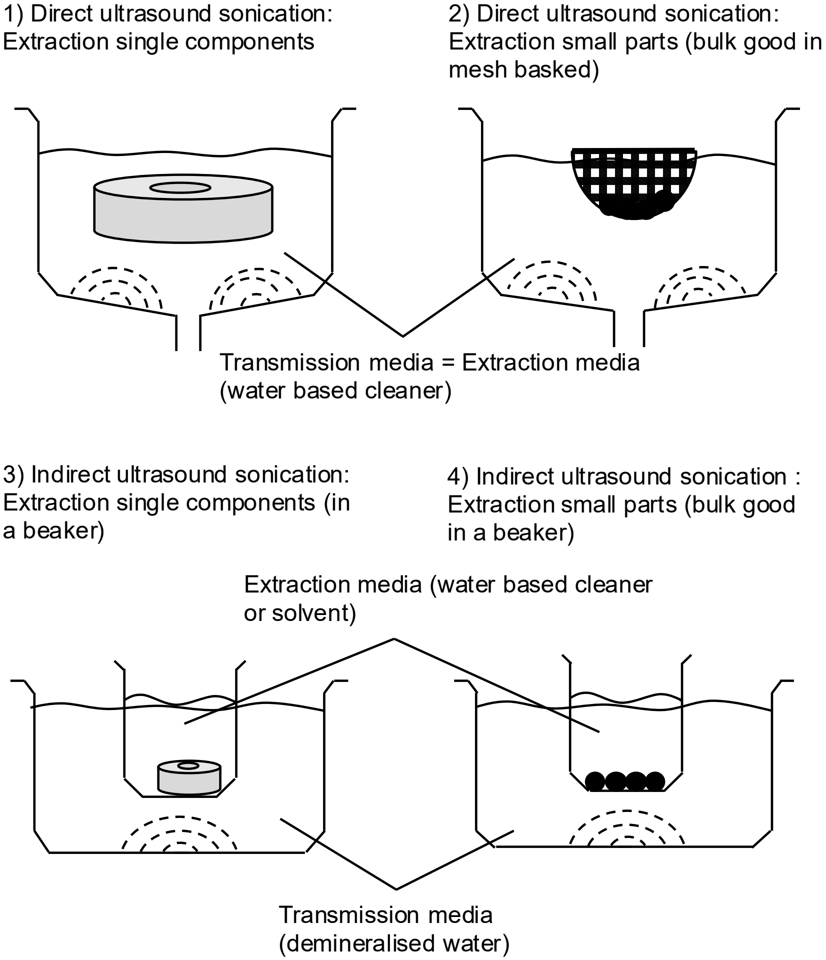


Figure 6-9: Examples of use of ultrasound extraction

A 6.4.3.2 Verifying performance features of ultrasound baths

To assess relative stability over time (aging) or to compare different ultrasound baths, the efficacy of the ultrasound system can be verified in addition to measuring the cavitation noise level. This is achieved by quantitatively determining the perforation of a sheet of aluminum foil by cavitation. The procedure must be carried out under defined conditions (foil thickness, location and orientation of the foil in the bath). If the ultrasound tank is used for direct sonication (see Figure 6-9), the aluminum particles created by cavitation in this test must be entirely removed again, so that they cannot be carried over into the downstream extraction procedures.

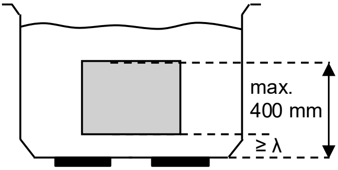
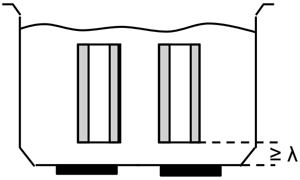
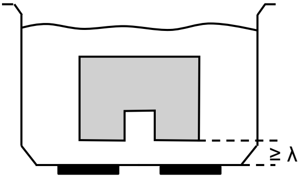
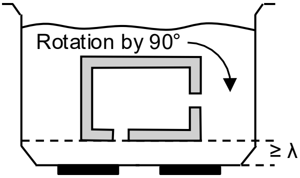
A 6.4.3.3 Examples of ultrasound wavelengths

Table 6-9: Examples of ultrasound wavelengths

Frequency	Wavelength λ
25 kHz	61 mm
35 kHz	43 mm
40 kHz	38 mm
120 kHz	12 mm

A 6.4.3.4 Examples of arranging components in the ultrasound immersion bath

Table 6-10: Examples of arranging components in the ultrasound immersion bath

Extraction	Arrangement in bath	Comment
External extraction	 Surface emitting ultrasonic waves	Distance between component and sound source should be ≥ λ (see Table 6-9) For distances > 400 mm between the surface to be cleaned and the sound-emitting surface, components will have to be rotated.
Simple inner cavity	 Surface emitting ultrasonic waves	Orientation of component opening to sound-emitting surface
Blind hole or similar shape	 Surface emitting ultrasonic waves	Orientation of component opening to sound-emitting surface Ensure cavity is filled
Inner cavity	 Surface emitting ultrasonic waves	Orientation of component opening to sound-emitting surface Ensure cavity is filled

6.4.4 Internal rinsing

6.4.4.1 Principle

Internal rinsing describes the extraction of contamination by means of a flow of liquid passed through the inner surfaces of a component. In the process, the entire (or almost entire) inspected object is completely filled with extraction liquid. In order to ensure that particles are detached effectively from the walls of the component, the flow through the interior should be turbulent and not laminar. A specially pulsed throughflow further enhances the efficacy of this extraction technique.

Consequently, internal rinsing is a suitable extraction method for automotive components that will conduct fluids in later use. Examples include:

- passive components such as tubing, lines, channels, filters and heat exchangers or

- active components needing to be actuated for the throughflow process, such as valves and injectors, or even driven, such as pumps (see Figure 6-11 in the annex).

With internal rinsing, at least one point of the inspected object is connected hermetically to a line holding extraction liquid. Once the medium has flowed through the inspected object, the liquid can be removed from the component via one or more lines connected to it. For example, the liquid can flow into a closed rinsing system or be allowed to drain off into an extraction basin without the influence of pressure.

Depending on the inspected object concerned, the set-up for extraction by internal rinsing can be very simple. For example, a pressure-rinsing set-up such as that illustrated in the annex (see Figure 6-5) can also be used to rinse fairly short sections of piping provided pressure-rinsing tools are replaced by rinsing devices.

In the case of active components, internal rinsing test benches may be highly complex if components need to be powered, driven or subjected to high pressure.

Where components have wide cross-sections for connections, e.g. cooling systems of commercial vehicles, extraction by internal rinsing often reaches its limits because a major effort is required to construct the extraction apparatus with the necessary volumes and flow rates of liquid. It may make sense in such cases to revert to extraction by agitation or pressure-rinsing.

The advantage of internal rinsing is the wetted inner area is clearly delimited during inspection. Thus there is no risk of the inspection medium flowing over external surfaces of the component that are not relevant to the extraction procedure. However, adapters for connections/rinsing tubing may generate and release particles due to friction. In the case of active components, there is also a risk of added contamination being generated from running-in processes and frictional wear when the components are activated.

The main parameters influencing the extraction method of internal rinsing are:

- Characteristics of the extraction liquid
- volume flow and rinsing time
- geometry and model of the inspected object
- pulsation and pulsation frequency
- type and frequency of movement (for active components)

6.4.4.2 Start parameters

As opposed to other liquid extraction methods, there are no meaningful start parameters for internal rinsing. This is because the volume flow required for a turbulent throughflow (calculable via the Reynolds number > 4000) depends on the geometry of the inspected object and the inspection medium used.

However, the minimum throughflow volume must be several times the inner volume of the component.

In the annex, a table of examples (see Table 6-11) lists the flow velocity required for an extraction liquid (cold cleaner) to rinse through tubes or lines of varying diameters in order to achieve a fully turbulent flow and thus maximize the efficacy of the extraction.

6.4.4.3 Materials and equipment

The materials and equipment used in the extraction step must comply with the general requirements of extraction equipment described in Chapter 6.2.

1. Extraction liquid

2. Where appropriate, use a component fixture, e.g. holders or clamps, for active components for switching, actuating, driving, etc.

3. Internal rinsing apparatus consisting of:

4. Adapters for filling the component, for the throughflow and for draining the liquid from the component

5. Media supply with container for extraction liquid, purification filter, pump or pressure supply; where appropriate, with pulsation mechanism

   Note 1: Internal rinsing systems can also be designed as vacuum rinsing systems, i.e. the liquid is not advanced through the component under positive pressure but rather sucked through the component using a vacuum device.

   Note 2: In a closed inner rinsing circuit, it would make sense to connect the analysis filter directly behind the component to be extracted. However, this is usually not possible, since the analysis filter has a high flow resistance, so it would not be possible to reach the flow velocity required for effective extraction in the inspected object.

6. If necessary, use additional containers (funnels, beakers) to collect the extraction liquid

7. Pressure-rinsing apparatus for final rinse of equipment under 4. and 7. with extraction liquid

8. Graduated vessel to measure volumes; e.g. beaker or measuring cylinder

9. If necessary, container for filtering the analysis liquid

10. If necessary, suction unit for removing residual liquid from component cavities

An example of the schematic structure of a rinsing system is provided in the annex, Figure 6-12.

6.4.4.4 Procedure

The following procedure must be adapted to the features of the inspected object and/or inspection equipment. The extraction must be performed in accordance with applicable work safety rules.

1. Procure all resources required for the inspection
2. Pre-clean all surfaces of the extraction apparatus in contact with media; where required, determine blank values
3. Prepare the inspected objects in accordance with Chapter 6.3
4. Fit adapters to the inspected object for rinsing tubes; if required, position the inspected object in such a way so as to enable the liquid to flow easily into the sampling container or collecting vessel (see also Figure 6-10 in annex)
5. Where appropriate: with active components, connect power, switching or drive device to the inspected object
6. Perform the internal rinsing procedure in accordance with all parameters, times and, in case of active components, operating parameters
7. Empty residual liquid from component areas in which liquid and particles could collect (if required, repeatedly). For objects with cavities that are difficult to access, use suction equipment (the resulting liquid is included in the analysis)
8. Final rinsing of connections, supply and drain lines, valves and other surfaces in the rinsing lines is performed during extraction

    Note 3: It is not necessary to rinse these areas without the inspected object. If any containers or devices are used which are not completely filled with extraction medium and subjected to turbulent throughflow during the interior rinsing procedure, they must rinsed separately (e.g. collection containers for the extraction liquid before filtration). This includes surfaces that come into contact with the extraction medium in the next step during filtration on the inflow side of the filter. A suitable procedure should also be developed, tested and defined for this final rinsing step (the resulting liquid forms part of the analysis liquid).

9. Transfer all the liquid for filtration and analysis

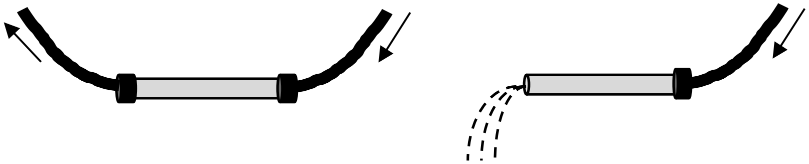
10. Fill out the inspection report

6.4.4.5 Documentation

see Chapter 9 DOCUMENTATION as well as Chapter 12 CASE EXAMPLES

Annex 6.4.4 Internal rinsing

A 6.4.4.1 Examples of extraction by internal rinsing



1) Internal rinsing in a clases system (adapter for tubing on both sides)

2) Internal rinsing by adapting a rinsing line (pressurless outflow)

3) Internal rinsing by adapting a pressure-rinsing tool (pressureless outflow)

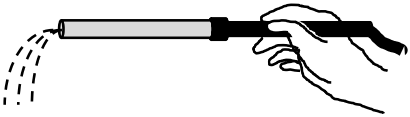
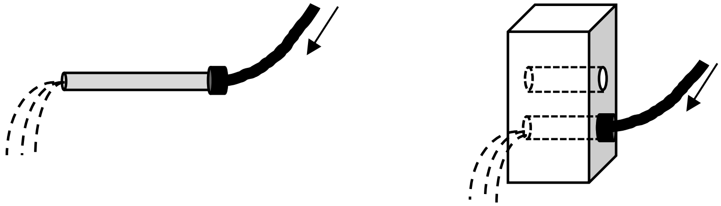


Figure 6-10: Examples of extraction by internal rinsing

A 6.4.4.2 Other application examples of extraction by internal rinsing

1) Internal rinsing pipes or lines

2) Internal rinsing of inner component areas (e.g. oil borings)



3) Internal rinsing componets (e.g. heat exchangers or filter housings)

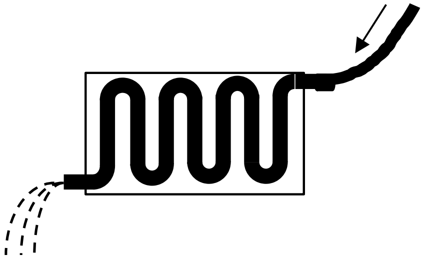


Figure 6-11: Other application examples of extraction by internal rinsing

A 6.4.4.3 Examples of turbulent throughflow parameters

The following table lists example parameters of a turbulent flow for a cold cleaner with a flash point of 62 °C and a kinematic viscosity of 1,9 mm²/s.

Table 6-11: Example parameters of a turbulent flow

Internal rinsing area* in mm	Flow rate in L/min
4	1.4
5	1.8
6	2.2
8	2.9
10	3.6
12	4.3
15	5.4
20	7.2
25	9.0
30	10.8
40	14.3
50	17.9

*e.g. pipe or bore diameter

The turbulent flow through the tube is calculated using the Reynolds Number Re > 4000, defined using the following formula:

$Re = \mathrm{w} \times \frac{d}{v}$:

Re: Reynolds number

w: velocity of flow

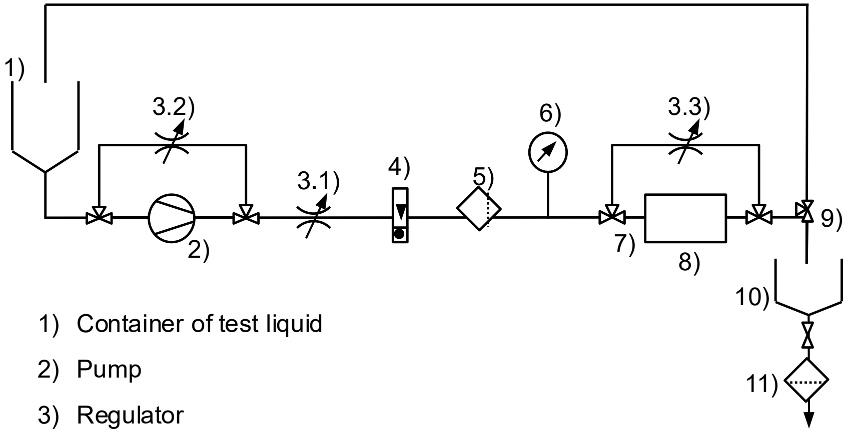
d: pipe diameter

ν: kinematic viscosity

The turbulent volume flow (dV/dt) for other liquids can be calculated as follows:

$\frac{dV}{dt} = \mathrm{Re} \times \mathrm{d} \times \pi \times \frac{v}{4}$

A 6.4.4.4 Example of a rinsing system



1) Container of test liquid
2) Pump
3) Regulator
    3.1 Main regulator
    3.2 Regulator at level of pump bypass
    3.3 Regulator at level of test component bypass
4) Troughflow meter
5) Purification filter
6) Manometer
7) Mounting device to hold test component
8) Test component
9) Three-way ball valve
10) Collection vessel for extraction liquid
11) Analysis filter

Figure 6-12: example of a rinsing system

6.4.5 Agitation

6.4.5.1 Principle

The inspected object is partially filled with extraction liquid, and the openings are sealed. As this liquid is agitated, particles adhering to the inner inspection surface are detached and transferred to the liquid. The agitation process enables the liquid to exert a force on the particles from different directions. It also enables dead zones and undercuts to be reached effectively by the liquid. Detached particles are then held in suspension.

The method is suitable for inspected objects with cavities that can be accessed at least via one opening and whose size and weight allow the inspection areas to be adequately processed. The method is not suitable for sampling narrow inner geometries, such as tubes or capillaries, because the impulse created by agitation is too low to be effective.

The set-up chosen for the agitation procedure depends on the shape, size and weight of the component, and the procedure can be carried out manually or by means of an automated device.

The method is not suitable for foaming liquids.

Note: It is not recommended to place simply-shaped, small components in a vessel filled with extraction liquid and subsequently agitate the sealed vessel manually or by means of a vibrating table. This is because particles can be generated if the components strike against one another (see Figure 6-13 in annex, Figure 4); ultrasonics or pressure-rinsing are the preferred extraction methods in such cases.

The main parameters influencing extraction by agitation are:

- Characteristics of the extraction liquid
- volume of extraction liquid used
- duration, amplitude and frequency of the agitation step
- number of fillings
- final rinsing of the inspected object

6.4.5.2 Start parameters

The start parameters for extraction by agitation are selected so as to maximize the extraction effect while still allowing the process to be performed manually if desired.

Table 6-12: Start parameters for agitation

Parameter	Start value
Filling volume	30-40%
Amplitude	approx. 30 cm
Frequency	1 Hz *)
Time	15 s

*) 1 Hz indicates one agitation stroke per second

During the qualification test/ declining tests (see Chapter 5), the agitation procedure or number of agitation movements is determined for the routine inspection depending on after which extraction step the declining criterion is attained. If the declining criterion is not achieved with these start parameters or if more suitable parameters are justified and documented, these start parameters may be modified.

However, a filling volume of 30-40% for components should not be altered because a too-low or too-high filling quantity does not create the necessary mechanical action to generate an efficient cleaning effect.

6.4.5.3 Materials and equipment

1. Extraction liquid
2. Pressure-rinsing apparatus for final rinsing of components and equipment and/or dispensing the extraction liquid (see Chapter 6.4.2)
3. Graduated vessel to measure volumes; e.g. beaker or measuring cylinder
4. Funnel: for filling and/or emptying extraction liquid

5. Appropriately sized abrasion-resistant seals/stoppers for the inspected object
6. If necessary, automated agitation device, e.g. vibrating table fitted with mounting device for the inspected object
7. Clock to control the duration of the agitation step
8. If necessary, sampling container or sampling vessel to hold the analysis liquid
9. If necessary, suction unit for removing residual liquid from component cavities
10. Device for filtering the analysis liquid

6.4.5.4 Procedure

The following procedure must be adapted to the features of the inspected object and/or inspection equipment. The extraction must be performed in accordance with applicable work safety rules.

1. Procure all resources required for the test
2. Pre-clean all surfaces of the extraction apparatus in contact with media; where required, determine blank values
3. Prepare the inspected object in accordance with 6.3; take special care to clean the exterior of the component thoroughly and to seal the component openings with suitable clean, abrasion-resistant closing devices
4. Remove the closing device from one opening that can be used to fully empty the inspected object
5. Determine the volume of extraction liquid required, i.e. 30-40% of the volume of the interior of the inspected object
6. Pour the extraction liquid into the object and seal the opening
7. Perform the agitation step while observing all the specified conditions (frequency, amplitude, duration)

8. Remove one closing device and pour the liquid contained in the inspected object into a sampling vessel or filtration unit with the help of a funnel. Avoid any loss of liquid or wetting of external component surfaces

9. Carefully perform a final rinsing step on the interior of the inspected object. This final rinsing procedure may take the form of a further agitation step using clean extraction liquid or a pressure-rinsing step. The resulting volume of liquid forms part of the analysis liquid

10. Ensure that the inspected object is fully emptied

11. Then, using a sufficient volume of extraction liquid, carry out a final rinsing step on all surfaces wetted by the extraction liquid (sampling vessel, filtration equipment, etc.). The resulting liquid is included in the analysis

12. Transfer all the liquid for filtration and analysis

13. Fill out the inspection report

6.4.5.5 Documentation

see Chapter 9 DOCUMENTATION as well as Chapter 12 CASE EXAMPLES

Annex 6.4.5 Agitation

A 6.4.5.1 Examples of use of extraction by agitation

1) Agitation of a pressure tank

2) Agitation of a pipe section (short, large diameter)

3) Agitation of a container

4) Agitation of small components in a container: not suitable

Figure 6-13: Examples of use of extraction by agitation

6.4.6 Dissolving

6.4.6.1 Principle

In cases where components have been treated with preservatives or grease, for example, effective particle extraction can only be achieved after first dissolving the layer of preservative or grease present. As a result, a delayed decline may take place in the course of the qualification tests.

In such cases, dissolving can be carried out as a preparatory step before performing the actual extraction procedure. In this process, the inspected object is first immersed in a suitable solvent (e.g. the inspection medium) for an appropriate length of time, typically without further physical cleaning effects, such as pressure-rinsing or ultrasonics.

Alternatively, components can also be completely filled and sealed if the inspection surfaces are on the interior.

Note: Dissolving, as described, is typically done by placing an inspected object in an extraction liquid. When using cold cleaners to dissolve contaminants, ultrasound can be additionally applied to enhance the cleaning effect. This does not constitute an ultrasound extraction, since ultrasound does not produce transient cavitation in cold cleaners. Instead of effective cleaning action, it therefore only produces a weak fine rinsing effect. The device in which ultrasound-assisted dissolving is performed must be approved for use with cold cleaners.

The volume of liquid used in the dissolving step as well as the final rinsing liquid for the vessel in which the dissolving step is carried out forms part of the analysis liquid.

The dissolving step can be speeded up during the extraction process by using an extraction liquid with a stronger chemical solvent action (verify compatibility with component as well as inspection equipment). In such cases, the respective safety regulations apply.

The main parameters influencing the dissolving step are:

1. characteristics of the dissolving liquid
2. duration of the dissolving procedure

6.4.6.2 Materials and equipment

1. Dissolving liquid (e.g. extraction liquid or medium with stronger dissolving properties)
2. Pressure-rinsing equipment to perform final rinsing step on the apparatus and/or to dispense the extraction liquid (see Chapter 6.4.2)
3. If necessary, funnel for filling or removing dissolving liquid
4. If necessary, suitable abrasion-resistant seals/stoppers for the inspected object
5. Clock to control the duration of the dissolving step
6. Dissolving container, beaker or bath from pressure-rinsing or ultrasound extraction apparatus

6.4.6.3 Procedure

The following procedure must be adapted to the features of the inspected object and/or inspection equipment. Dissolving must be performed in accordance with applicable work safety rules.

1. Procure all resources required for the inspection
2. Pre-clean all surfaces of the dissolving container in contact with media, where required, determine the blank value
3. Place the component in the dissolving container
4. Fill the dissolving container with dissolving liquid until the component is fully immersed. Ensure that all surfaces are completely wetted, e.g. in case of components with cavities
5. Leave the component in the dissolving liquid during the dissolving period
6. Remove the component, and transfer it to the next step of the extraction procedure
7. Transfer the dissolving liquid to the filtration process

8. Then, using a sufficient volume of extraction liquid, perform a final rinsing step on all surfaces wetted by the dissolving liquid (sampling vessel, filtration equipment, etc.). The resulting liquid forms part of the analysis liquid

9. Transfer all the liquid for filtration and analysis

10. Also rinse any surfaces that come into contact with the extraction medium on the inflow side of the filter during analysis filtration

11. Fill out the inspection report

If the dissolving procedure is only carried out on the inner surfaces of a component, the described procedure must be modified accordingly

The component must be completely filled with dissolving liquid (ensure that all surfaces are fully wetted and that no air bubbles are present) and sealed during the dissolving step (e.g. with stoppers). The component is then emptied, and the dissolving liquid is transferred to the filtration process.

6.4.6.4 Documentation

see Chapter 9 DOCUMENTATION

6.5 Dry extraction

As described in Chapter 3.1.3.3 on extraction method selection, in case of barely adhering or dry, non-adhering particles, or in case of components that do not come into contact with liquids during their operation (and also some during their manufacture) or can be damaged if they come into contact with a liquid, e.g. air filters, it is possible to use dry extraction.

6.5.1 Air jet extraction

6.5.1.1 Principle

With this extraction method, particles are detached from the inspected object by means of a jet of clean, oil-free compressed air. The tools and procedure are similar to those required for liquid extraction by pressure-rinsing.

The method is suitable for external surfaces, or for the inner surfaces of components accessible with a jet of compressed air. It can be utilized, for example, to extract contaminants from electronic components, single components of engine air intake tracts that cannot be cleaned using the liquid throughflow method, or also to remove contamination from logistics packaging, such as blister packs, small load carriers or cardboard.

This form of extraction requires a fully sealed chamber with the possibility to intervene manually as well as connections for compressed air (e.g. glove box). It must be possible to vent the chamber to prevent a positive pressure from being created inside it (possible particle loss due to escaping air).

Air jet extraction is performed in two steps Figure 6-14 in the annex):

1. In the first step, particles are detached from the inspected object with a jet of compressed air and adhere to the walls of a chamber wetted with liquid. After air jet extraction, the inspected object is removed from the chamber.

2. In the second step, the particles adhering to the chamber walls are rinsed off and transferred for analysis using a process similar to the final rinsing step performed after extraction by pressure-rinsing.

The main parameters influencing air jet extraction are:

- Pressure of the jet of compressed air
- Geometry of the jet nozzles
- Distance and angle to inspected object
- Sequence of extraction of surfaces
- Time per surface or forward feed
- Repetitions per surface

6.5.1.2 Start parameters

Table 6-13: Start parameters for air jet extraction

Parameter	Start value
Nozzle shape	Round full-jet nozzle
Nozzle diameter	1.5 mm
Volume flow (pressure)	40 L/min (1.5 bar)
Air jet distance	max. 10 cm
Air jet duration/component surface area	0.3 s/cm²

Note: When sampling larger surface areas, the extraction time can be reduced by using several nozzles (e.g. combined in an air jet tool). However, care must be taken to ensure that the above-mentioned parameters apply for each nozzle aperture.

During the qualification test/declining tests (see Chapter 5), the final duration of application of the jet per component surface is determined for the routine inspection depending on after which extraction step the declining criterion is attained.

If the declining criterion is not achieved with these start parameters or if more suitable parameters are justified and documented, these start parameters may be modified.

6.5.1.3 Materials and equipment

The materials and equipment used in the extraction step must comply with the general requirements of extraction equipment described in Chapter 6.2.

1. Supply of clean, oil-free compressed air (cleanliness of the compressed air must fulfill the blank value criteria), control valve to regulate pressure and manometer to display the pressure. Air jet tool with nozzle and switching option (finger switch on air jet pistol or foot pedal in compressed air line)

   Note: A quick method for checking particle cleanliness is to assess a particle trap that has had jet extraction air blown on it.

2. If required, device to secure the component: e.g. rest, mounting device

3. Fully sealed air jet and pressure-rinsing chamber with intervention options for guiding air jet and final rinsing tools (e.g. glove box) and handling the inspected object. The box must have a pressure vent to prevent a positive pressure from being created inside the chamber. Extracted particles should be prevented from escaping via the vent

4. Pressure rinsing apparatus for final rinsing procedure consisting of:

   a) Pressure-rinsing tool, e.g. “nozzle stylus”, which can be controlled manually for rinsing the extraction units, parallel jet or flat jet nozzle

   b) media supply with container for extraction liquid, purification filter, pump or pressure supply

   c) Device for filtering the analysis liquid

5. If necessary, graduated vessel to measure volumes: e.g. beaker or measuring cylinder, and stopwatch to adhere to extraction times or determine the flow rate used in the final rinsing step by means of volumetric measurement

6.5.1.4 Procedure

The following procedure must be adapted to the features of the inspected object and/or inspection equipment. The extraction must be performed in accordance with applicable work safety rules.

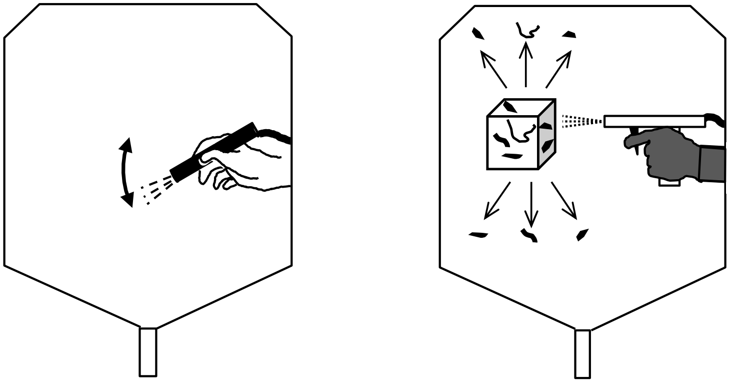
1. Procure all resources required for the inspection
2. Prepare the inspected objects in accordance with Chapter 6.3
3. Use extraction liquid to pre-clean all surfaces of the air jet chamber coming into contact with compressed air and media as well as other extraction equipment; where required, determine the blank value. In order to bind detached particles, all the walls of the air jet chamber must be wetted with the test medium before commencing the air jet extraction procedure
4. Blow-dry all surfaces that come into contact with the inspected object (e.g. holders, racks, gloves, etc.)
5. Place the inspected object in the air jet chamber, and secure it if necessary
6. Perform the air jet extraction procedure in accordance with all specified parameters and times and the exact sequence
7. Remove the inspected object from the air jet chamber
8. Using extraction liquid, perform a final rinsing step on all inner surfaces of the air jet chamber (chamber walls, gloves, fittings, holders, etc.) to remove all the extracted particles now adhering to the walls and transfer them for analysis. A suitable procedure should also be developed, tested and defined for this final rinsing step
9. Transfer all the liquid for filtration and analysis
10. Fill out the inspection report

6.5.1.5 Documentation

see Chapter 9 DOCUMENTATION

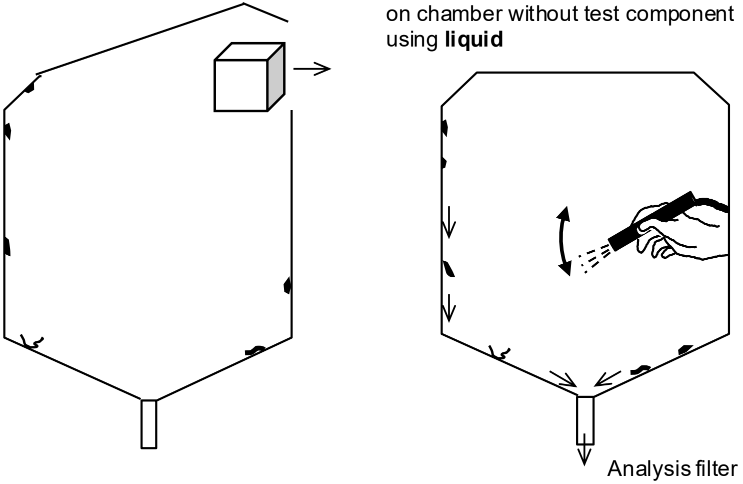
Anhang 6.5.1 Air jet extraction

A 6.5.1.1 Principle and procedure for air jet extraction



Step 1: Prewetting of extraction chamber with **liquid** (manual or automatic chamber flushing)

Step 2: Extract particles from test component using a jet of **compressed air**



Step 3: Remove test component

Step 4: Perform final rinsing step on chamber without test component using **liquid**

Figure 6-14: Principle and procedure for air jet extraction

6.5.2 Air throughflow extraction

6.5.2.1 Principle

With this form of air extraction, the inspected object is flushed with air using a procedure similar to that of internal rinsing in the case of liquid extraction. This method is suitable for checking the internal cleanliness of air conducting components, e.g. engine air intake tract. With this method, large volumes of air are guided through components with cross-sections several centimeters in diameter. There are two different versions of this method, as shown in the annex:

- Throughflow extraction for large cross-sections at high flow rates with primary and secondary extraction (see Figure 6-15 in the annex)
- Throughflow extraction for smaller cross-sections at low flow rates directly onto the filter (see Figure 6-16 in the annex)
- Throughflow extraction for smaller cross-sections at high flow rates into a liquid that is subsequently filtered (see Figure 6-17 in the annex)

Throughflow extraction is split into two partial extractions (see also Figure 6-15 in the annex):

1. **Primary extraction**: The inspected object is installed on the test bench using component-specific adapters. Particles extracted by the clean (pre-filtered) air as it flows through the component are deposited onto a large-surface (high flow rates!), fine-meshed metallic membrane filter located in a primary filtration unit. This so-called primary analysis filter is removed in an appropriately clean manner after the primary extraction step and forwarded to the secondary extraction step.

2. **Secondary extraction**: Secondary extraction step: in this step, liquid extraction by means of pressure-rinsing (see Chapter 6.4.2) is carried out to remove the particles originating from the inspected object that are present on the primary analysis filter and to transfer them to a conventional secondary analysis filter suitable for use with light microscopy and/or gravimetry.

Note: The air throughflow extraction method can also be implemented to inspect gas-conducting components with smaller cross-sections and flow rates in the automotive industry. Such components are found in systems that conduct (compressed) gases and are a few millimeters/centimeters in diameter. A diagram of the basic structure is provided in the annex (see Figure 6-16 and Figure 6-17). In both of these examples, the component is flushed with clean and oil-free compressed air. After that, in Figure 6-16, the extraction air is passed directly through an analysis filter. The flow resistance of the analysis filter determines the flow velocity and thus the extraction effect. In Figure 6-17, after extraction, the air is guided into a liquid-filled bath. The particles extracted from the component are thus bound in the liquid and can subsequently be deposited onto an analysis filter and analyzed. The bath should then be rinsed off as necessary. This allows for the inspected object to be flushed at higher flow rates than in the example in Figure 6-16. Here, unlike in the method described above, only one analysis filter is needed rather than two (one primary and one secondary filter).

The main parameters influencing the air throughflow extraction method are:

- air throughflow rate
- geometry and model of the inspected object
- type and frequency of movement (for active components)
- duration of air throughflow

6.5.2.2 Start parameters

The flow rate of air through the inspected object cannot be used as a general start parameter because it depends on the rate at which air will flow through the component when in operation. These values must be specified in the customer-supplier relationship.

Two minutes are recommended as a parameter for the start time for each extraction step in the declining test/qualification test.

6.5.2.3 Materials and equipment

The materials and equipment used in the extraction step must comply with the general requirements of extraction equipment described in Chapter 6.2.

1. Where appropriate: secure component: e.g. mounting device or clamps. In the case of active components: use devices for switching, actuating, etc.
2. Air throughflow test set-up comprising:
    a) air pre-filter

b) system of pipes to guide air through the inspected object

c) primary filtration unit with primary analysis filter (e.g. 10 µm metallic sieve filter).

Note: The interior of the primary filtration unit (walls) must be given a final rinse with liquid and the liquid drained off at the lowest point.

d) pipe system with flow gauge and regulator

e) pump to generate the required flow rate of air for the inspection

3. Component-specific adapters (may need to be constructed in some cases) to connect the inspected object to the tubing of the inspection set-up
4. Pressure-rinsing extraction apparatus (see Chapter 6.4.2) to perform the secondary extraction step on the primary analysis filter
5. Where appropriate: if the pressure-rinsing apparatus mentioned in Point 4 is located elsewhere and cannot be used here, further pressure-rinsing equipment to perform final rinsing step on the primary filtration unit

6.5.2.4 Procedure

The following procedure must be adapted to the features of the inspected object and/or inspection equipment. The extraction must be performed in accordance with applicable work safety rules.

1. Procure all resources required for the inspection
2. Pre-clean all relevant surfaces of the extraction apparatus; where required, determine the blank value
3. Prepare the inspected objects in accordance with Chapter 6.3
4. Use component-specific adapters to connect the inspected object to the inspected set-up
5. Where appropriate: with active components, connect power, switching or drive device to the inspected object

6. Carry out the air throughflow extraction procedure while observing the flow rate and duration; in the case of active components, adhere to operating parameters

7. Perform final rinsing step on the interior of the primary filtration unit with liquid to transfer any particles that may have sedimented on the walls to the primary analysis filter

8. Drain off final rinsing liquid at the lowest point of the primary filtration unit

9. Remove the primary analysis filter and transport it to the pressure-rinsing extraction apparatus in an appropriately clean manner

10. Perform a full pressure-rinsing extraction step (in accordance with the procedure described in Chapter 6.4.2) using the primary filter membrane as the inspected object to transfer the particles to the secondary analysis filter

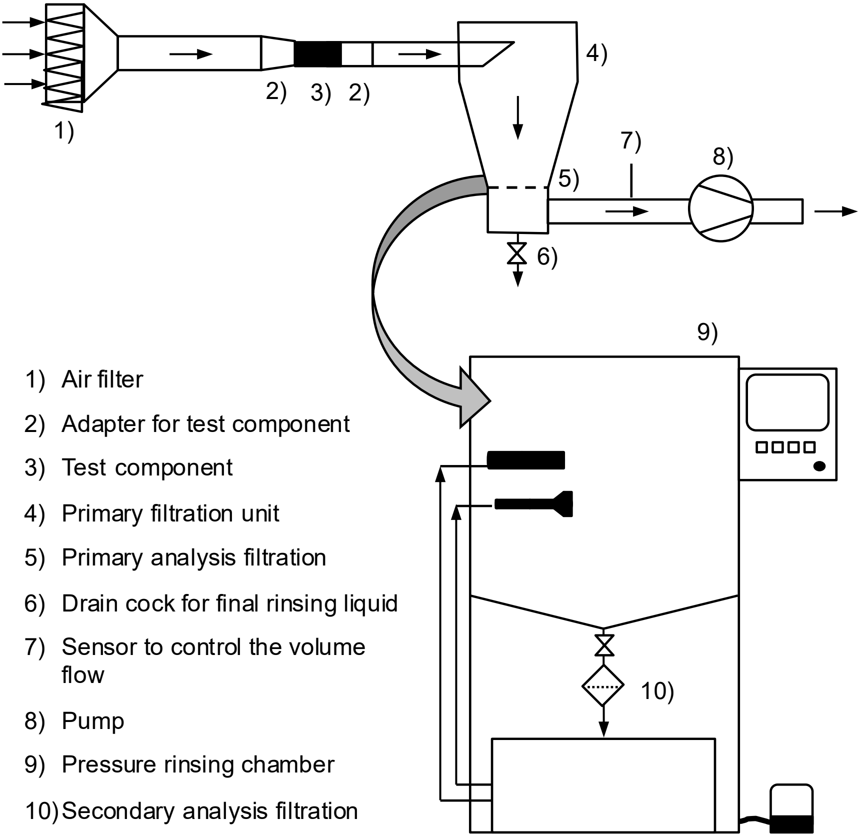
11. Fill out the inspection report

6.5.2.5 Documentation

see Chapter 9 DOCUMENTATION

Annex 6.5.2 Air throughflow extraction

A 6.5.2.1 Principle set-up required for air throughflow extraction on components such as engine air intake components



1) Air filter
2) Adapter for test component
3) Test component
4) Primary filtration unit
5) Primary analysis filtration
6) Drain cock for final rinsing liquid
7) Sensor to control the volume flow
8) Pump
9) Pressure rinsing chamber
10) Secondary analysis filtration

Figure 6-15: Principle set-up required for air throughflow extraction (e.g. for engine air intake components)

A 6.5.2.2 Principle set-up required for air throughflow extraction on components such as components with low volume flow

1) Intake oil-free compressed air
2) Regulator
3) Air filter
4) Manometer
5) Mounting device to hold test component
6) Test component
7) Actuator for test component(only for active components)
8) Collection vessel for extraction liquid
9) Analysis filter

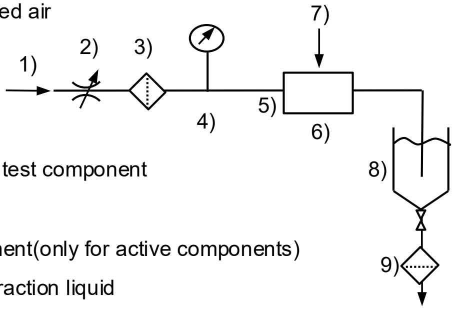


Figure 6-16: Principle set-up required for air throughflow extraction on components (e.g. components with low volume flow)

A 6.5.2.3 Principle set-up required for air throughflow extraction on components such as parts of pneumatic systems

1) Intake oil-free compressed air
2) Regulator
3) Air filter
4) Manometer
5) Mounting device to hold test component
6) Test component
7) Actuator for test component(only for active components)
8) Analysis filter

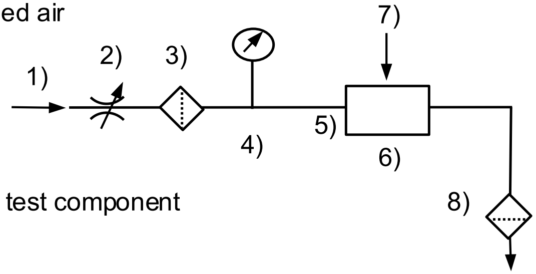


Figure 6-17: Principle set-up required for air throughflow extraction (e.g. for components of pneumatic systems)

6.5.3 (Brush nozzle) suction

6.5.3.1 Principle

In this extraction method, particles are removed from the surface of the inspected object by suction. This extraction method is typically based on the use of modified industrial or clean room vacuum cleaners. In suction extraction, a suction nozzle is passed over the surface of the inspected object at a defined distance.

The extraction effect can be enhanced by using a brush attachment on the suction nozzle which is attached with contact but without pressure. For one thing, this bundles the suction air current, resulting in faster flow velocities on the surface of the inspected object. For another, particles are loosened from the surface by the bristles of the suction nozzle and then vacuumed up.

The extracted particles are separated out onto an analysis filter by the suction air current or onto a particle trap by a cyclone separator. In case of larger components and higher particle content that would result in overlapping and thus produce analysis filters/particle traps that are difficult to analyze, it is also possible to collect the particles in a vessel. The particles in the collection vessel are then transferred onto one or more analysis filters with liquid (see also Figure 6-19 in the annex).

For suction extraction, the inspected objects do not need to be placed in a chamber or tank. This means that suction extraction is also suitable for large and unwieldly components that can sometimes be extracted without being transported to a cleanliness laboratory. Suction extraction is not suitable for small, loose components that could get sucked in.

Note 1: Unlike other extraction methods, in suction extraction, the extraction medium is not prepared (filtered) but rather consists of the ambient air in which the inspection is performed. The blank value of the inspection thus depends greatly on the cleanliness of the ambient air with regard to airborne particles such as textile fibers. If it is not sufficiently clean, then the inspection should be done in a space with appropriately prepared ambient air (e.g. clean air booth).

The main parameters influencing suction extraction are:

- Flow rate of the suction air
- Geometry and cross-section of the suction nozzles
- Distance and angle to inspected object

- Sequence of extraction of surfaces
- Time per surface or forward feed
- Repetitions per surface

Note 2: In principle, suction can also be used in combination with other extraction methods such as air jet extraction using air or other gases to collect the extracted particles and separate them for later analysis. This edition of VDA 19.1 does not go into this in any further detail, since, at the time of publication, there was not yet enough empirical information available on the use of a combined application. Feasibility should be verified for the specific implementation and implemented as part of a free analysis (see Table 3-2) (must be agreed in customer-supplier relationship).

6.5.3.2 Start parameters

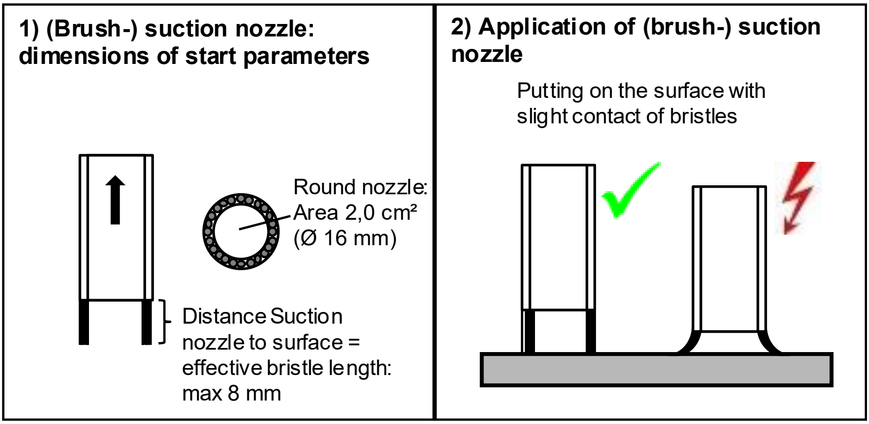
The start parameters for (brush) extraction are listed in Table 6-14.

Table 6-14: Start parameters for suction extraction

Parameter	Start value
Intake area of the suction nozzle (suction nozzle with brush attachment)	2.0 cm² (round jet nozzle 16 mm)
Suction flow rate	≥ 20 m³/h
Suction distance	Brush with pressureless component contact (effective bristle length = distance of suction nozzle from component surface): max. 8 mm (see Figure 6-18)
Suction time/component surface area	see Figure 6-20 and Figure 6-21 or formula

Note 1: Before using the extraction method (brush) suction with a brush, it is necessary to clarify whether the component surface can be damaged by contact with the bristles (mechanical damage, static charge, etc.). If so, then the suction should be performed without a brush attachment while maintaining a maximum distance of 8 mm from the nozzle.

The suction nozzle, as per the start parameters, is shown in Figure 6-18.



1) (Brush-) suction nozzle: dimensions of start parameters

2) Application of (brush-) suction nozzle

Figure 6-18: Suction nozzle according to start parameters

The suction time used per square centimeter of component surface area in order to create the declining curve depends on the size of the component. In order to suction smaller components carefully, more time is needed in relation to the size of the component than is needed for large components. As a reference point for determining the suction time per square centimeter of component surface area, the following formula can be used:

$$t_{St/A} = \frac{(60 \times A_{cp})^{0.4}}{A_{cp}}$$

$t_{St/A}$: Area-specific start volume in mL/cm²
t_{St}: Start volume in mL
A_{cp}: Sampled area of the inspected object in cm²

The values for the (brush) suction start time per component are determined using the following formula:

$$t_{St} = (60 \times A_{cp})^{0.4}$$

Individual values of these formulas can also be found in Table 6-15. The diagrams corresponding to the curves can be found in Figure 6-20 and Figure 6-21 in the annex.

During the qualification test/declining tests (see Chapter 5), the final suction time per component surface is determined for the routine inspection depending on after which extraction step the declining criterion is attained.

If the declining criterion is not achieved with these start parameters or if more suitable parameters (e.g. suction nozzle adapted to part geometry) are justified and documented, these start parameters may be modified.

Table 6-15: (Brush) suction start times (for start parameter set)

Inspected object area in cm²	Start suction time/ inspected object area in s/cm²	resulting start suction time per inspected object in s
500	0.123	62
700	0.101	71
1000	0.082	82
2000	0.054	108
3000	0.042	127
5000	0.031	155
7000	0.025	178
10.000	0.020	205
15.000	0.016	241
20.000	0.014	270

Note 2: The formulas and tables are general recommendations for deriving the starting suction time per component surface for a declining test. It may make sense to increase this starting value if, for example, the component is very complex.

Note 3: If using other nozzles that do not match the start parameters, it may be necessary to adjust additional suction parameters such as distance or flow rate in order to achieve adequate suction.

Note 4: If inspected electronic objects are reused after the suction extraction, ESD protection measures are necessary.

6.5.3.3 Materials and equipment

1. if necessary, part fixture, e.g. holders or handling equipment for the inspected object
2. suction system comprised of:
    a) pump system for achieving the necessary suction volume flow
    b) pipe or hose system for channeling the exhaust air
    c) (brush) suction nozzle for component extraction
    d) U unit for separating the extracted particles (filter clamping point and/or cyclone separator for separation onto a particle trap or a collecting vessel)
3. if necessary, room or suction booth with filtered air in case ambient air fails to reach the necessary blank values due to airborne particles
4. if necessary appropriate extraction apparatus (see Chapter 6.4.2) for extracting the particles and repreparing them on an analysis filter if a collecting vessel is used for suction

Note 1: When large components are extracted with long suction times, the suction nozzle can be guided automatically (e.g. using robot or axis system) in order to comply with the suction distance and suction passes.

Note 2: A preliminary filter can be used to determine the system blank value or for final suctioning.

6.5.3.4 Procedure

The following procedure must be adapted according to the details of the inspected object and the suction system. The extraction must be performed in accordance with applicable work safety rules.

1. Procure all resources required for the inspection

2. Pre-clean all extraction-related surfaces of the extraction apparatus as well as the contact surface of the inspected object; if necessary, determine the blank value

3. Prepare the inspected objects in accordance with Chapter 6.3

4. Perform the (brush) suction procedure in accordance with the nozzle distance, the suction volume flow and the suction time; suction the inspected object at even velocity in slightly overlapping passes

5. Perform final suctioning of all surfaces that were in contact with the component (contact surfaces, any gloves or foil packaging, etc.) as well as all air-conducting components before the separating system; if using a brush attachment, remove and suction

6. if necessary perform a complete extraction (as per procedure in Chapter 6.4.2) of the collection vessel as an inspected object. Transfer the particles from the interior onto one or more analysis filters

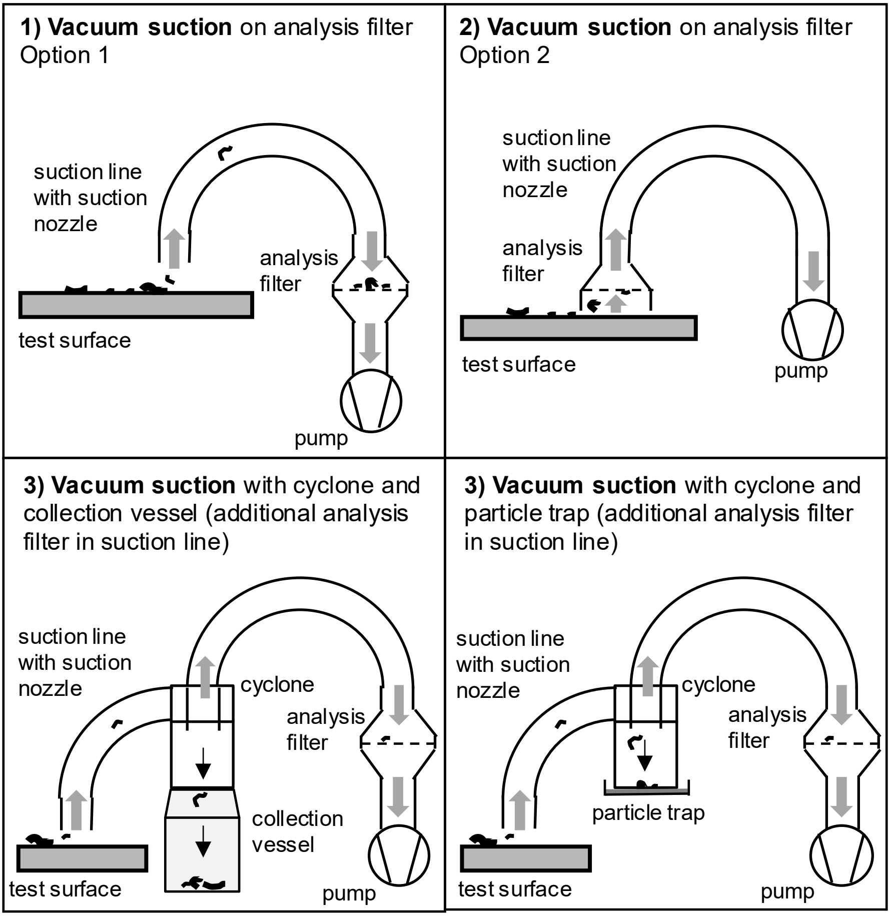
7. Fill out the inspection report

6.5.3.5 Documentation

see Chapter 9 DOCUMENTATION

Annex 6.5.3 (brush) suction

A 6.5.3.1 Principle set-up examples



1) Vacuum suction on analysis filter Option 1

2) Vacuum suction on analysis filter Option 2

3) Vacuum suction with cyclone and collection vessel (additional analysis filter in suction line)

3) Vacuum suction with cyclone and particle trap (additional analysis filter in suction line)

Figure 6-19: (brush) suction - principle set-up examples

Note 1: If using a 5 µm analysis filter, it can be necessary to use special mesh filters with a higher free cross-section (high-capacity filter with thinner filaments) in order to achieve the necessary suction volume flow.

Note 2: Not all principle set-ups shown can be used with the start parameters.

A 6.5.3.2 (brush) suction start time

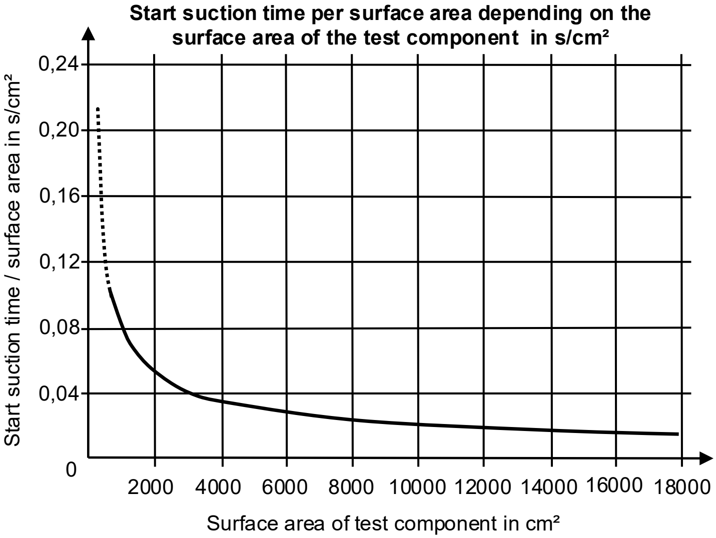


Figure 6-20: (Brush) suction start time – start time per surface based on the inspection surface in s/cm² (for start parameter set)

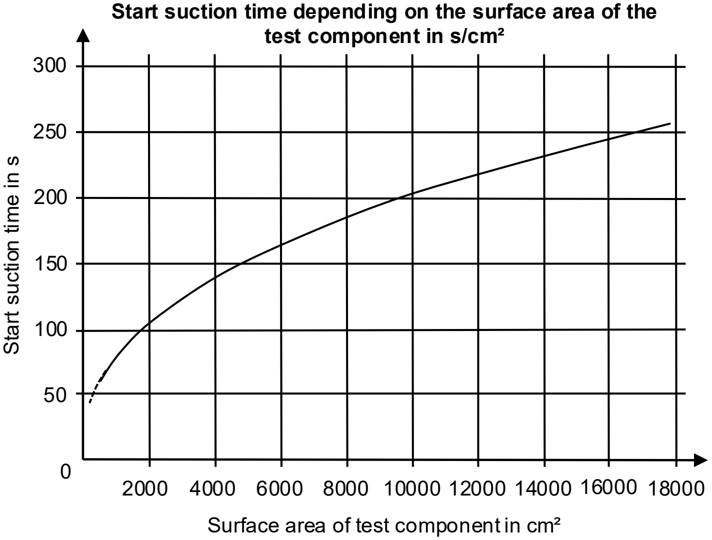


Figure 6-21: (Brush) suction start time – start time per component based on the inspection surface in s (for start parameter set)

6.5.4 Stamping test

6.5.4.1 Principle

With this extraction method, an adhesive area (adhesive pad or adhesive surface) is pressed onto the surface of the inspected object, e.g. by means of a stamp, and the particles are transferred onto the adhesive pad as the stamp is lifted off. So particles are extracted and deposited onto a surface for later analysis in a single step. The particle analysis is done as a direct light-optical analysis or – in case of suitable stamps – with a scanning electron microscope (see Figure 6-22 in the annex). Particle stamps are not suitable for gravimetric analysis.

Due to the extraction effect area being precisely delineated, the stamping test is well-suited to restricted component surfaces with cleanliness specifications, e.g. a sealing surface. The geometry of the surface must be suitable for applying the stamp (even or convex, not concave, no crevices, no narrow interior areas). The material of the inspected object and the surface structure must also be appropriate. The surface must be dry and free of oil and grease. Note that with rough or porous component surfaces (e.g. rough cast surfaces), the adhesive of the stamp sometimes may not be able to “flow” into the crevices of the surface, so that the extraction only takes place on the rough peaks. Also, no particles should be released from the inspection surface by the adhesive strength. This is especially relevant for edges with burrs.

The main parameters influencing stamping extraction are:

- Adhesive strength of the stamp
- “Fluidity” of the adhesive or the adhesive surface to permeate the surface roughness of the inspected object
- Pressing pressure of the stamp against the inspected object
- Pressing time of the stamp against the inspected object

6.5.4.2 Start parameters

At the time of publication of this VDA 19.1 edition, there are no standardized start parameters for the stamping test. Which stamps should be used and how the application should be implemented must be agreed in the customer-supplier relationship and defined in the inspection specification.

Like the other extraction methods, the stamping test is also qualified by means of a declining test. The result of the qualification determines the number of stamps to be used consecutively for the inspected surface.

Note 1: A stamp can usually be applied repeatedly until its adhesive strength weakens. So a stamp is not limited to extracting one surface the size of the adhesive pad – a single stamp can actually be used for extraction several times (about 6-8 times, greatly depending on the quality and cleanliness of the inspection surface, see also Figure 6-23 in the annex). When the next stamp is used for the same inspection surface (according to the declining test), the surface stamping can be performed in reverse order to compensate for the loss of adhesive strength.

Note 2: The surface of a particle stamp is usually white, so it can be used for light-optical analysis of the same settings and evaluation parameters as for an analysis filter (see Figure 8-9 or Figure 8-10). Other stamps can also be used to test for specific issues. To detect light-colored particles, it is possible to use black stamps, for example, which then have to be analyzed with adapted parameters. To extract larger surfaces, larger adhesive pads can be used. These larger pads can be rolled onto the surface by a rocker, since the adhesive strength can potentially be too great when the pad is laid flat over the full surface, making it impossible to pull the adhesive pad back off.

Note 3: In stamping, the blank value is largely determined by the initial cleanliness of the adhesive pad as well as the cleanliness of the ambient air if the stamp is handled open, with no protective packaging during extraction and analysis. Under these boundary conditions, conventional stamps can be used for the extraction of particles of 50 µm or greater. The initial cleanliness of a stamp can be tested (zero measurement) but the test must be performed under very clean environmental conditions, since the adhesive pad is exposed and continuously binds sedimented particles.

6.5.4.3 Materials and equipment

1. if necessary, part fixture, e.g. holders for fixing light inspected objects during stamping extraction
2. Stamp, e.g. consisting of:
    a) Housing or base
    b) Adhesive pad or adhesive carrier
    c) If necessary, spring-loaded element for a defined pressing pressure
    d) Cover for protecting the cleanliness and integrity of the adhesive surface when it is not in use or being transported for

analysis

6.5.4.4 Procedure

The following procedure must be adapted according to the details of the inspected object and the utilized stamp.

1. Procure all resources required for the inspection
2. Open the cover of the particle stamp (if there is one, pull the protective film off of the adhesive surface)

   Note 1: The cover needs to be protected from contamination when stowed during the stamping operation.

3. Stamp the inspection surface; placing and pressing the stamp at the start of the inspection surface, pull it off, and place it slightly overlapping on the adjacent inspection field. Repeat until the entire inspection surface has been stamped (see Figure 6-23.) If the adhesive strength of the stamp weakens significantly, use a new stamp for the rest of the extraction
4. If the analysis is not performed immediately afterwards, as soon as the stamping test is done, the utilized stamping test is stowed away and protected (e.g. with a cover) from contamination from the environment until the analysis.

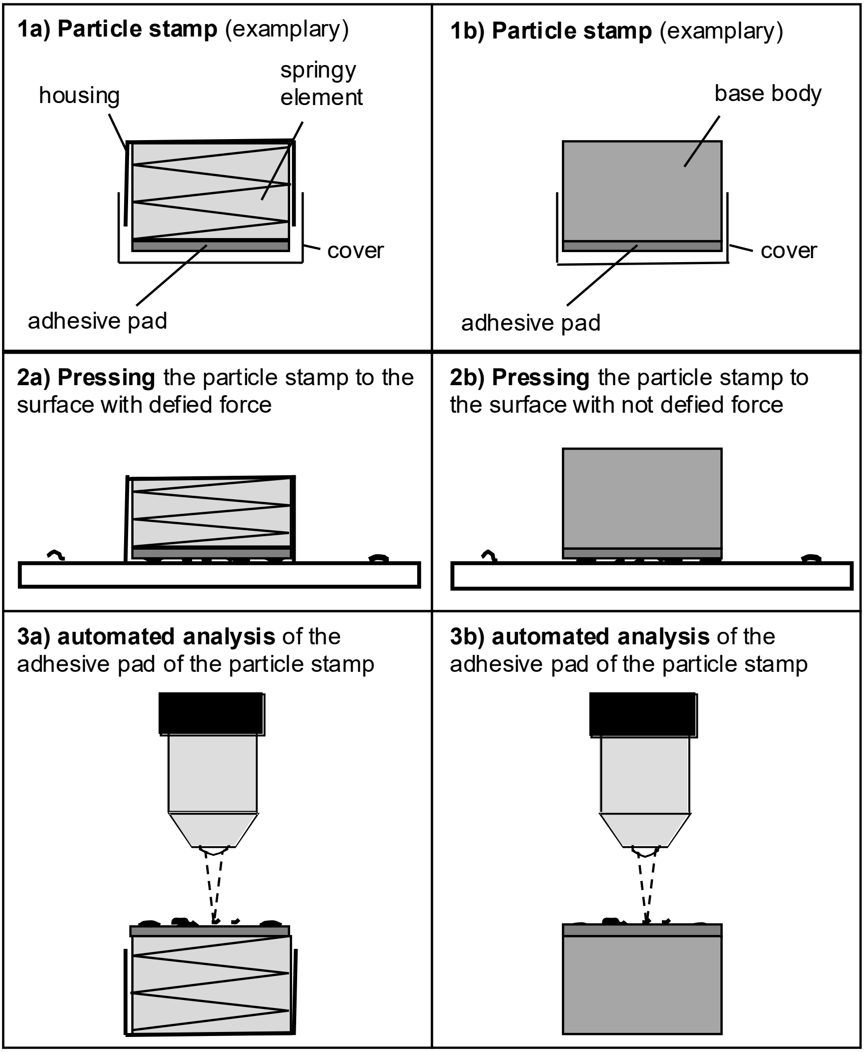
Note 2: If inspected objects are going to be stamped on both sides and are placed on a surface for this purpose, this should be factored into the blank value. If inspected objects are wrapped in foil packaging, once the foil packaging is cut open, first stamp one side of the inspected object without repositioning the part, and then stamp the other side.

6.5.4.5 Documentation

see Chapter 9 DOCUMENTATION

Annex 6.5.4 Stamping test

A 6.5.4.1 Principle: Set-up, application and analysis of the stamp



1a) Particle stamp (examplary)

1b) Particle stamp (examplary)

2a) Pressing the particle stamp to the surface with defied force

2b) Pressing the particle stamp to the surface with not defied force

3a) automated analysis of the adhesive pad of the particle stamp

3b) automated analysis of the adhesive pad of the particle stamp

Figure 6-22: Set-up, application and analysis of the stamp

A 6.5.4.2 Stamping an inspection surface

Stamping of the entire test surface

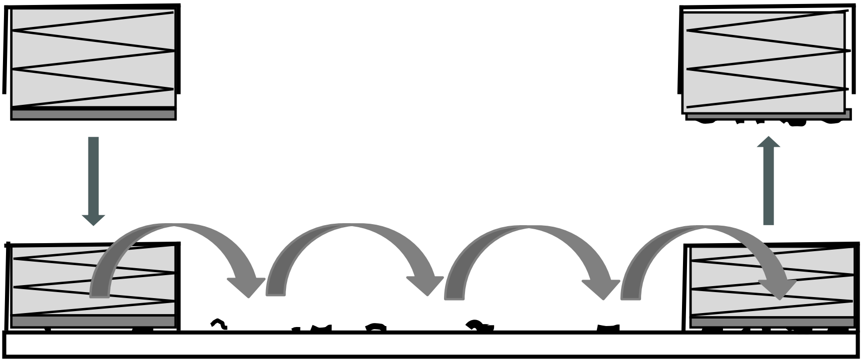


Figure 6-23: Stamping an inspection surface

7 ANALYSIS FILTRATION AND SEPARATION

7.1 Analysis filtration

The task of analysis filtration is to deposit the particles extracted from the component and suspended in the analysis liquid onto the surface of an analysis filter so that they can be analyzed. This is generally done using vacuum filtration.

In recent years, particle-counting techniques and extended analysis methods, which both require particles to be located singly without overlapping on an analysis filter, have become much more popular than gravimetry. Consequently, the filtration step is now crucial to the analysis result. The careful selection of filtration equipment and analysis filter(s) as well as the precise execution of the filtration procedure are decisive steps that play a major role on the quality of the subsequent analysis results.

7.1.1 Selecting the analysis filtration method

The properties of analysis filters, such as resistance to chemicals, capacity to retain particles, and also further aspects such as optical characteristics (e.g. color or material contrast), may vary considerably depending on the subject and analysis task concerned. If the cleanliness analysis is carried out within the scope of the standard analysis procedure in VDA 19.1, i.e. detection of particles upwards of 50 µm with gravimetric and/or light-optical analysis, the following analysis filter is recommended:

5 µm PET sieve cloth filter or 5 µm PA sieve cloth filter

Note: If a gravimetric analysis needs to be done in line with a cleanliness inspection, it is recommended to use a PET sieve cloth filter, since it tends to absorb less humidity in comparison to PA filters.

7.1.1.1 Chemical resistance

All of the equipment used in the filtration process as well as the analysis filter utilized must be compatible with the extraction liquid implemented (where appropriate, also the final rinsing liquid or particle-fixative) (see also Table 7-2 in the annex).

7.1.1.2 Particle retention capacity

7.1.1.2.1 Filter pore size

The pore size of filters is a dimension which characterizes the retention capacity with regard to specific particle sizes. However, this pore size does not correspond to an exact geometric size with all filter types, for instance open-pored sieve filters (see also Figure 7-4 in the annex). In case of foamed filters or closed-mesh fabric filters, a pore size is also indicated, even though this size is not uniform or geometrically fixed.

The function of the analysis filter is to retain the particles in the size range relevant to the analysis (and ideally only these particles). The pore size of the analysis filter is selected according to the cleanliness specification. The filter must be capable of reliably retaining the smallest particle size stipulated in the cleanliness specification. To ensure that elongated particles, much smaller in width than in length, are also retained, the following rule of thumb applies:

filter pore size = 1/10 to 1/5 of the smallest specified particle size,

with 1/10 being recommended for larger particles (≥ 50 µm) and 1/5 for smaller particles (< 50 µm). This is because smaller particles generally have a more compact shape than larger particles, which tend to have a highly diverse range of shapes (see also Figure 7-3 in the annex).

Note 1: This recommendation is a reasonable maximum value for the filter pore size, but a lower value can be used as long as the analyzability of the filter is not affected.

Note 2: If only individual large particles (e.g. 600 µm or larger) are specified and must be analyzed, it might also make sense to deviate from the 1/10 recommendation and use a filter of smaller pore size (e.g. 20 µm) to reliably retain the large particles, including elongated ones. In the qualification of extraction procedures (including cleanliness specifications of individual large particles), a sufficient number of particles needs to be separated out to be able to evaluate the declining curve. This should be taken into account when selecting the filter pore size.

7.1.1.2.2 Filter cascade

To pre-select particle sizes, analysis filtration can be performed in several steps using filters with different pore sizes. To do this, a filter holder into which several filters can be fitted is used (see Figure 7-2 in the annex).

For example, the use of a filter cascade enables only large particles to be deposited on a coarser-meshed membrane filter, thus facilitating counting by microscopy. The high number of small particles are retained by a finer filter downstream. If gravimetric analysis is required, then the 5 µm standard sieve cloth filter and all the coarser filters must be included in order to determine the residue weight. In case of a standard analysis, the cascade filters defined in the specification for the gravimetric analysis must be considered. For light-optical analysis, all the filters that ensure reliable retention of the smallest tested particle size must be evaluated.

7.1.1.3 Further properties of analysis filters

An analysis filter generally has to withstand the typical temperatures it is subjected to during the drying process in the oven and must also be mechanically robust (tear-resistant) when handled with forceps or dried by vacuum.

In free light-optical analysis, free SEM/EDX analysis or extended analyses, it may be necessary to use special filters to detect certain particle types (e.g. low-contrast particles) or due to the analysis method itself:

- Filters with special optical characteristics (e.g. colored filters or filters made to be transparent) to give a good light-optical contrast, or made from specific materials to give a high material contrast or good conductivity or resistance in the scanning electron microscope.

- Filters that do not generate a measuring signal of their own as this could overlay particle signals, e.g. Raman or FT-IR inactive filter materials (e.g. metallized gold, chrome or aluminum filters).

7.1.2 Handling analysis filters

In order to avoid adverse influences from handling analysis filters, the following points should be observed:

- Always store analysis filter membranes in sealed containers to minimize contamination from the environment.

- Visually inspect the cleanliness and condition of analysis filter membranes before use. Where appropriate, discard damaged filters and pre-clean soiled filters with the same extraction liquid that will be used in the inspection.

- Always handle analysis filter membranes with clean forceps and only hold the edge of the analysis filter membrane.

  Note 1: Sharp or pointed objects may damage analysis filter membranes.

  Note 2: Easy-to-remove sieve cloth filters in special dispenser systems are available on the market.

- The analysis filter membrane should always be held horizontally (no bending or tipping too far) so as not to lose any particles.

- The particle-laden side of the analysis filter should not come into contact with other surfaces at any point (potential particle loss). An exception is made when putting on covers to fix the particles for microscopic analysis and for archival.

  Note 3: The lids of analysis filters for microscopic analysis may alter the shape of particles due to clamping. If the glass lid is removed after light-optical analysis, e.g. in order to carry out an extended analysis, there is a risk that particles will be lost through adhesion to the glass lid.

- On completion of filtration, careful drying and subsequent analysis, analysis filters should be stored in a suitable container (e.g. Petri dish with a supporting screen to aid drying and removal of the analysis filter). The analysis filter must be correctly associated with a specific component. This can be ensured by clearly marking the storage containers.

7.1.3 Drying analysis filters

In extraction methods in which an analysis filter comes into contact with liquid, the filters must be dried for the subsequent analysis. The required dryness of analysis filters varies depending on the analysis method to be used:

- For gravimetric analysis, i.e. the determination of the residue weight of the separated particles, the filters must be thoroughly dried both before and after the particle separation (until constant weight), because even a small amount of residual humidity can greatly skew the result of the mass determination (see also Chapter 8.2.1 on Gravimetry).

- For light-optical analysis, the filter does not need to be dried until constant weight but only enough that any remaining liquid or humidity cannot optically modify (potential glare) the filter and separated particles.

- Never place wet or damp filters in an SEM/EDX system, because this delays the generation of the necessary vacuum, strains the pump system and can even damage a detector. It is not necessary, however, to fully dry the filter until a constant weight as for gravimetry.

Various systems can be used for drying analysis filters:

- Drying cabinets or drying ovens: The drying is done through temperature and without air circulation (risk of particle loss due to air current). Typically, multiple filters can be dried in parallel.

- Combined systems with a hotplate and additional vacuum, which allow analysis filters to be dried quickly. Typically one filter can be dried at a time.

When solvent-soaked filters are dried, the drying system must be designed accordingly (intended use).

The drying temperature and duration are not standardized values but must be adapted to the combination of analysis filter and extraction liquid.

They also depend on the amount of residual liquid that remains in the analysis filter after vacuum filtration.

The maximum drying temperature must also be selected so as not to damage or optically alter the analysis filter (filter curls or becomes discolored).

For the two materials of the filters that are recommended for standard analysis, refer to values in the following Table 7-1.

Note: In dry extraction methods, there is no need to dry the analysis filters, assuming that no gravimetric analysis is required or that the constant weight necessary for gravimetric analysis can be achieved without drying.

Table 7-1: Characteristics of PET and PA analysis filters

Filter material	PET	PA
Particle retention capacity (5 µm screen)	comparable	
Moisture absorption in % (at 20°C and 65% rel. humidity)	0.4% (low)	4 – 4.5 % (high)
recommended drying temperature (example according to manufacturer's information)	max. 90°C	max. 70°C

7.1.4 Materials and equipment

1. Analysis filter, selected on the basis of the characteristics required for the given cleanliness inspection

2. Filtration equipment including vacuum pump. The items required for this depend on the type of filtration procedure selected (see Figure 7-1 in the annex)

   Note 1: If the negative pressure is too high, particles could pass through the analysis filter or the filter could become damaged.

3. Forceps for handling the analysis filter membrane

   Note 2: The forceps used may not be magnetic nor become electrostatically charged. This applies to all items of equipment coming into contact with the analysis filter because this could cause particle loss due to magnetism or electrostatic charging.

   Note 3: Analysis filters may also be handled with a clean spatula. All appropriate formulations also apply to spatulas.

4. Extraction liquid for the final rinsing step after the filtration procedure, e.g. using a wash bottle

5. Petri dish or similar clean, sealable container for handling and storing analysis filters

6. Suitable drying system

7. Particle-fixative (optional): a substance to fix the collected particles onto the analysis filter

Note 4: A fixative is used to prevent particle loss when handling and analyzing the analysis filter. In the case of gravimetric analysis, a fixative may only be utilized once the residue weight has been determined.

7.1.5 Procedure

The following section describes the procedure for extraction methods in which liquids are used. Chapters 7.2.1 and 7.2.2 contain instructions for separating on particle traps and particle stamps in dry extraction methods. The filtration must be performed in accordance with applicable work safety rules.

1. Procure all the materials necessary for the filtration step:
   Prepare the filtration equipment. Depending on the apparatus used in the extraction procedure, analysis filtration can be performed in two ways (see Figure 7-1):

   a) Direct filtration (filtration directly on the extraction apparatus): the filter unit is situated immediately at the outlet of the catch basin for collecting the analysis liquid

   b) Separate filtration: The analysis liquid is first collected in a clean vessel (e.g. beaker or sampling vessel) and then filtered through a separate suction filter

2. If necessary, conditioning of the analysis filter

   a) Microscopic analysis: analysis filter does not require conditioning

   b) Gravimetric analysis: The tare weight of the analysis filter has to be determined (see Chapter 8.2.1); to avoid negative residue weights, the analysis filter must be pre-conditioned

3. Place the analysis filter in the filter holder by means of forceps

   Note 1: In the case of especially thin analysis filters (e.g. polycarbonate), it may be helpful to place a filtration aid (e.g. suitable analysis filter as a support) on the downstream end.

4. Filtration of the analysis liquid:

   a) Direct filtration: Using clean liquid, carefully perform final rinsing step on the sampling container (e.g. pressure-rinsing basin or ultrasound bath) to avoid any particle loss. The final rinsing liquid is included in the analysis.

b) Separate filtration: Pour the liquid from the sampling vessel (e.g. beaker from ultrasonic extraction) into the filter funnel, then perform a final rinsing step on the sampling vessel. The final rinsing liquid forms part of the analysis liquid. The size of the vacuum flask limits the volume of liquid which can be filtered

Note 2: Sometimes the extraction step and filtration step are carried out at different locations (far away from one another), meaning that the sampling vessel has to be transported a long distance. In such a case, be sure that the exterior of the sampling vessel is sufficiently clean in order to prevent any contamination present from reaching the extraction liquid during the filtration step. If the analysis liquid is stored for a prolonged period of time, particles may sediment and agglomerate. With counting analysis methods, it is essential to break up the agglomerated particles before commencing the analysis step. This can be achieved by agitating the analysis liquid or placing the vessel in an ultrasound bath. The method chosen must not modify the original sizes of particles in the liquid. Stored sampling vessels generally require gentle agitation to return sedimented particles into suspension. Sampling vessels (including closing devices) must be thoroughly rinsed with clean liquid to avoid any particle loss. The final rinsing liquid forms part of the analysis liquid.

5. Filtration of the analysis liquid: A more uniform distribution of particles on the filter (important for microscopic analysis) can be achieved if a “cushion” of liquid is always present on the analysis filter. However, if the analysis liquid only passes through the margins of the filtration unit, there is a risk that the particles will remain at the edge and overlap one another.

Note 3: If filtration is performed and does not produce a satisfactory distribution of particles on the analysis filter, particle flotation can be attempted in order to improve the homogeneity of the particle deposition.

6. To prevent particle loss, rinse the surfaces of the filtration unit that were wetted with analysis liquid as well as any utilized containers.

Note 4: When preparing analysis filters, do not aim any fluid jets directly at the analysis filter surface, because this can disturb the even distribution of the particles.

7. Analysis filter for gravimetric analysis (optional): Wash away undesired chemical residues by post-treating the analysis filter with a suitable solvent

8. Remove the upper section of the filter holder in the presence of a vacuum

9. Transfer any particles present on the upper section of the filter holder to the analysis filter with a careful final rinsing (be careful not to use too much final rinsing liquid so as to avoid particle loss)

10. Where appropriate, aerate the filtration apparatus. Carefully remove the suction-dried analysis filter with forceps (risk of particle loss), and place it in a clean, labeled Petri dish (hold horizontally)

11. Dry the analysis filter by keeping the Petri dish partly open (in the case of analysis filters to be analyzed gravimetrically, dry the analysis filter until the weight remains constant. See Chapter 8.2.1)

12. Analysis filter for microscopic analysis (optional): fix the particles using a particle fixative and then dry the filter again

    Attention: Analysis filters intended for gravimetric analysis should not be treated with particle-fixative until after completion of the gravimetric analysis, since the particle-fixative affects the residue weight.

7.1.6 Documentation

see Chapter 9 DOCUMENTATION

7.1.7 Verifying particle occupancy on the analysis filter

To use automated optical systems for particle analysis, the analysis filter has to be prepared in such as way as to ensure that particles are evenly distributed over the surface of the analysis filter without overlapping or agglomerating. The following points are important in this regard:

- the occupation density in percent, i.e. the proportion of the surface of the analysis membrane occupied by particles.

- the homogeneity of occupancy, i.e. the uniformity of particles distributed over the surface of the analysis filter (are nests of particles present or are the particles mainly located at the margin?)

- occupancy with fibers: fibers are often much longer than other particles. Fibers are capable of covering large areas of the analysis filter and therefore often touch or overlap numerous particles and render individual analysis impossible.

With light-optical analysis systems, the density of particle occupation on the filter in percent should be calculated and documented. The critical occupancy density depends on the type of filter implemented. This is shown in the annex (see Figure 7-6) for mesh filters, foamed membrane filters and particle traps and stamps.

If the occupancy of the analysis filter is such that it cannot be analyzed, the extraction procedure must be repeated with another component of the same type, and a further filtration step carried out. To optimize filter occupancy and thus filter analyzability, the following alternatives are available:

1. Use an analysis filter with a larger diameter (provided the filtration unit and analysis system used technically allow this).

2. Distribute the analysis liquid over several analysis filters.

   Note 1: If the analysis filter retains a high quantity of very small particles that are not relevant to the analysis result, an analysis filter with a larger pore size can be selected. This decreases the occupation density and lowers the risk of particles overlapping one another. This also helps to maintain the contrast between detected particles and the analysis filter background. If gravimetric analysis of the analysis filter is required as well as microscopic analysis, this is problematic because a conflict arises between the reduction in filter occupancy as far as particles overlapping and the lower detection limit of the scale are concerned (see Chapter 8.2.1).

3. Use a filter cascade: The filter cascade contains analysis filters with different pore sizes to separate small and large particles.

The annex (see Figure 7-5) shows some examples of incorrectly prepared analysis filters together with possible remedies.

Note 2: If, for certain reasons, the already generated filter (now called output filter) should be evaluated with a high occupation density, e.g. because no other inspected object is available to repeat the process, then the only solution is to prepare it again in order to achieve better filter analyzability. The particles are rinsed from the overloaded output filter and then distributed on a filter cascade or multiple filters. The output filter should be included or evaluated later. Any repreparation of filters must be documented in the inspection report.

7.2 Separation

7.2.1 Particle trap

With the (brush) suction extraction method, there are also versions of the procedure in which the particles are not separated onto an analysis filter but instead onto a “particle trap” as described in VDA 19.2. It is not possible to affect the size of the separated particles to a certain extent as it is done with filtration by selecting the filter pore size. This must be kept in mind as far as the resulting particle load of the particle trap, which determines the optical analyzability (see also Figure 7-6 in the annex).

No drying is necessary after the actual extraction and the separation of the particles on the particle trap. The particle trap can be sent for analysis without any additional procedural steps. It is important to close the particle trap with a lid immediately after extraction. Otherwise particles sedimented from the ambient air could also become trapped on the adhesive surface of the particle trap, unless the extraction and analysis takes place in a suitably clean environment (clean room).

7.2.2 Particle stamp

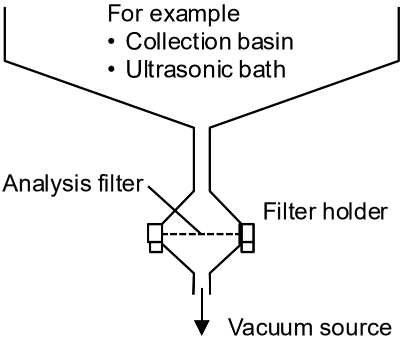
In the stamping test (see also Chapter 6.5.4), particles are extracted from the component surface and separated onto a surface suitable for analysis in a single step – by pressing the adhesive stamp face onto the inspection surface. No drying is necessary.

The notes on the delineation of the particle size range, the deposition of particles on the analysis surface and the handling until analysis are the same as for the particle trap in the preceding sub-chapter 7.2.1.

Annex 7 Filtration

A 7.1 Different analysis filtration methods

A) Direct filtration



B) Separate filtration

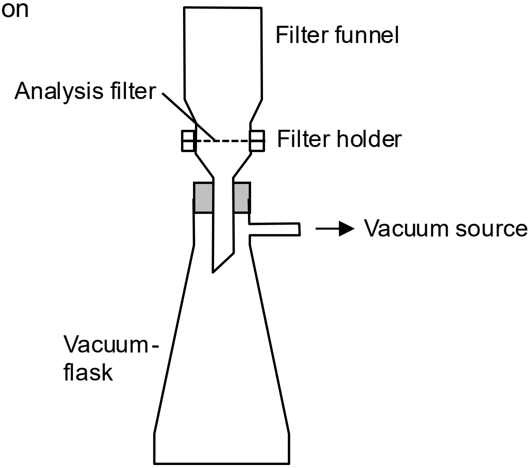
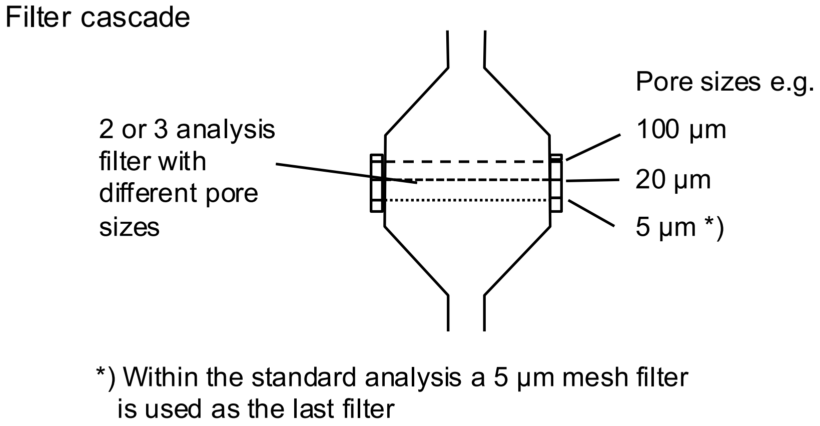


Figure 7-1: Different analysis filtration methods

A 7.2 Filter cascade


Filter cascade

*) Within the standard analysis a 5 µm mesh filter is used as the last filter

Figure 7-2: Filter cascade

A 7.3 Selecting the filter pore size

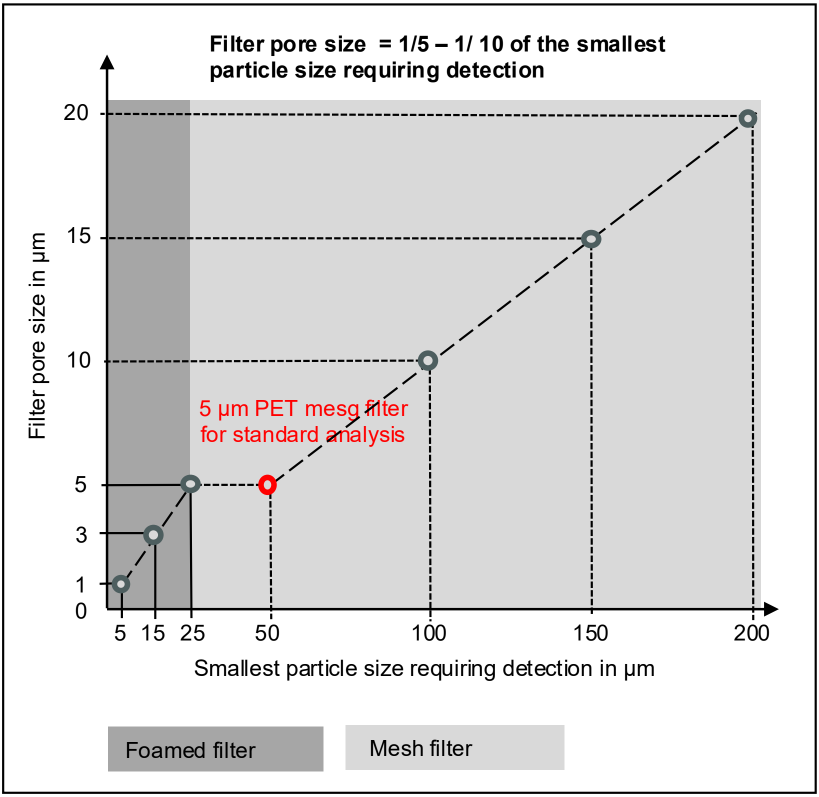


Figure 7-3: Selecting the filter pore size

A 7.4 Compatibility of analysis filters with extraction liquids

Table 7-2: Compatibility of analysis filters with extraction liquids

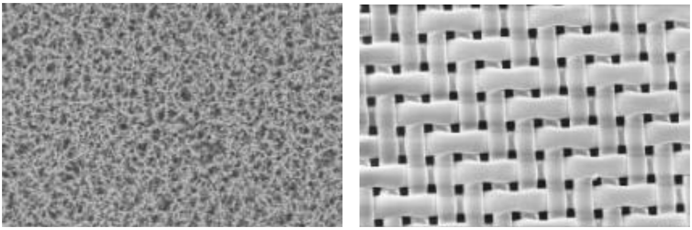
Filter material		**Medium (inspection or final rinsing liquid)**				
		Aqueous neutral cleaner	**Isopropanol**	**Ethanol (spirit)**	**Aliphatic hydrocarbons e.g. cold cleaners**	**Ketones e.g. acetone**
Foamed membrane	Cellulose nitrate	+	-	-	+	-
	Cellulose acetate	+	+	-	+	-
	Polyamide/nylon	+	+	+	+	+
Mesh	Polyester	+	+	+	+	+
	Polyamide/nylon	+	+	+	+	+

+ Filter material is compatible and will not be damaged by contact with the liquid

- Filter material is not compatible and will be damaged by contact with the liquid

Note: The table lists only a few of the most common types of analysis filter. In some cases, e.g. if resistance to a certain inspection medium is required, or if a certain type of filter is necessary for the analysis method, different filter types may have to be selected. If no special conditions are specified, the use of the analysis filter suggested in Chapter 7.2 is recommended.

A 7.5 Example of analysis filters



cellulose nitrate, foamed membrane filter

PET mesh filter

20 µm magnification 200 x

Figure 7-4: Examples of analysis filters

Foamed membrane filter

Advantages: Foamed filters have an even surface that is suitable for light-optical analysis, especially for particles ≤ 25 µm at the necessary high resolution.

Disadvantages: The undefined, foam-like structure of the material also retains pigment particles that are much smaller than the nominal pore size of the filter. These are not relevant to the cleanliness specification but may optically darken the filter, severely impairing light-optical analysis (gray or black analysis filter). This type of filter often absorbs more humidity (which impairs gravimetric analysis).

Sieve cloth filter

Advantages: Sieve cloth filters have a geometric pore size and separation limit. As a consequence, these filters retain fewer pigment particles that are much smaller than the nominal filter pore size, facilitating the light-optical analysis. They tend to absorb less humidity (more reliable gravimetric results).

Disadvantages: With high degrees of magnification or very poor illumination, the structure of the mesh filaments may cause artifacts/reflections and impair light-optical analysis. This disadvantage only occurs with particles < 25 µm. For particles ≥ 25 µm, at the appropriate optical resolution, these mesh filters usually work well.

Note: The moisture absorption of the filters depends not only on the surface structure (foamed or mesh) but, too a great extent, on the material as well (see also Table 7-1).

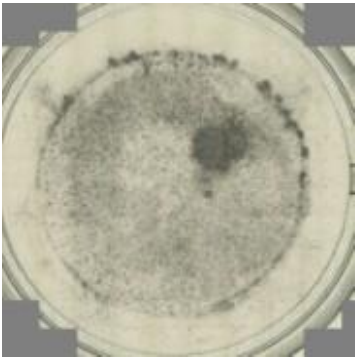
A 7.6 Examples of problems encountered with analysis filtration and possible remedies

Good filter occupancy:

- Uniform
- Most particles isolated

Excessive filter occupancy:

- Extract fewer components per filter
- Use coarser analysis filter
- Use filter cascade



Inhomogeneous filter occupancy:

- Optimize filter holder or filtration process
- Post-process filter (re-float particles or gently shake filter holder with a small amount of liquid)

Examples of filter images

Excessive filter occupancy:

- Extract smaller component lots per filter
- Use coarser analysis filter
- Use filter cascade

Filter completely clogged:

- Not analyzable optically
- Only analyzable by gravimetry

Pieces of cardboard on the filter:

- Test component packaging may be unsuitable

Large number of fibers on filter

- Storage location of test components may be unsuitable

Figure 7-5: Examples of problems encountered with analysis filtration and possible remedies

A 7.7 (Filter) occupancy and analyzability

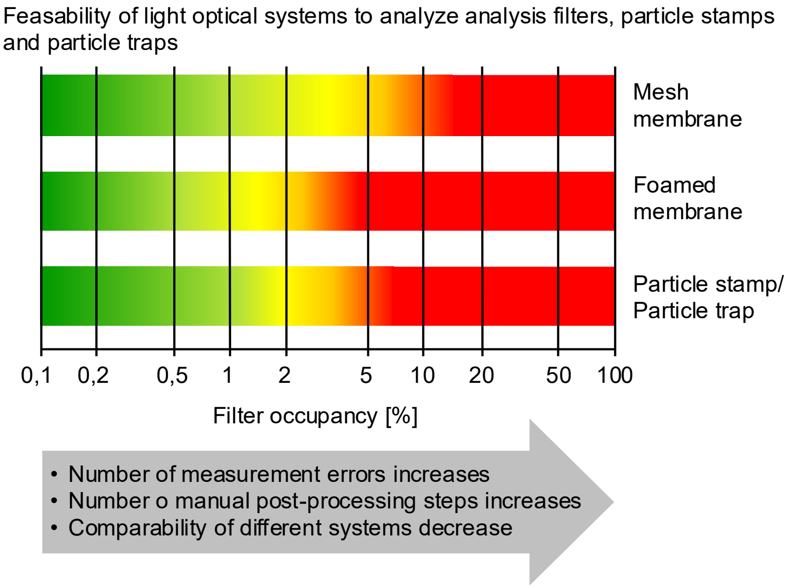


Figure 7-6: (Filter) occupancy and analyzability

Light-optical analysis starts to become difficult when sieve cloth filters have a filter occupancy upwards of 3% and foamed membrane filters an occupancy of 1.5% and above. The number of measurement errors and manual corrective steps increases while the comparability of results from analyses performed using different systems decreases. The analyzability of analysis filters also depends on other factors (homogeneous occupancy, percentage of fibers, etc.). Consequently, these values only serve as a rough indication and require individual assessment in each case.

With particle traps and stamps, the occupation densities at which these problems can be expected are between those of the sieve cloth filters and those of the foamed filter.

Note: If filter occupancy is very homogeneous, it may be possible to analyze filters with a higher percentual particle occupancy.

8 ANALYSIS METHOD

8.1 Overview

This section of the guideline describes the various techniques which can be implemented to analyze particulate contamination. The selection of a suitable analysis method and its field of use are described in Chapter 3 SELECTING THE INSPECTION METHOD and depend on the purpose of the inspection.

The following section briefly describes the structure and contents of Chapter 8 (see also Table 8-1):

Chapter 8.2 describes three analysis methods (with increasingly comprehensive analysis results as well as increasing complex equipment):

- Gravimetric analysis, described in Chapter 8.2.1, requires little equipment and is used to determine the total mass of particles extracted from the inspected object.

- Light-optical analysis is described in Chapter 8.2.2. First, Chapter 8.2.2.1 explains the fundamentals of light-optical analysis as well as the options for measuring particle sizes and the respective resolutions required, as well as typification by fiber form and optionally the determination of metallic shine. Building on this foundation, Chapter 8.2.2.2 describes light-optical standard analysis for particles ≥ 50 µm with the goal of achieving high comparability of analysis results. General conventions for the adjustment of image brightness and a detection threshold are defined for this purpose. This standard analysis can be used for light-optical systems with incident illumination and for the analysis of dark and metallic particles on white analysis filters. In free light-optical analysis, which can also be used to inspect cleanliness limit values upon approval, methods primarily intended for detecting low-contrast particles are described in Chapter 8.2.2.3. The chapter also describes the analysis of particles < 50 µm and light-optical measurement systems that differ from microscopes and scanners and the direct inspection of surfaces. Another key component of inspecting cleanliness limit value is meticulously double-checking the optical evaluations as described in Chapter 8.2.2.4. The other sub-chapters in 8.2.2.2 deal with materials and equipment, the analysis procedure and documentation.

- The SEM/EDX analysis in Chapter 8.2.3 is structurally identical to light-optical analysis. Chapter 8.2.3.1 describes the foundations of automatic SEM/EDX particle analysis with material classification. A standard analysis procedure for comparable analysis results with conventions for settings and evaluation parameters as well as a set of basic material classes is described in Chapter 8.2.3.2 and is used to analyze particles ≥ 50 µm on carbon-based filters. If particles < 50 µm need to be analyzed, alternative contrast options (contrast of particles against filter background) are necessary to detect particles made of very light elements. If other material classes are used for certain product groups, refer to Chapter 8.2.3.3 for information on free SEM/EDX analysis. Both SEM/EDX standard analysis and free analysis can be used to inspect cleanliness limit values – the former without prior approval and free SEM/EDX analysis upon agreement in the customer-supplier relationship. The other sub-chapters in 8.2.3 also deal with materials and equipment, the analysis procedure and documentation.

Chapter 8.3 briefly describes the options for monitoring processes with regard to particle cleanliness but does not go into detail on the actual methods.

Chapter 8.4 on extended analysis describes methods that can be used to further characterize particles, e.g. in line with cause research or process optimization. General descriptions are provided as to how the methods work and the information they provide, but no details are provided as to their technical implementation, parameterization, inspection procedures or standardized evaluations.

Chapter 8.4.1 describes other light-optical analyses such as the characterization of particles based on a particle catalog or particle height determination. Chapter 8.4.2 again deals with SEM/EDX analyses, and Chapters 8.4.3 through 8.4.6 briefly cover LIBS analysis, Raman spectroscopy, infrared spectroscopy and x-ray microtomography.

Table 8-1: Overview of Chapter 8.2: Verifying cleanliness limit values

Chapter 8.2 Verifying cleanliness limit values			**By arrangement with customer**
8.2.1	Gravimetry		no
8.2.2	Light-optical analysis		
8.2.2.1	Principles	Necessary optical resolution (particle analysis for 5 µm and higher) • Particle length and width • Fiber definition • Optional: metallic shine	no
8.2.2.2	Light-optical standard analysis	• Particle analysis for 50 µm and higher • Brightness and threshold • Valid for dark particles on white analysis filters	no
8.2.2.3	Free light-optical analysis	• Particles < 50 µm • Low-contrast particles • Other systems for light-optical analysis + direct inspection	yes
8.2.2.4-8.2.2.8-	Follow-up check, materials, equipment, procedure, calibration, documentation		no
8.2.3	SEM/EDX analysis		
8.2.3.1	Principles	• Measuring principle SEM (particle detection) and EDX analysis (elemental composition of particles) • Ways of defining material classes	no
8.2.3.2	SEM/EDX standard analysis	• Particle analysis for 50 µm and higher • Accelerating voltage and detector • Brightness/contrast and threshold • Minimal EDX counts • Elements to be considered • Material classes and zero-rules	no
8.2.3.3	Free SEM/EDX analysis	• Particles of 5 µm and higher • Different image formation • Different evaluation of EDX spectra and material classes	yes
8.2.3.4-8.2.3.8	Follow-up check, materials, equipment, procedure, calibration, documentation		no

8.2 Verifying cleanliness limit values

8.2.1 Gravimetry

8.2.1.1 Principle

As shown in Figure 8-1, the total mass of the particle load extracted from an inspected object can be determined by weighing the analysis filter with an analysis scale before and after the analysis liquid is filtered.

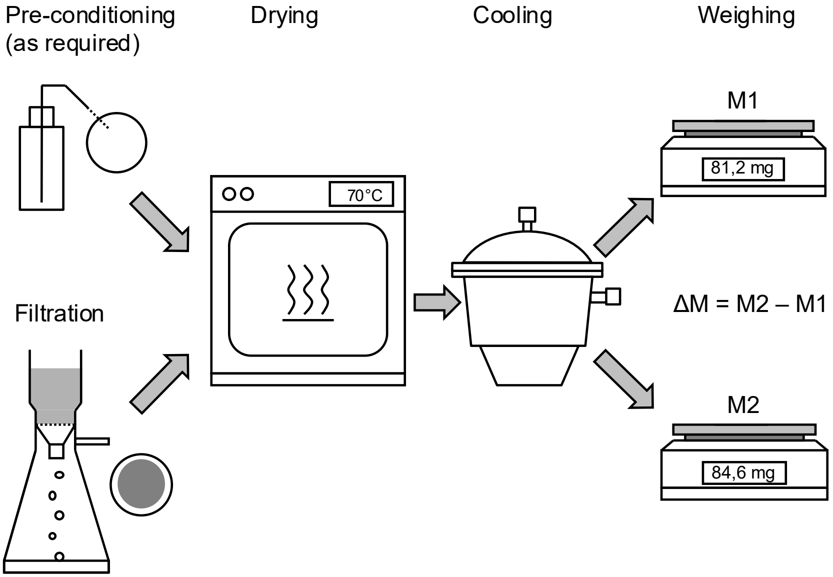


Figure 8-1: Diagram of the gravimetric analysis procedure

The result of the gravimetric analysis is called the residue weight and represents an integral value. Its magnitude depends on the total quantity and size of the particles extracted as well as their respective material composition. Gravimetric analysis does not give any information about the quantity, size or nature of the particles concerned and thus provides very little information about their damage potential.

To accurately determine the weight difference, the analysis filter has to be carefully prepared, dried and cooled to room temperature. If very small differences in mass need to be determined, climatic conditions in the room need to be regulated more precisely and the design of the weighing area becomes more complex.

If additional analyses are required as well as gravimetric analysis, e.g. light-optical analysis, the gravimetric residue weight must always be determined first.

A dilemma is often encountered when preparing an analysis filter for simultaneous gravimetric analysis to determine weight and light-optical microscopy to determine particle size distribution.
This is because the analysis filter should contain a maximum quantity of particulate contamination in order to obtain a reliable gravimetric result, but low numbers of single, separate particles for light-optical analysis.

Weight constancy: The temperature and duration of the drying process vary according to the material the analysis filter is made of and the type of inspection and final rinsing liquids implemented. Drying conditions are determined as being suitable when weight constancy of the analysis filter is achieved, i.e. when the analysis filter does not lose any more weight as the result of a longer drying period. The respective time and temperature settings need to be determined at least once for each combination of filter and inspection medium used (e.g. cellulose nitrate filter combined with cold cleaner, 150 minutes at 70°C).

Note 1: Weight constancy is achieved if no change in weight relevant to the gravimetric result occurs after the same analysis filter has been subjected to a second drying step and weighed again.

Note 2: Drying conditions (time and temperature) may vary for each combination of extraction liquid and analysis filter. See filter manufacturer's instructions for details.

Note 3: Whether a particle trap or a particle stamp is suitable for a gravimetric analysis must be checked individually.

Non-particulate residues: To stabilize the tare weight of the clean analysis filter before commencing the inspection, it may be necessary to rinse it briefly with extraction liquid before performing the first drying process in order to remove any volatile substances present in the filter material.

In some cases, the analysis filter may need to be rinsed with an appropriate liquid after the filtration step in order to remove any chemical residues that are not particles but which could influence the gravimetric result. Examples of such residues include tensides from aqueous cleaning media, or greases or wax originating from the component that are difficult to dissolve.

In some cases, particles may have to be fixed on the analysis filter for the purpose of further analysis, e.g. by means of a fixative. This may only be applied once gravimetric analysis has been completed.

8.2.1.2 Material and equipment

For more information, refer to Chapter 7 ANALYSIS FILTRATION AND SEPARATION. The following are also required:

1. Desiccator: The desiccator prevents the analysis filter from absorbing any humidity from the environment during the cooling process after it has been dried

   Note 1: Depending on cleanliness requirements, or when relatively high residue weights have to be determined, the use of a desiccator may not be necessary. In order for this condition to apply, the maximum permissible blank value may not be exceeded.

2. If necessary, ionization unit (if it is known that the weighing process is affected by electrostatic interference)

   Note 2: Models with beta emitters must be monitored. The ionization unit generates positively and negatively charged ions to neutralize the electrostatic charge on the analysis filter as this could impair the weighing result. The ionization unit must be located as close as possible to the weighing platform. Ionization units with fans are not suitable.

3. Analysis scale: The minimum readability requirement is 1 d (1 digit) = 0.1 mg = 0.0001 g (four-digit scale).

8.2.1.3 Environmental conditions

The lower detection limit or sensitivity of gravimetric analysis is not solely determined by the lower determination limit of the analysis scale. Constant levels of humidity of the immediate environment and also the cleanliness of the air have a significant influence. In a non-controlled environment, the result is also affected by the length of time a dried analysis filter is exposed to the environment before being weighed. Consequently, time periods are to be kept as consistent as possible during the procedure.

The table on which the scale is set up should not transmit any vibrations and must be non-magnetic and protected against electrostatic charges (no steel, plastic or glass). The room in which the scale is located must be low-vibration, and the scale table should be vibration-cushioned. When using a five-digit scale (accurate to 0.01 mg), humidity must be controlled.

Direct sunlight and draughts (even in clean rooms) must be avoided. The scale may not be positioned near air-conditioning units, heaters or doors.

8.2.1.4 Detection limit of the gravimetric analysis

If a four-digit scale is used in rooms where the temperature and relative humidity conditions are not controlled, the lower detection limit is 1 mg. In connection with the guideline requirement that the percentage of the blank value may be max. 10 percent of the total load, only particle loads with a residue weight (M) upwards of 10 mg can be detected.

In order to minimize the costs for gravimetric analysis, the following compromise is made in practice: It is permissible to use four-digit scales to determine residue weights when inspecting components of down to 3 mg, since this is above the detection limit of 1 mg. However, the blank value is then below the detection limit (the last digit of the scale display is used for rounding), can no longer be precisely determined and is indicated as M < 1 mg (see also Annex 8.2.1).

In order to assess components with particle loads below 3 mg or under 10 mg with the correct blank value, it is necessary to use a scale with a higher resolution in a room with controlled temperature and relative humidity conditions.

Another way of analyzing components with very small particle loads by means of gravimetry is to increase the residue weight (M). This is achieved by sampling several components simultaneously, or by filtering the analysis liquid from several components through one analysis filter. The minimum number of components for an inspection lot or the minimum total inspection surface that should be extracted and separated out onto an analysis filter can be determined using the following formula:

$$Inspection\ lot\ size or. Test\ surface \geq \frac{Resolution\ of\ the\ scale\ x 100}{Limit\ value\ (per\ part\ or\ per\ surface)}$$

Example 1: Resolution of the scale 0.1 mg, limit value 1 mg per component

$$Inspection\ lot\ size \geq \frac{0.1\ mg \times 100}{1\ mg} = 10$$

Note: The detection limit indicated here is based exclusively on the readability of the analysis scale without consideration for linearity errors or reproducibility, etc.

8.2.1.5 Procedure

1. Procure all resources required for preparing the analysis filter and for the analysis procedure

2. Pre-Condition the analysis filter to stabilize its weight (optional):

Note 1: To stabilize the weight of an analysis filter, first of all it is treated with analysis liquid before the first drying process in order to remove any substances that can be washed out from the filter material. This would otherwise occur during the analysis filtration step and lead to a lower actual residue weight. This must be verified before using the combination of analysis liquid and analysis filter for the first time. As long as no reduction in residue weight occurs and, with higher residue weights, pre-conditioning can sometimes be omitted under certain conditions.

   a) Place the membrane in the filter holder and filter a sufficient volume of clean analysis liquid through it to remove any soluble substances contained in the analysis filter

   b) Pre-dry the membrane by sucking air through the analysis filter with the vacuum pump

3. Pick up the analysis filter with forceps and place it in a marked clean Petri dish

4. Determine the initial weight M1 (tare weight):

   a) Place the partly covered Petri dish containing the analysis filter (= goods to be dried) in the pre-heated drying oven; verify the temperature and time required to dry the analysis filter.

   b) Remove the dried goods and place immediately in the desiccator; check the amount of time required to cool the analysis filter

   c) Take the dried goods out of the desiccators; immediately remove the analysis filter from the Petri dish with forceps, and place it on the weighing surface of the analysis scale

   d) Read off and document the value shown for the initial weight M1 of the analysis filter (tare weight)

Note 2: If the analysis filter is dried using a device that combines a hotplate with a vacuum, there is no need to cool the analysis filter in the desiccator, as long as the analysis filter is dried directly on the hotplate and weighed immediately after the drying operation.

5. Using forceps, put the analysis filter back into the Petri dish, and close the lid (analysis filter is now ready for analysis filtration)
6. Perform the analysis filtration step (see Chapter 7)
7. Determine the final weight M2 (gross weight):
    a) Place the partly covered Petri dish containing the analysis filter (= goods to be dried) in the pre-heated drying oven; verify the temperature and time required to dry the analysis filter
    b) Remove the dried goods and place immediately in the desiccator; check the amount of time required to cool the analysis filter
    c) Take the dried goods out of the desiccators; immediately remove the analysis filter from the Petri dish with forceps, and place it on the weighing surface of the analysis scale
8. Read off and record the displayed value for the weight M2 of the analysis filter (gross weight)
9. Using forceps, put the analysis filter back into the Petri dish, and close the lid
10. Calculate the residue weight (net weight) as the difference of M2 and M1

Important: During all handling steps, ensure that no particles present on the analysis filter are lost in the process.

8.2.1.6 Calibration

The analysis scale is calibrated according to the manufacturer's instructions, typically once a year.

8.2.1.7 Documentation

see Chapter 9 DOCUMENTATION as well as Chapter 12 CASE EXAMPLES

A 8.2.1 Lower detection limit of the gravimetric analysis

Table 8-2: lower detection limit of the gravimetric analysis

Resolution of the scale	**four-digit**	**five-digit**
	0.0001 g = 0.1 mg	**0.00001 g = 0.01 mg**
lower detection limit	1 mg	0.1 mg
Required blank value criterion (max. 10% of the residue weight)	1 mg	0.1 mg
Detectable residue weight M (cleanliness inspection)	10 mg	1 m
Requirements for environmental conditions	none	humidity-controlled

In order to minimize the costs for gravimetric analysis, the compromise indicated in Table 8-3 is implemented for four-digit scales.

Table 8-3: lower detection limit of the gravimetric analysis (compromise)

Resolution of the scale	**four-digit**
	0.0001 g = 0.1 mg
lower detection limit	1 mg
Required blank value criterion (max. 10% of the residue weight)	< 1 mg
Detectable residue weight M (cleanliness inspection)	3 mg

8.2.2 Light-optical analysis

While gravimetric analysis only gives information about the total particle load extracted from the component, more detailed information can be obtained using light-optical analysis. With this method, particles can be measured and counted as well as characterized.

Light-optical analysis of analysis filters, particle traps or particle stamps can be conducted using different types of microscopes or flatbed scanners according to requirements. For specific applications, it is also possible to use cameras or camera systems for direct inspection or measuring cells in which filtration and light-optical analysis are combined. Because the function of components may already be impaired by one or only a few particles with specific characteristics, it is imperative that such particles be detected reliably. In order to do this, the entire effective surface area (see Figure 8-28 in the annex) of an analysis filter is inspected.

Standard analysis with fixed parameters, which was developed for detecting dark and metallic particles on white analysis filters with incident illumination, can be used to verify cleanliness specifications with no need for additional agreements in the customer-supplier relationship.

It is also possible to use light-optical systems with their analysis parameters adapted for a special inspection (e.g. detection of low-contrast particles), provided that certain minimum requirements (e.g. pixel resolution or the use of particle size definitions defined here) are met. This would have to be agreed in the customer-supplier relationship. Light-optical systems can also be used for extended analyses, e.g. if color or other morphological information is being evaluated.

Light-optical analysis of an entire analysis filter membrane is generally performed using a fully automated process. If only a small quantity of large particles needs to be measured, this can be done manually.

8.2.2.1 Fundamentals and principle

With light-optical analysis, the analysis filter containing the particles extracted from the inspected object (or another carrier/another surface) is illuminated in image fields using a suitable light source and reproduced by a magnifying lens, generally in the form of pixels on a camera sensor. “Image processing” is used to detect particles and determine size features. However, objects can only be detected if they differ optically (typically in brightness) from the background. Thus, for example, white particles cannot be detected if they are on a white analysis filter membrane, and very pale particles can only be partially identified (see also Annex A 8.2.2.6). This is not a fault or shortcoming of the light-optical system concerned but is rather due to the nature of the detection method and its principle of function.

Which particles are recognized in detail and how they are measured and characterized is highly individual and depends on several factors:

- Imaging lens (magnification and resolution)
- Type (bright field, dark field, reflected light, transmitted light, grazing light) and individual design of illumination
- Illumination of the image fields
- Threshold value (the threshold values) which enables the image processing software to differentiate between particles and the filter background (binarization threshold)
- Definition criteria for measuring and characterizing particles as well as the exact algorithms used to implement them
- Individual composition and optical characteristics of the respective contamination particle (color, brightness, homogeneity, surface topography and roughness, etc.)
- Others

All these factors influence the result of a light-optical particle analysis. For this reason, it is only possible to fully compare light-optical analysis results if identical systems with identical settings are used to analyze the same type of contamination particles.

Detecting, measuring and characterizing particles using light-optical analysis for threshold verification

As shown in Figure 8-2, areas of the analysis filter membrane (including the particle) are magnified by an imaging lens and reproduced on a camera sensor (or line camera in the case of a scanner). The camera sensors are made up of individual, light-sensitive elements (pixels). In this way, via the degree of magnification selected/set, the size of the camera sensor and the pixel number, a specific length in the plane of the inspected surface is assigned the size of a camera pixel (see example of micrometer scale in Figure 8-2). This gives an image scale in µm/pixels which is used to measure particles.

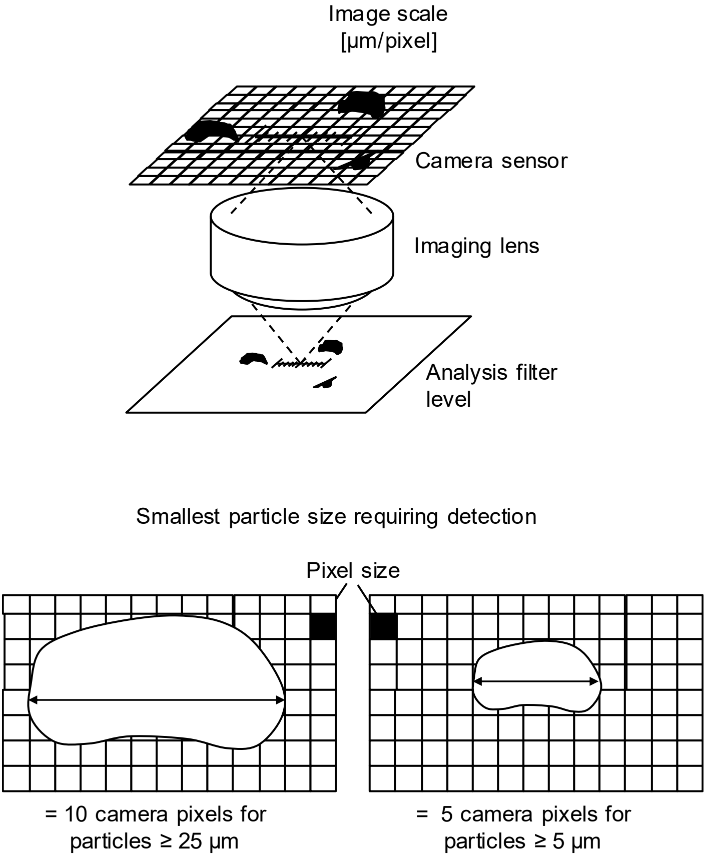


Figure 8-2: Pixel resolution in the light-optical image

To determine particle sizes sufficiently accurately, the longest dimension of the smallest particle requiring analysis should be reproduced on at least 10 pixels of the camera image. In a standard analysis where the smallest particles to be measured are 50 µm in size, this therefore results in the necessary pixel resolution of at least ≤ 5 µm/pixel.

Where very small particles need to be measured (beyond the range of standard analysis), such as 5 µm or 15 µm, it may make sense not to apply the 10 pixel criterion. Table 8-4 summarizes the necessary pixel resolutions.

Table 8-4: Required resolution according to particle size

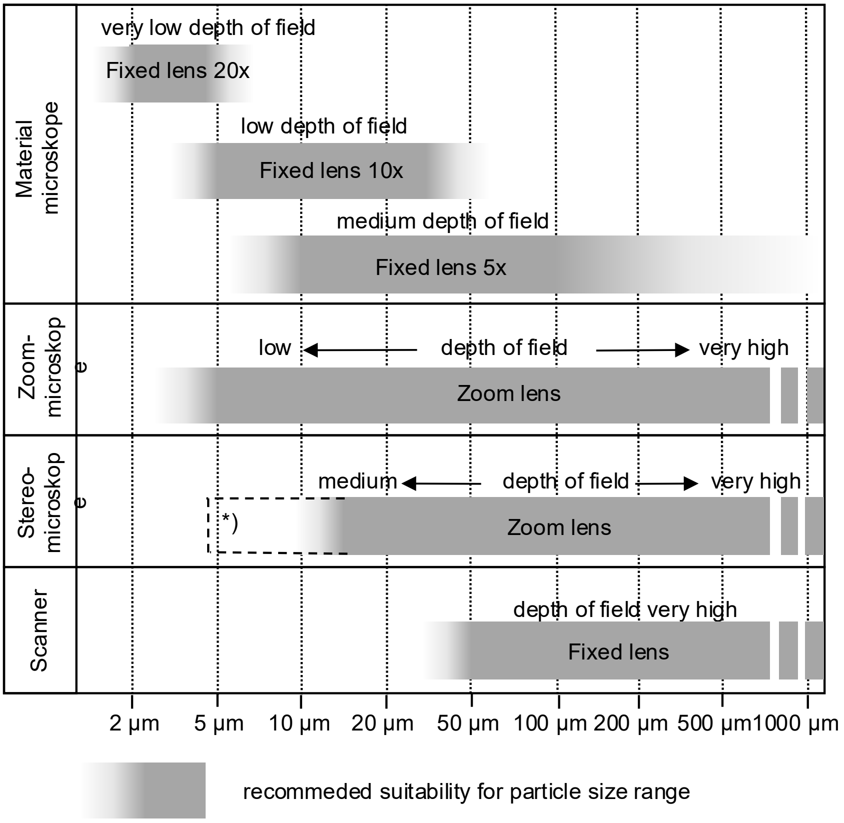
Particle size	**Detection at**
≥ 50 µm	≤ 5.0 µm/pxl
≥ 25 µm	≤ 2.5 µm/pxl
≥ 15 µm	≤ 2.5 µm/pxl
≥ 5 µm	≤ 1.0 µm/pxl

The number of pixels and the size of the camera are not the only factors that determine the accuracy of a particle measurement; the optical characteristics of the imaging lens play a more important role. For example, the lens or lens setting (zoom level) of the microscope determines the resolving power and depth of field. Figure 8-3 gives an overview of the suitability of different lenses for analyzing different-sized particles, as well as giving information on the depth of field.

The higher the degree of magnification and resolution selected/set, the smaller the size of particles that can be measured. However, because higher degrees of magnification reduce the depth of field, it may become difficult to depict large particles clearly. In cases with high resolutions and a low depth of field, a motorized z-drive and auto-focus function can be used to compensate for uneven features on the surface of the analysis filter.

Note 1: A higher degree of magnification demands a larger quantity of image fields in order to inspect the analysis filter comprehensively. This increases the analysis time as well as the volume of data to be processed or archived.

When selecting the degree of magnification, a compromise should always be made between a high optical resolution on the one hand and a good depth of field, short analysis time and low data volume on the other hand.



depth of field:		
	very low	1 – 10 µm
	low	10 – 50 µm
	medium	50 – 100 µm
	high	100 – 1000 µm
	very high	> 1000 µm

Figure 8-3: Example overview of suitability of different lenses for particle analysis

Note 2: Like stereo microscopes, zoom microscopes or macroscopes also have a zoom lens with variable magnification. With a stereo microscope, the eyes of the observer view the sample from slightly different angles via a common lens (parallax). This gives the sample a three-dimensional appearance when viewed through the lens. If stereo microscopes are used for automated measurements, the beam path for the camera should be directed in such a way as to prevent this parallax from occurring, or it should be corrected. Particles of 5 µm and up can then also be inspected with stereomicroscopes (area marked with *) in Figure 8-3). If this is not the case, only particles of 15 µm and up can be inspected. With a zoom microscope, the beam path through the lens is identical for both eyes as well as for the camera. However, with solely video zoom microscopes, there is no eyepiece at all, only a beam path for the camera. Here, the image is viewed exclusively on a screen.

As already mentioned, in order to apply the optical method effectively to determine particle size ranges, analysis filters (or particle traps/particle stamps) have to be well-prepared with a particle occupancy that is not too dense and with particles neither overlapping nor touching one other. Isolated cases cannot be avoided but can be corrected through manual intervention. One criterion for being able to analyze analysis filter membranes as well as particle traps and stamps accurately is the percentual occupancy of particles on the filter. This value should be read off and documented to help the user when applying the light-optical analysis method. The percentage of filter occupancy encompasses all areas of images that are considered to be particles (of all types). This applies not only to the particle sizes mentioned in the cleanliness specification but also to all pixels in the filter image. For further information on filter occupancy, see Chapter 7.1.7.

For **particle detection**, the image-processing software assigns some image areas to particles and the remaining areas to the background of the analysis filter. To do this, the brightness range of the image is generally divided into gray values varying between black and white. In the case of particle analysis, 256 shades of gray have become established. If the number of pixels in the image possessing specific gray values are spread out over this range, a so-called “histogram” is obtained (see also Figure 8-32 in the annex).

Note 3: Often, brightness is also indicated in a histogram as a percentage and not as a gray scale. 0% then corresponds to the black value, and 100% corresponds to the white value.

Note 4: In line with free light-optical analysis, contrast mechanisms other than brightness contrast can also be used to detect particles on a surface.

The type and intensity of the lighting is selected so that the particles to be detected have the necessary brightness and thus the necessary position in the histogram to clearly stand out from the brightness of the background (analysis filter, particle trap or particle stamp). The particles are then typically detected through image processing by setting one (or two) gray value thresholds for binarization of the corresponding brightness ranges. The adjustment of the image brightness and the setting of the binarization threshold are described and specified in great detail for standard analysis (Chapter 8.2.2.2).

Here, the goal is to achieve the best possible comparability for light-optical analyses on white analysis filters (or particle traps and stamps) with incident illumination for dark or metallic particles.

Note 5: To detect metal particles, we typically work with crossed polarizers. As a result, metal particles, which would have bright, shiny spots without these polarizers, are greatly darkened as a whole, bringing them far below the binarization threshold and making them detectable as particles.

To detect bright or low-contrast particles, for example, it can be necessary to deviate from the parameters of standard analysis (e.g. filter type and filter color, type and intensity of lighting, binarization threshold, etc.). This is described in Chapter 8.2.2.3. The performance of such analyses, which are optimized for the application or for certain particle types, and their parameterization should then be defined in the customer-supplier relationship. The analysis results are different from the results of a standard analysis, and significantly more particles can be detected, which is precisely the goal of this optimization: to find particles that cannot be detected by standard analysis. This does not make a component that is inspected for technical cleanliness “worse or dirtier”. It just means that particles that are not detectable in standard analysis can now be seen. This must be taken into account when interpreting the analysis results and comparing them against the cleanliness specifications.

In the context of light-optical analysis for threshold verification, the **particle size measurements and typifications** listed in Chapters 8.2.2.1.1 through 8.2.2.1.4 are possible.

8.2.2.1.1 Particle length

Particle length, measured as the largest possible vertical distance between two parallels touching the particle (see Figure 8-4), is designated as $\text{Feret}_{\text{max}}$ in image processing. This length specification corresponds to the “worst-case damage potential” of a particle that can bridge a particle-sensitive point in an automotive system, e.g. the contact gap between electronic elements.

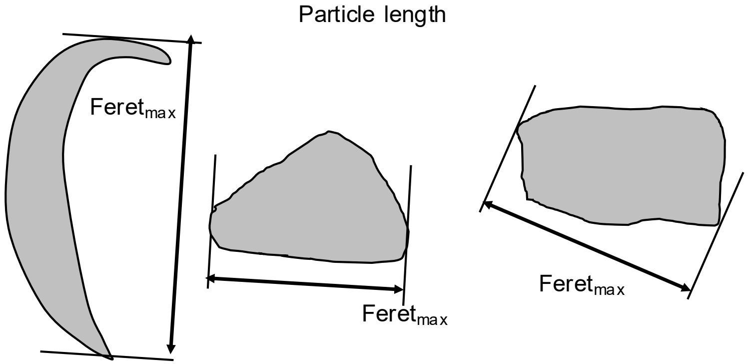


Figure 8-4: Definition of particle length as Feret$_{max}$

8.2.2.1.2 Particle width

Particle width, measured as the smallest possible vertical distance between two parallels touching the particle (see Figure 8-5), is designated as Feret$_{min}$ in image processing. With respect to damage potential, this can correspond, for example, to the width of a channel that a particle of this width can still go through.

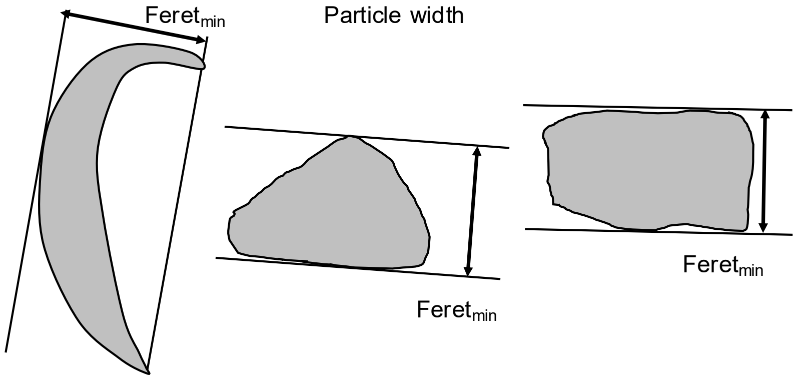


Figure 8-5: Definition of particle width as Feret$_{min}$

The annex (see Figure 8-27) mentions two other particle widths that can also optionally be indicated in a light-optical standard analysis.

Note 7: The particle area or the total particle area can also be a suitable dimension to indicate when describing the damage potential of particles. This particularly applies to optical applications in which relevant optical signals can be largely determined by the area of the particles in relation to the size of the shadow or the signal loss. The grouping of particles into particle area distributions, similarly to particle size distribution, is not covered in VDA 19.1 but can be arranged in the customer-supplier relationship if necessary.

8.2.2.1.3 Typification of particles as fibers and fiber measurement

Every production or laboratory environment that has people in it can be assumed to contain textile fibers from clothing, which then also come up in component cleanliness inspections. Textile fibers are constantly able to fly and float – even if they are very long (many millimeters). Since textile fibers are typically very long but not functionally critical for many technical systems, it is important to reliably separate them from compact, potentially damaging particles.

For the purpose of **typifying** (see Figure 8-6) a structure as a fiber, VDA 19.1 uses the following definition:

- Option 1 (maximum inner circle):
  - not metallically shiny (see Chapter 8.2.2.1.4)
  - stretched length/maximum inner circle > 20
  - and width measured over maximum inner circle ≤ 50 µm (see Figure 8-27)
- Option 2 (middle inner circle):
  - not metallically shiny (see Chapter 8.2.2.1.4)
  - stretched length/middle inner circle > 20
  - and width measured over middle inner circle ≤ 50 µm (see Figure 8-27)

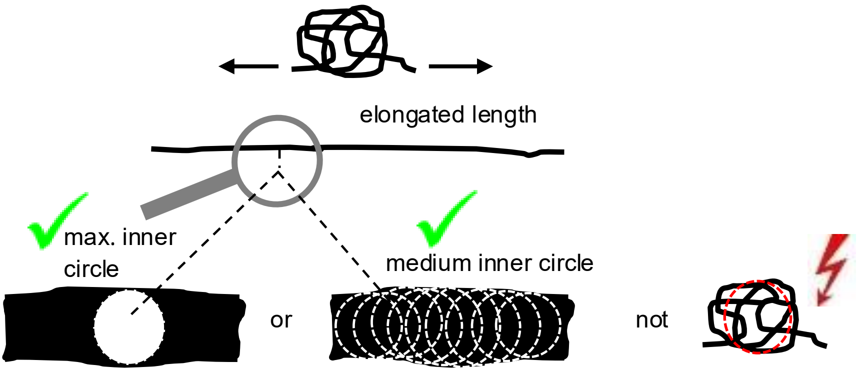


Figure 8-6: Typification of fibers

The fiber length can be measured in two ways (see Figure 8-7).

Note: If a fiber count is done without the optional detection of metallically shiny particles, then the "not metallically shiny" portion of the fiber definition is omitted. Since, in this case, long, thin metal chips could potentially also be categorized as "fibers", the categorization should be corrected in the double-checking process if necessary.

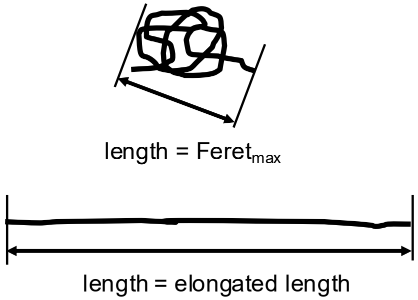


Figure 8-7: Measurement of fibers

In contrast to other particles, material fibers tend not to have a fixed shape, meaning that their orientation, position, bend or twist on an analysis filter is usually completely random. With such an arbitrary shape, stating the length as $\text{Feret}_{\max}$ is less suitable for characterizing such particles. Therefore, the length of a fiber can alternatively be expressed as the so-called "elongated length".

This length, which corresponds to an “untangled and elongated fiber”, can be calculated using computational image-processing methods. In a cleanliness specification and the associated inspection specification, it should be indicated whether fibers are indicated by $\text{Feret}_{\text{max}}$ or elongated length.

The fiber definition should be used to preselect nearly unavoidable textile fibers but not for reliably detecting fiber materials from workpieces or production processes such as glass fibers or carbon fibers.

Attention: (Textile) fibers are practically impossible to avoid or control in a defined manner in the manufacturing process of components or their logistical chain. When creating cleanliness specifications with fiber requirements, take into account the tremendous difficulty involved (see also Chapter 2 CLEANLINESS SPECIFICATION and INSPECTION STRATEGY).

If, in a given application, the individual fibers are not functionally critical and it is the total amount of fibers that needs to be controlled, e.g. in order to prevent a narrow hydraulic cross-section from getting clogged, then note the following: It makes little sense to specify the permissible lengths of individual fibers, because there is no process in production that makes it possible to regulate the length the textile fibers or restrict the release of fibers according to size. The total fiber input can be restricted, however, by protecting components.

A good dimension for describing such total fiber loads is total fiber length, i.e. the sum of the elongated lengths of all fibers on a component or analysis filter (see Figure 8-8).

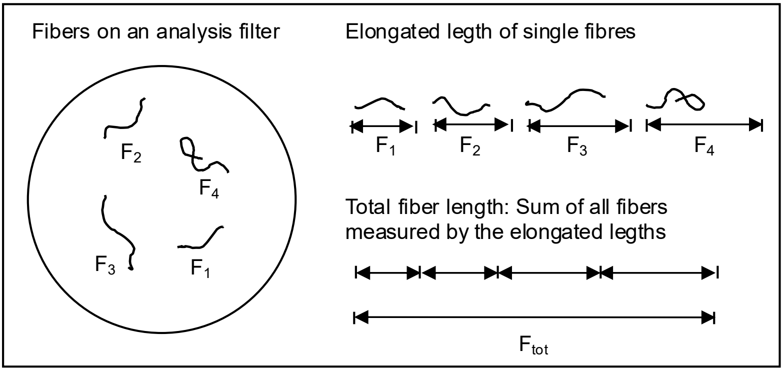


Figure 8-8 Meaning of total fiber length

The analysis of fibers can involve the following challenges:

- Due to the extraction and the resulting “packing” of particles on an analysis filter, fibers can sometimes agglomerate with each other or with particles. This makes them difficult to detect separately and manually double-check.

- Due to their optical characteristics, in automatic analysis, fibers are often detected in parts rather than in full length. Reliable detection may therefore require meticulous double-checking.

8.2.2.1.4 Characterizing metallic shiny particles (optional)

When determining technical cleanliness, it may be very important to characterize metallic particles. This is partly due to the fact that metals are key materials in the manufacture of functionally-relevant systems and therefore very commonly found on inspected objects as contaminant particles originating from processing or assembly steps. Secondly, they are classified as being functionally-critical in a wide range of applications because of their material properties (e.g. hardness or conductivity).

Metal particles can only be determined with certainty by applying extended analysis methods. Universal, reliable detection using only light-optical techniques is not possible. This is due to their varying optical appearance, which depends on the metal and the processing step the particles originate from. Consequently, the color, brightness, surface structure, shape and homogeneity of a particle’s optical characteristics may differ significantly.

Despite this, many metallic particles display a common feature: provided the particle surface is not matt, oxidized or soiled with soot or other contaminants, a metallic reflection or metallic shine occurs. This effect can be used to help determine the particle type.

Metallic shine is a property caused by freely moving electrons in the metals. It causes light reflected from metals to be polarized in the same direction as the light shined on the metals. This polarized metallic shine can be detected by multiple technical methods (imaging with incident illumination):

- It is detected by evaluating and comparing two images: One analysis is carried out using crossed polarizers to detect all the particles present (pole image), which is also used to detect and count particles, and another analysis is performed using either parallel polarizers or no polarizers (bright image). If bright spots (close to or the same as the white value in the histogram) in the bright image are detected in the same areas that the pole image assigned to particles, and if these spots are dark (nearly black) in the pole image, such particles can be classified as having a metallic shine.

- If a color camera is used to detect the particles, the direction of polarization of a color channel can be rotated specifically so that the metallically reflective spots appear in the corresponding color on an image taken with crossed polarizers. Thus, a single image is enough to detect metallic shine.

- Images can also be taken using cameras with pixel elements consisting of four pixels each with differently oriented integrated polarization filters. This makes it possible to typify metallically shiny particles from just one image.

For scanners, microscopes and other light-optical detection units without a polarization unit, this analysis technique using a pole image and a bright image cannot be applied. Nevertheless, the occurrence of bright reflections (areas of a particle with a white value close to or the same as the white value in the histogram) can be used to pre-characterize metallic shiny particles. However, there is a risk that particles with another form of shine may be classified as being metallic shiny particles.

Note: The typification of metallic particles can also be performed by evaluating the shine based on a measurement of the shine in images taken from different illumination angles.

A number of system requirements and parameters determine whether a particle is characterized as being metallic and shiny during an automated analysis. At the time this version of VDA 19.1 went to press, it was still not possible to standardize these:

- Type of imaging lens

- Degree of magnification or zoom level

- Type and exact geometry of illumination

- Method and exact parameter settings for characterizing metallic shine

- Individual properties of metallic particles but also the orientations of the individual particles

Therefore, results of the automated characterization of metallic shiny particles can only be fully compared with one another in case of identical systems, identical parameter settings and identical particle characteristics. However, individually adapting different systems and their parameter settings can be a lot of work.

Despite all its limitations, in many cases the characterization of metallic shine can be a very practical aid. In order to be able to use it to analyze technical cleanliness and validate cleanliness specifications, the following points need to be clarified or adhered to by the user/operator of the light-optical analysis systems:

- Check to ensure that metal particles that are routinely tested in the samples of the cleanliness laboratory are constituted so as to be generally typified as metallically shiny with the utilized system and the given setting parameters. This can require preliminary testing with extended analysis methods. This can be done primarily for factory laboratories of companies in which the inspected objects are manufactured; for a contract laboratory, this is usually not possible.

- In the follow-up check, every single filter analysis should be checked to see if the typification, which was done automatically, can be confirmed through visual inspection by a specially trained operator or if individual particles need to be reclassified.

8.2.2.2 Light-optical standard analysis

In order to achieve maximum comparability, despite this starting situation with different analysis systems, which could all have their unique strengths, a “standard analysis” is defined for light-optical particle analysis according to VDA 19.1.

There are four prerequisites for the sensible application of light-optical standard analysis:

- a light-optical analysis system with the corresponding prerequisites (see Chapter 8.2.2.5 on materials and equipment)

- a cleanliness specification that only covers particles ≥ 50 µm

- well prepared white analysis filters with particles distributed on them evenly and not too densely packed (see Chapter 7)

- well educated personnel, specially trained for this work

With the goal of consistent evaluation and thus greater comparability of analysis results, the basic idea is to establish conventions only in the image adjustment and evaluation – as independently as possible from the utilized light-optical system (material microscope, stereomicroscope, zoom microscope or scanner system and associated lighting) and thus independently of the image formation.

Note 1: The use of light-optical standard analysis alone cannot guarantee complete comparability of analysis results of different systems. How high the achieved level of comparability is, especially in conjunction with the given contaminant particles, must be considered on a case-by-case basis. In any case, the comparability is better than without the use of standard analysis, however.

Note 2: Switching from standard analysis to a differently parameterized light-optical analysis can produce different analysis results.

For various reasons, it may make sense to deviate from the conventions of standard analysis, e.g.:

- if the cleanliness specification makes it necessary to analyze particles smaller than 50 µm,
- if the cleanliness specification comprises properties and typifications other than those designated as part of standard analysis, e.g. if there are specifications on particle material or third particle dimension,
- if it is necessary or desirable to optimize the detection of certain particles through the use of contrast methods and/or parameters other than those of standard analysis.

These deviations must be approved and documented if they are used in the customer-supplier relationship to verify cleanliness specifications.

If a cleanliness specification meets the criteria of a standard analysis and if there are no other agreements in the customer-supplier relationship, standard analysis should be used.

For the adjustment of the image brightness and thus the form and position of the histogram as well as the setting of either one or two thresholds which are crucial for differentiating between particles and background (known as “binarization threshold,”) additional conventions are established to increase the comparability of analysis results. There are two possible cases: Light microscopes with polarizers and scanners without polarizers.

8.2.2.2.1 Light microscopes with polarizers

In these systems, the light used to illuminate the analysis filter is polarized linearly by means of a polarizer, and the light reflected from the sample, which is detected by the magnifying optics, is directed by an additional 90°-rotated polarizing filter (analyzer). Due to the crossed polarizing filters, particles are darkened, and reflections from metallic particles are blocked. The targeted particles show up as dark against a light filter background. The brightness of the image is not adjusted so that the maximum of the brightness distribution of the filter background (the histogram maximum) is pushed to 55% ± 5% of the total brightness range (via the brightness of the illumination or camera exposure time, etc.). The relevant image information (the dark particles) is to the left of this maximum for dark gray values.

The binarization threshold is set at 70% relative to the maximum of the gray value distribution, see also Figure 8-9. Structures to the left of this gray value threshold are detected as particles.

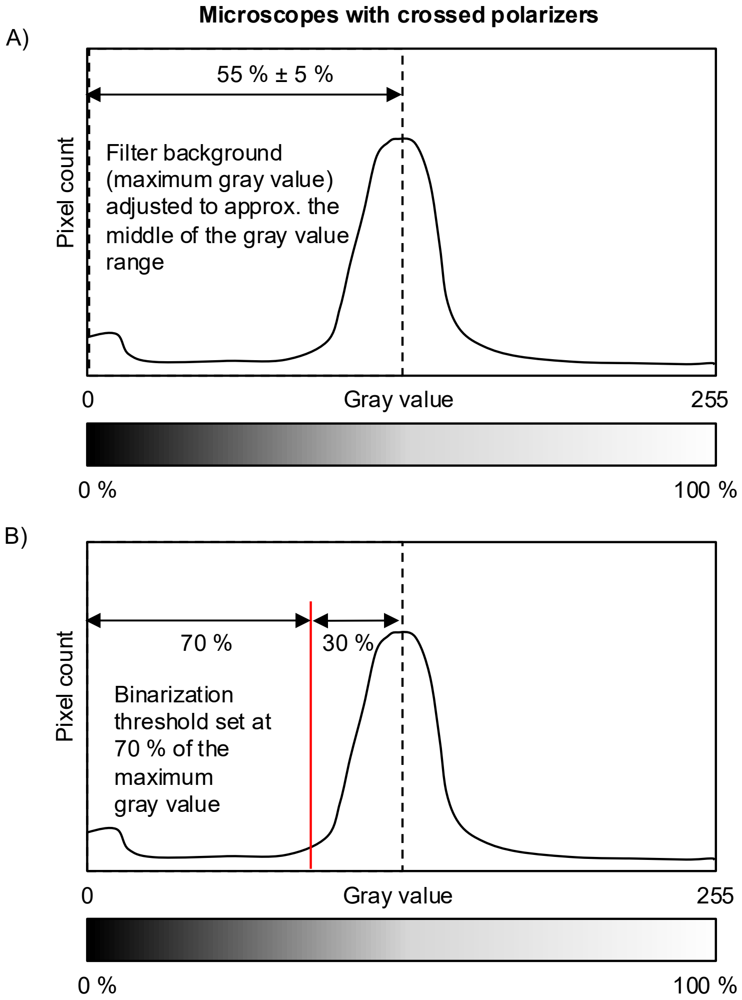


Figure 8-9: Adjustment of image brightness and binarization threshold in light microscopes with polarizers

8.2.2.2.2 Scanners without polarizers

Unlike an image with crossed polarizers, an image without polarizers includes relevant image information to the left and right of the histogram maximum, i.e. object structures that are darker and brighter than the filter background. For scanner systems, the image brightness is set so that the histogram maximum is at 50% of the total brightness range.

To detect particles, two binarization thresholds are set relative to the gray value maximum – one at 70% and another at 145% (see also Figure 8-10). Structures to the left of the bottom gray value threshold and to the right of the top gray value threshold are detected as particles. The middle range of the filter background is essentially “cut out”.

One disadvantage of this method in comparison to systems with crossed polarizers is that particles with light and dark portions are often split into two or more parts, since the area of transition from light to dark within the particle passes go through the brightness range of the filter background (which is cut out). The particles are then closed again using methods of image processing (dilation and erosion), as shown in Figure 8-31.

Note 1: When this method is used for connecting separate particles, adjacent but physically separate particles can potentially be connected, and their number and size may be detected inaccurately. Structures within a particle that would change the geometry and size under unfavorable conditions could also be connected.

Note 2: In the analysis of mesh filters, the directed illumination of scanners can cause reflections on the mesh filaments, which could be picked up as (small) bright particles. Suitable methods (“despeckle”) must be used to ensure that these interference signals/reflections are not counted in the particle results.

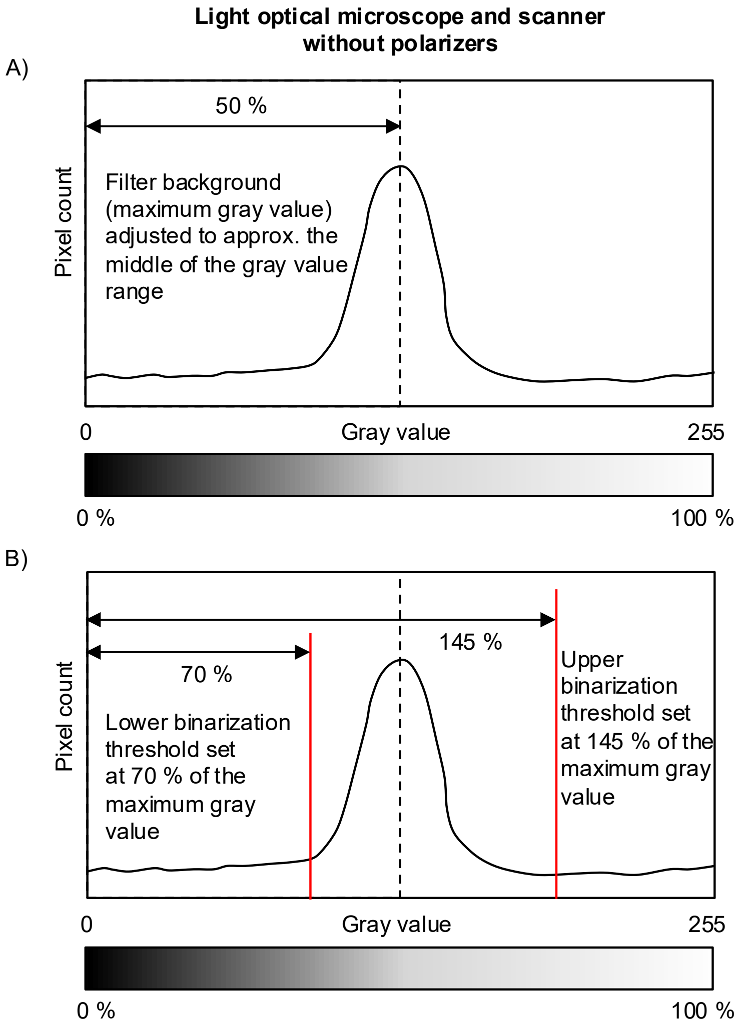


Figure 8-10: Adjustment of image brightness and binarization threshold in light-optical scanner systems without polarizers

8.2.2.3 Free light-optical analysis

The standard analysis described earlier was developed in order to detect dark and metallic particles ≥ 50 µm on white analysis filters as reliably and comparably as possible using automated light microscopes or scanners with incident illumination. This makes it possible to check a wide field of cleanliness requirements in the production of automotive components with no need for additional arrangements in the customer-supplier relationship.

If it is necessary to reliably detect particles < 50 µm or bright and thus low-contrast particles, however, then other parameters and sometimes other materials and equipment must be used, which then has to be agreed in the customer-supplier relationship. This also applies to direct inspection, i.e. the analysis of particles directly on the component surface.

So free light-optical analysis is far from a minor deviation from a standard analysis. On the contrary, it is adapted to suit the specific issue being analysed and therefore an optimized analysis. It usually detects more particles than a standard analysis – and that is the goal when detecting low-contrast particles. Keep this in mind when evaluating the results of cleanliness inspections, especially if the preceding analyses were performed with standard analysis methods only. Also note that the different methods of free analysis are not comparable, neither with one another nor with standard analysis.

Moreover, technical advancements have produced light-optical analysis methods that are not coupled to conventional light microscopes and have widened the application range of particle cleanliness inspections.

Note: If the methods of free light-optical analysis is used to inspect cleanliness limit values, the requirements for full-surface and qualified extraction also apply, and suitable analysis filtration with adequate retention capacity is required.

In line with free light-optical analysis, refer to the following application examples:

- Detection of particles < 50 µm (Chapter 8.2.2.3.1)
- Detection of low-contrast particles (Chapter 8.2.2.3.2)
- Additional light-optical analysis systems (Chapter 8.2.2.3.3)
- Direct inspection (Chapter 8.2.2.3.4)

8.2.2.3.1 Detection of particles < 50 µm

The optical resolution should be selected according to the smallest particle size to be detected (see Table 8-4). The particles must be separated on an analysis filter with an appropriate retention capacity and, at high magnifications and low depth sharpness, the filter must have a sufficiently smooth and even surface (see Figure 7-3).

In case of additional requirements, e.g. for the detection of low-contrast particles, the conventions and settings of light-optical standard analysis as per Chapter 8.2.2.2 can be used.

Note: The analysis of very fine particles as small as 5 µm or 15 µm can be a very involved and expensive process due to the necessary equipment and its cleanliness, the auxiliary materials and the corresponding environment (achievable blank values). The cost and effort can be significantly greater than what is required for a standard analysis.

8.2.2.3.2 Detection of low-contrast particles

Particle detection relies on a sufficient contrast between particles and (filter) background. In a light-optical standard analysis, this is achieved with a white filter background and dark particles or metal particles that are darkened using crossed polarizers.

The limit of what is detected as a particle and what belongs to the background is determined by a “binarization threshold”. As a result, bright or white particles cannot be detected or are only detected partially.

There are several approaches to the detection of low-contrast particles. They will be described here in brief but without going into detail as to the actual materials and equipment used or the adjustment and evaluation parameters.

One way to modify contrast properties is through the selection of lighting, as shown in the diagram in Figure 8-11:

- With incident illumination as it is typically used in light-optical analyses, it is only possible to detect dark particles (not bright ones) on a white analysis filter, as described earlier.

- With a grazing light illumination, i.e. illumination that is just about parallel to the (filter) surface, the background appears dark, and all particles that protrude above the surface appear bright, allowing them to be detected.

- With transmitted light illumination, as shown in the diagram, the filter appears light, and all particles appear dark, regardless of their brightness under incident illumination. However, this requires a transparent or translucent filter (including the support, if there is one). With sieve cloth filters, a non-transparent filter structure can also be calculated out of the image.

Note: These contrast characteristics are only described here conceptually. In case of particles with special optical properties (transparent, bright highlights, etc.) detectability may be limited.

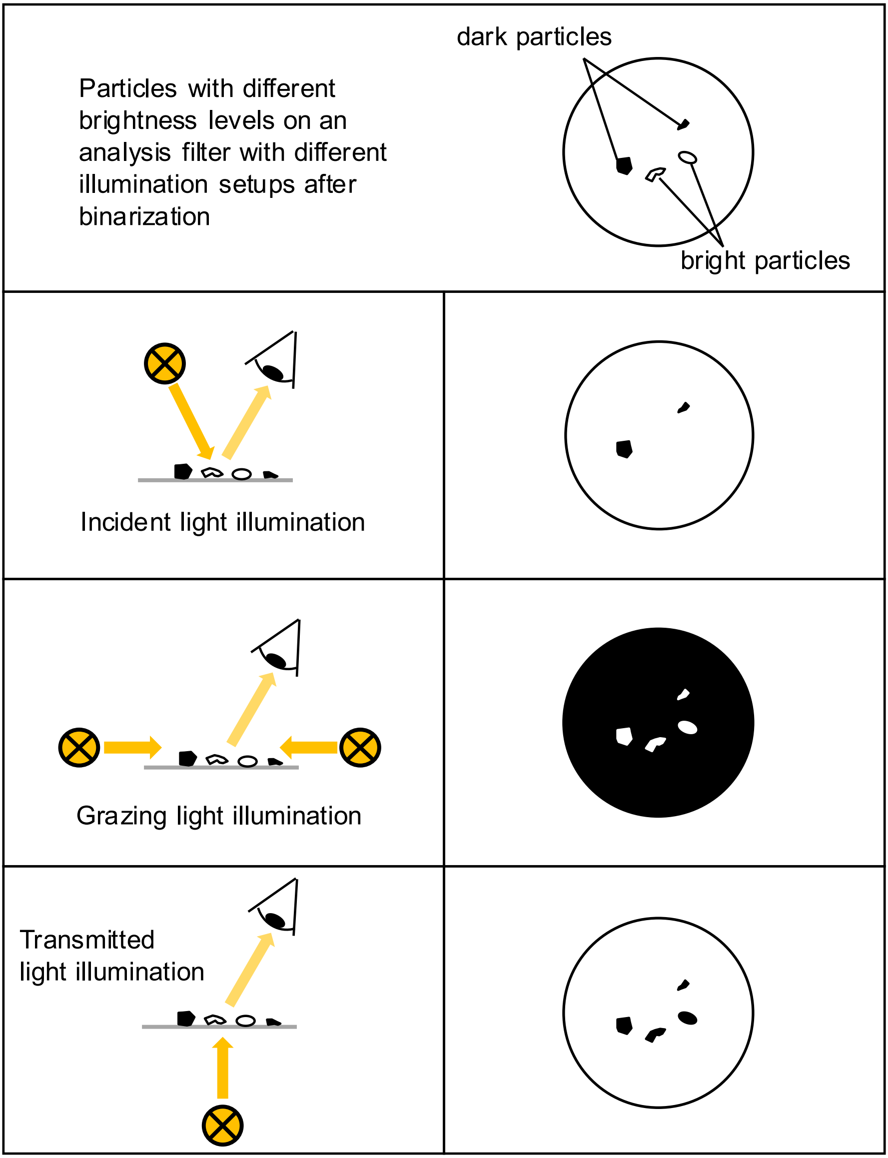


Figure 8-11: Contrast conditions under various types of lighting

Figure 8-12 shows additional approaches to detecting low-contrast particles:

- The threshold for binarization can be increased slightly, bringing it closer to the gray value of the (filter) background. This makes it possible to detect somewhat lighter particles as well. However, this increases the risk of parts of the background being identified as particles. Particles along the edges would then also be enlarged and measured larger or merge together.

- To detect light and dark particles in one analysis, special colored filters can be used in combination with specially adapted image acquisition and evaluation. This is mostly done using yellow analysis filters with a color and brightness value that enables the widest possible range of both light and dark particles to be detected without interfering with the values of the background.

- Another way to detect both dark and light particles is to make the analysis filter transparent. This can be done with cellulose nitrate filters using a suitable liquid. The transparent filter is analyzed twice: once with a white background as in standard analysis and a second time with a black background and an adapted evaluation for detecting light particles. When adding up the two analysis results to produce a total result, note that there are particles that are detected in both analyses and can thus be counted twice in the result.

- Another approach uses image processing methods that do not (only) rely on the brightness contrast between particles and their background. Instead, they use many different algorithms to tell if a structure stands out from the background and can be evaluated as a particle. Artificial intelligence methods can also help train such detection methods.

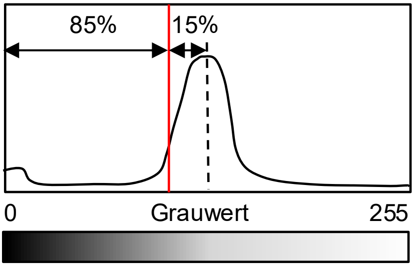
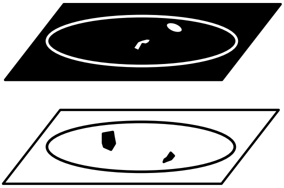
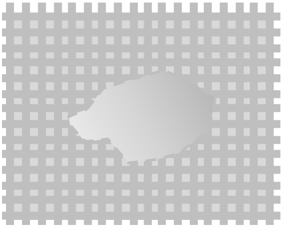
Implementation of a light optical standard analysis but with higher binarization threshold (e.g. 85% instead 70%	
Light microscopic detection of bright and dark particles on a yellow analysis filter with adapted parameter setup for image analysis	
Light microscopic detection of bright and dark particles on a transparent cellulose nitrate membrane one by one on a black background and a white background	
Application of extended image analysis algorithms or machine learning to detect low contrast particles on the filter background	

Figure 8-12: Approaches to detecting low-contrast particles

8.2.2.3.3 Other light-optical analysis systems

In addition to classical light microscopes and scanners, particle analysis can also be done using differently designed light-optical system. These are described conceptually in Figure 8-13:

- All types of camera systems, including smartphone cameras with a sufficient optical resolution, can be used to analyze filters, particle traps and particle stamps. To determine particle size distributions, the entire particle-loaded area (e.g. the effective filter surface) must be detected. If only the largest permissible particle is defined in a cleanliness specification, it is only necessary to ensure that this largest particle is detected.

- Portable probes with integrated camera and lighting functions or camera systems (e.g. cellphone camera,) including software or application for evaluating and visualizing the analysis results can be used to evaluate analysis surfaces (e.g. analysis filter, particle trap, particle stamp). One advantage of such measurement systems is that they can be used in locations that are not connected to a laboratory, e.g. directly in production.

- Flow-through cells in which the particles are separated directly from a liquid flow onto an analysis sieve and analyzed with integrated lighting and camera functions. After analysis, the sieves are backflushed in the device and are immediately available for the next analysis.

- By integrating filtration and analysis without time-consuming drying and handling of analysis filters, it is possible to perform many analyses in a short amount of time. This is especially true when such systems are coupled with automatic extraction of the inspected object. So these systems are not only suitable for checking cleanliness limit values but also for monitoring tasks.

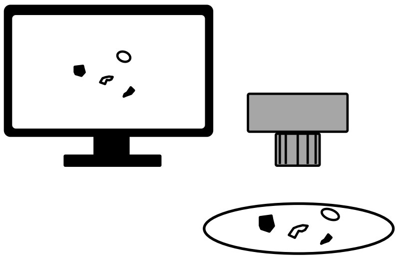
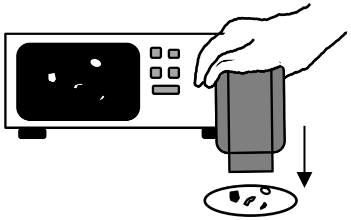
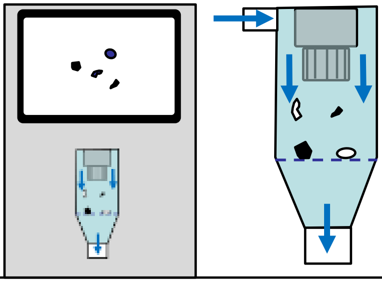
Camera systems	
Sensor head with camera and integrated illumination	
Flow cell with integrated filtration, camera and illumination	

Figure 8-13: other systems for light-optical analysis

8.2.2.3.4 Direct inspection

A direct inspection is done under ideal analysis conditions, since the particles can be detected directly on the inspected component surface. Since the extraction and filtration steps are not necessary, the sources of error associated with these steps are eliminated. What is more, the particles are located in their original spatial distribution on the component surface, which can sometimes provide additional insights into their origins. Direct component inspection can be done using light-optical microscopes if the components are not too large, or it can be done with flexible camera systems or probes. The relevant areas must be accessible to the optical system and the lighting, so poorly accessible component interiors cannot be inspected. The test surfaces must be even enough to be within the depth of field of the optical analysis system and must be constituted or able to be illuminated such that the targeted particles have a sufficient contrast with the component surface.

Note: If direct inspection is used to test cleanliness limit values, it is also subject to the requirements for a full-surface analysis of the entire surface areas of inspected objects under a cleanliness specification as well as the requirements for a sufficient optical resolution. The requirements for extraction and analysis filtration do not apply.

8.2.2.4 Follow-up check

Even when analysis filters have been prepared well and feature a uniform distribution of particles that are not too close to one another (see also Chapter 7.1.7 and Figure 7-5 and Figure 7-6 in the Annex,) the following unavoidable errors may occur due to optical/technical limitations:

- Particles are divided up if they have areas possessing the same degree of brightness as the filter background or if such an area forms due to an overlapping particle
- Particles are touching one another or overlapping and are measured as a coherent object
- Particles are mischaracterized

Note 1: Incorrect characterization may also occur when different types of particle overlap, e.g. if a small metallic shiny particle touches a fiber. In such cases, the particle is characterized as being a coherent metallic shiny object.

Due to this risk of error, the results of light-optical, automated cleanliness analyses should always be double-checked by a skilled operator. This follow-up check and subsequent correction process does not constitute a prohibited modification of analysis results. Rather, this is an important step for obtaining valid analysis results.

The operator is not only authorized but actually required to correct any results that come out wrong in the automatic analysis.

Certain editing options are available for the follow-up check, e.g.:

- Adapting/adjusting the evaluation area (see Chapter 8.2.2.4.2)
- Separating objects (see Chapter 8.2.2.4.3)

- Connecting/completing objects (see Chapter 8.2.2.4.4)
- Deleting objects (see Chapter 8.2.2.4.5)
- Modifying the typification of particles (see Chapter 8.2.2.4.6)

Note 2: After the manually performed correction steps on the evaluation image have been completed, the next step is typically a new automatic evaluation via image processing, which then produces corrected and improved analysis results.

In the follow-up check, it can be helpful to approach particles again and observe them, for example, at a higher magnification, under varying illumination or other contrast methods in order to verify that they have been correctly measured or typified. This is possible with light-optical microscopes. With flatbed scanners, it is generally not possible – the image can only be observed at a higher zoom level.

8.2.2.4.1 Effort required for follow-up check

In line with the follow-up check, the filter residue should be checked, since this is an indicator of the analyzability of the filter (see Chapter 7.1.7 and Figure 7-6 in the annex). The follow-up check is not intended to compensate for poor preparation. A follow-up check should therefore only be done for analysis filters that meet the requirements for analyzability with regard to filter residue and homogeneity of distribution.

Note 1: If an analysis result is needed for non-analyzable filters, a repreparation can be taken into consideration. Ideally, a new cleanliness inspection should be performed on another component with optimized analysis filtration (see Chapter 7.1.7).

VDA 19.1 does not dictate a fixed number of test steps to be included in the follow-up check. However, the following criteria should be considered when determining the number of follow-up check steps:

- As a basic requirement, the ten largest particles of each type class should be checked. If a lot of editing needs to be done during these checking steps, it is recommended to check some more particles.
- If there is a cleanliness specification with a limit value, it can be used as an additional reference point. For example, if no metallically shiny particles > 400 µm are permissible, then check up to this limit value to see if the finding “specification not met” may be incorrectly based on an overlapping of particles or an incorrect typification. The same goes for a specified number of particles in a given size class. If this

number is exceeded, make sure that it is not due to particles overlapping. If, however, after checking the ten largest particles, you find that they are consistently detected correctly, there is no need to keep checking up to the last particle.

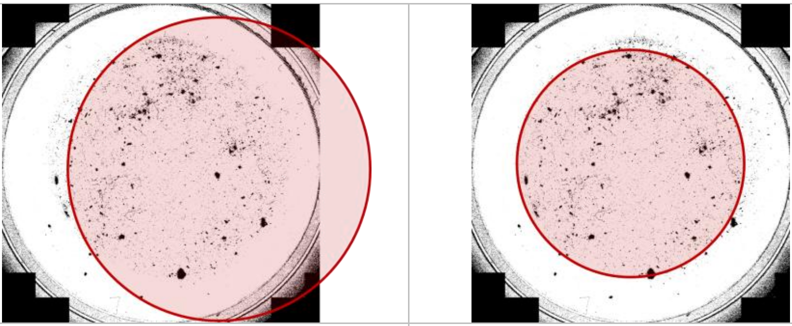
Note 2: When developing the steps of the follow-up check based on the cleanliness specification, it is not necessary to check the entire particle size distribution. The largest particles should be checked in particular. If, despite acceptable filter residue arrangement, there are still a lot of editing steps necessary, there is no need to go on editing countless particles. In this case, make a note in the test report indicating, for example, that you have checked up to a particle size of x µm and that the determined particle size distribution cannot be determined accurately enough due to agglomerates.

- If a cleanliness specification includes requirements for fibers, note that the actual largest fibers cannot be reliably determined by simply checking the largest fibers. This is due to the fact that fibers are often detected as smaller fiber fragments or may be low-contrast and therefore not reliably detectable with the conventions used for standard analysis. Reliable and complete detection of fibers can only be achieved by manually checking the entire filter surface and can require a lot of effort. For this reason, it should be discussed and agreed in the customer-supplier relationship to what extent this costly testing for fibers is actually necessary. In the absence of such an agreement, the largest fibers should be checked, and the test report should refer to the limited reliability of fiber detection in automatic analysis. In case of doubt, do not perform conformity assessment for fibers.

- If a lot of editing needs to be done during the follow-up check, this is usually associated with poor analyzability of the analysis filter. In this case, do not bother with too many editing steps, since investing a lot of time and effort in the follow-up check will not necessarily lead to reliable analysis results.

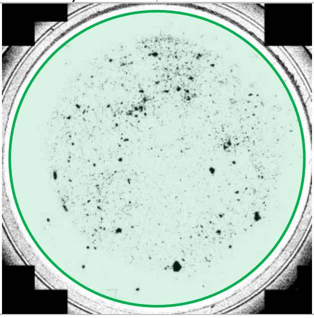
8.2.2.4.2 Adjusting/adapting the evaluation area

Depending on which measurement system is used, it may be necessary to adapt (by adjusting or expanding/shrinking) the evaluated area. Basically, (assuming this was not determined before the evaluation) it needs to be checked whether the entire relevant area of the analysis filter was detected (Figure 8-14).



Evaluation area adjusted (examined area within the red circle ≠ relevant area of the analysis filter)

Evaluation area selected too small (examined area within the red circle ≠ relevant area of the analysis filter)



Evaluation area correctly selected (examined area within the green circle ≠ relevant area of the analysis filter)

Figure 8-14: Analysis filter evaluation area

8.2.2.4.3 Separating objects

In automatic evaluation, it can happen that particles that are close together or on top of each other are detected as a particle agglomeration rather than individual particles. These particles would then need to be separated in the follow-up check. If it is not clear whether there are one or more particles, the following strategies can be used to help answer the question:

- Observe the particle in the magnified live image, and modify the focus
- In the live image, switch between bright field image and image with crossed polarizers
- Determine whether there are different materials involved by evaluating the surface structure or evaluating the shine

After the manual separation on the screen, the separated particles can then be accurately detected by the automatic image evaluation of the analysis system with regard to number, size and typification. Figure 8-15 shows an example of the separation of objects.

There are also limits of the (local) particle residue that can no longer be corrected or can no longer be corrected in full through follow-up inspection and correction.

The separation of objects is subject to the following limits:

- In case of overlapping particles, the object separation process cannot always determine the actual length of all overlapping particles, because part of one particle is covered by another particle and is not visually accessible.

- In case of agglomerates consisting of many particles, it is not always clear how many particles there are (see Figure 8-16).

In this case, it is recommended to omit the particle separation process and make a corresponding note in the test report to indicate the agglomerate.

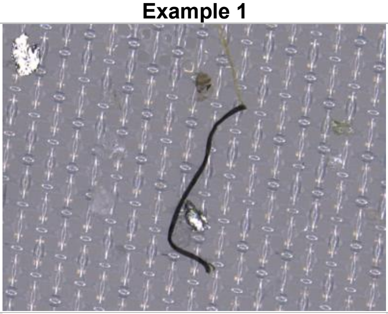
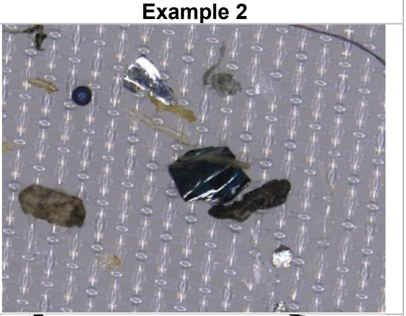
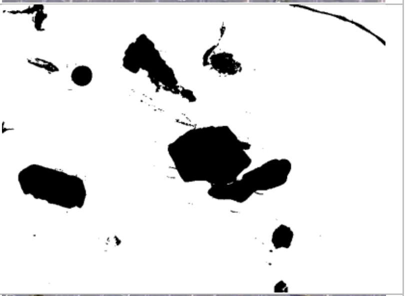
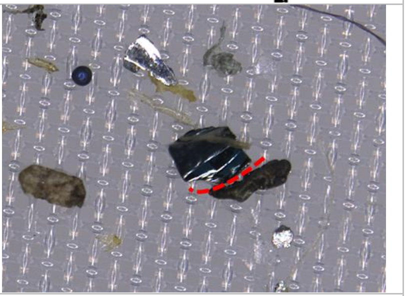
	Example 1	**Example 2**
1. Original image		
2. Binary image		
3. Original image with correction (red)		
Comment	The figure above shows a metal particle lying on a fiber. In evaluation, these two particles are detected as a single particle. Separating the two particles allows for editing in order to correct the result.	The figure above shows two particles touching. In evaluation, these two particles are detected as a single particle. Separating the two particles allows for editing in order to correct the result.

Figure 8-15: Separating overlapping particles

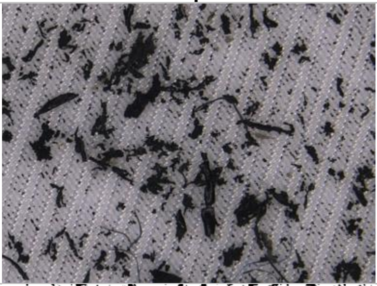
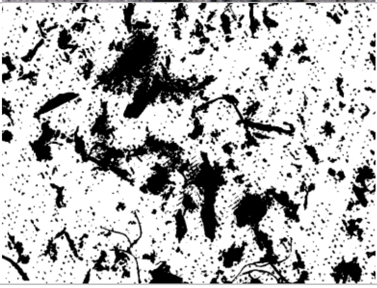
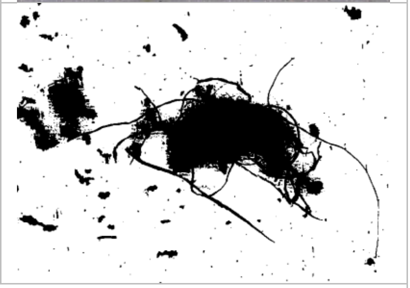
	Example 1	Example 2
1. Original image		
2. Binary image		
Comment	The figures above show particle agglomerates. In evaluation, these agglomerates are detected as a single particle. Since individual particles cannot be reliably detected within these agglomerates, no particle editing will be done.	

Figure 8-16: Borderline cases

Touching or overlapping fibers can be separated using the following procedures:

– If fibers are not relevant for the analysis result, the non-fiber-particles that are relevant for the result can be separated out without connecting the resulting fiber fragments. Please note that small fiber fragments could then potentially no longer be classified as fibers and therefore attributed to the non-fibers.

– If fibers are relevant for the analysis result and their actual lengths therefore need to be detected as accurately as possible, after the non-fiber-particle is separated out, the fiber fragments can then be additionally reconnected (see Figure 8-17).

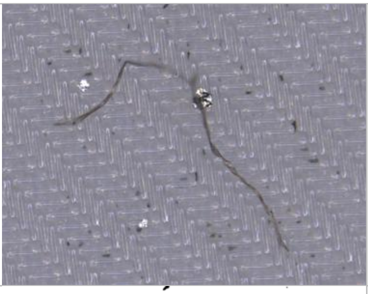
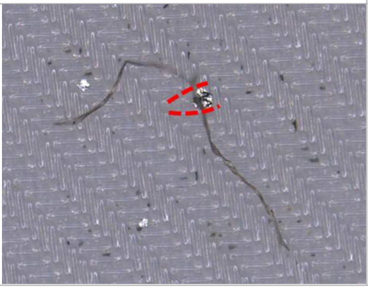
1. Original image		Option 1 (fibers not relevant): The figure shows a fiber with lighter sections and a metal particle touching the fiber.
2. Binary image		In the evaluation, the fiber is detected in segments, and the part of the fiber that has the particle touching it is detected as metallically shiny.
3. Original image with correction (red)		Separating the metal particle allows the result to be corrected. Option 2 (relevant for fibers): seeFigure 8-19

Figure 8-17: Separating touching particles (Option 1)

8.2.2.4.4 Connecting/completing objects

In automatic evaluation, it can happen that particles are not detected in their full length. This can occur, for example, with overlapping particles or brightness differences in the particle.

Such particles should then be connected or completed in the follow-up check. Figure 8-18 shows examples of objects being connected.

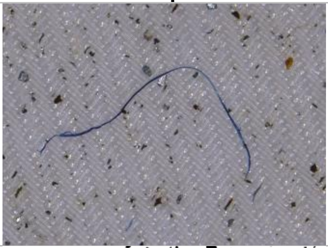
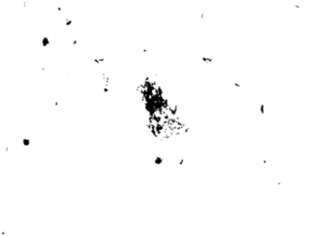
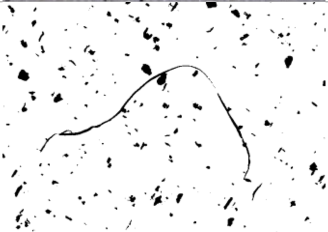
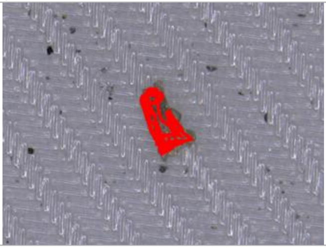
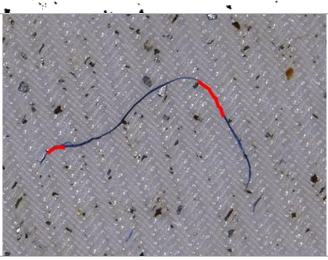
	Example 1	Example 2
1. Original image		
2. Binary image		
3. Original image with correction (red)		
Comment	• The figure shows a particle with low brightness contrasts with the filter background. • In the evaluation, the particle was not detected in full (but rather in fragments). • Connecting the fragments allows for the evaluation to be corrected.	• The figure shows a fiber that includes some lighter sections. • In the evaluation, the fiber was detected in multiple fragments. • Connecting the fragments allows for the evaluation to be corrected.

Figure 8-18: Connecting objects

Note 1: In sieve cloth filters, sometimes a particle may be half on and half under the filter and its length is therefore not correctly detected. This can occur with fibers, for example. If fibers are relevant, an attempt should be made to connect the fiber fragments so as to detect the fiber in its full length. If fibers are not relevant, then they will not necessarily require editing. Please note, however, that small fiber fragments may potentially be classified as “not metallically shiny”.

Note 2: If the follow-up check reveals many low-contrast particles that were only detected partially, such that they cannot be detected reasonably completely in the follow-up check, add a note to this effect in the test report. Low-contrast particles can be detected using an adapted procedure if necessary (see Chapter 8.2.2.3.2).

Figure 8-19 shows examples of objects being separated and connected in cases where fibers are relevant.

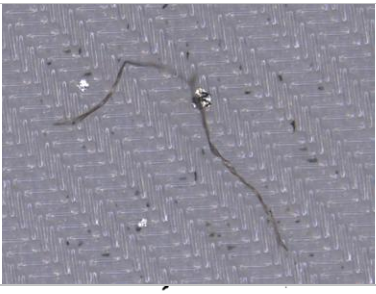
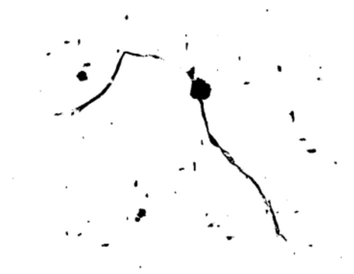
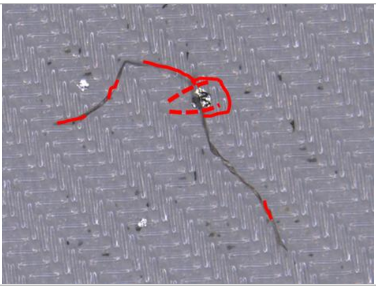
1. Original image		Option 2 (relevant for fibers): The figure shows a fiber with lighter sections and a metal particle touching the fiber.
2. Binary image		In the evaluation, the fiber is detected in segments, and the part of the fiber that has the particle touching it is detected as metallically shiny.
3. Original image with correction (red)		Separating the metal particle as well as connecting the fiber fragments allows the result to be corrected. When connecting fibers with a "bulge," note that this will increase the stretched length. This should be noted in the test report.

Figure 8-19: Separating (and connecting) objects (Option 2)

8.2.2.4.5 Deleting objects

Particles should not be deleted during the follow-up check except in justified exceptional cases (see Figure 8-20).

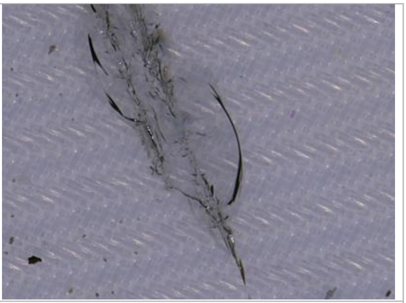
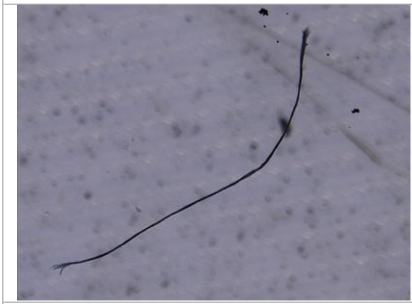
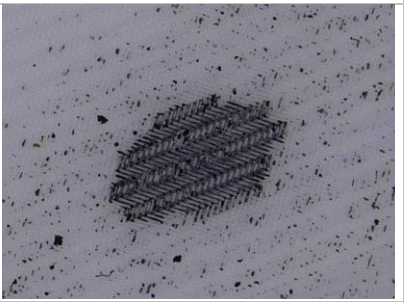
	
Plastic particle of a specific color that can be attributed to a utilized adaptor or similar	Scratch in cover glass
	
Fiber on cover glass	Film residue/stain

Figure 8-20: examples of particles that can be deleted in the follow-up check

The exceptional cases in which it is permissible to delete particles include the following:

Particle is located on the utilized cover glass and thus does not come from the cleanliness inspection. This can be determined based on the fact that the focus points are different for particles on the filter and on the cover glass.

Particles come from a utilized adapter, plug, etc. and can be attributed to these sources with high probability based on their color.

- Under certain circumstances, counting issues can be caused by filmy contamination such as grease or oil spots. If these spots cannot be removed through post-treatment of the filter (as the preferred option) or no information is available as to a suitable post-treatment fluid, the step can be taken to delete these objects or a note can be made in the test report to assist with the interpretation of the results, indicating that spot-like objects were detected as particles.

- Particles or contaminants, etc. underneath the filter

- If reusable cover glasses are used, they can potentially have scratches that can be detected as particles. If this occurs, the detected “scratch particle” can be deleted, provided that it can be ensured that no relevant particles would be deleted along with it or incorrectly detected.

Any deletion of particles must be documented in the test report.

8.2.2.4.6 Modifying the typification of particles

If particle typification is performed as part of automatic evaluation, for various reasons, particles may not always be attributed to the appropriate type class. The typification can then be modified in the follow-up check.

When dealing with a shiny particle, in order to determine if the shine is actually metallic and originates from a metal particle, it can be helpful to examine the bright image of the particle, compared to the image with crossed polarizers.

If the particle is shiny in the bright image and deep black in the image with crossed polarizers, in all likelihood, it is a metallic particle.

Figure 8-20 shows typical examples of metallic particles, and Figure 8-22 shows examples of non-metallic particles that are nonetheless shiny and look metallic in the bright image.

Note 1: Smaller adjacent metal particles or bright highlights on the analysis filter can also cause non-metallic particle or fibers to be classified as “metallically shiny”.

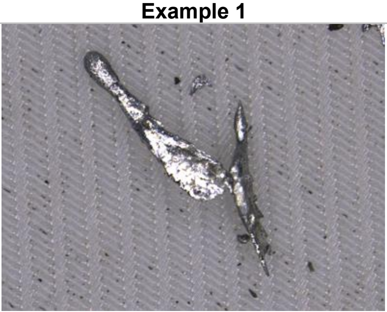
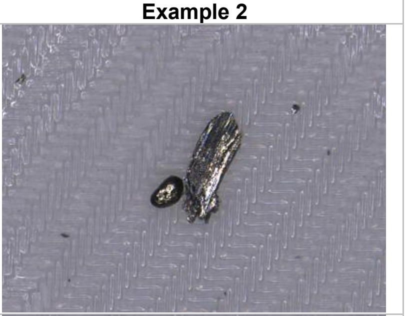
	Example 1	**Example 2**
Bright image		
Image with crossed polarizer		
Comment	The metallic particles above appear shiny in the bright image and are jet black in the image with crossed polarizers.	

Figure 8-21: Examples of metallic particles

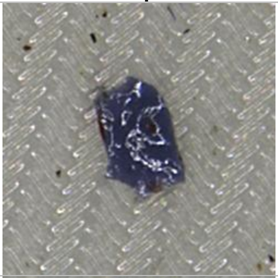
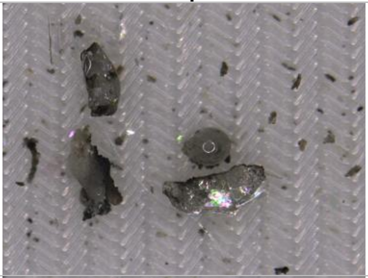
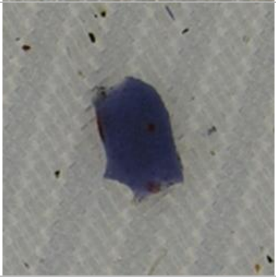
	Example 1	Example 2
Bright image		
Image with crossed polarizer		
Comment	The non-metallic particles above appear somewhat shiny with a metallic texture in the bright image but are not jet black in the image with crossed polarizers.	

Figure 8-22: Examples of non-metallic particles

To help determine whether a particle is actually metallic or not, the following questions can be asked:

- Is the presence of metallic particles likely? Does the tested component include anything metallic in its composition? Can the production process lead to the presence of metallic particles in some other way?
- Is this black fiberglass-reinforced plastic, which has a certain shine to it?
- Could sparkling particles (shiny mineral particles or similar) potentially be present?
- Could there be coating particles present which potentially contain small adhering metal particles?

- Is it possible that particles were incorrectly detected due to bright highlights on the mesh of a sieve cloth filter?

When a particle is classified based on metallic shine alone, both false negative and false positive typifications can occur. This can happen when metallic particles have no shine or when non-metallic particles do have a shine. Figure 8-23 and Figure 8-24 shows examples of particles that are difficult to classify based on their visual appearance. These are limitations that depend on the measurement concept and can only be corrected in the follow-up check under certain conditions.

Note 2: Where difficult-to-classify particles result from internal processes, it can sometime make sense to compile a particle catalog in order to help with particle classification (see also Chapter 8.4.1)

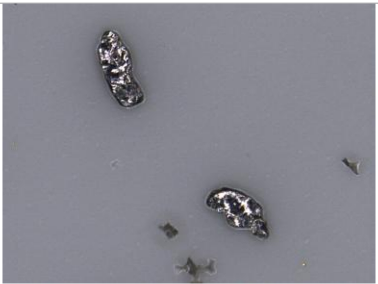
	#1 (Mica particles)	**#2 (SiC particles)**
Bright image		
Image with crossed polarizer		
Comment	The non-metallic particles above appear somewhat shiny in the bright image and are jet black in the image with crossed polarizers. They are therefore very likely to be identified as metallic in automatic analysis, but they are of mineral origin.	

Figure 8-23: Examples of <u>non</u>-metallic particles that appear to have a metallic shine

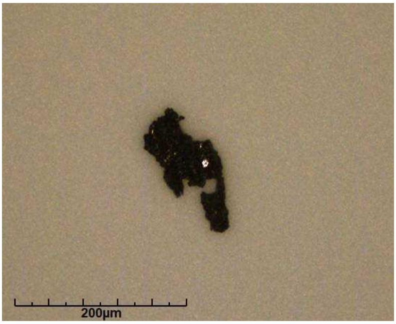
	(oxidized metal particles)	
Bright image		
Comment	The metallic particles above do not appear shiny in the bright image or have very few bright highlights. They are therefore not identified as metallic in automatic analysis	

Figure 8-24: Examples of metallic particles that do not appear to have a metallic shine

As described in Chapter 8.2.2.1.3, fibers are classified as fibers based on their length-width ratio. Shorter fibers that do not meet this criterion are automatically classified as particles. If this is not detected in the follow-up check, they can be identified as fibers by the operator even if they do not meet the fiber criterion.

Another cause of fibers being misidentified as particles is the presence of an adjacent particle which causes the fiber to appear wider than it is so that it no longer meets the fiber criterion.

Long, thin particles (often plastic) can also originate from processes, however, e.g. due to abrasion or flash. Such particles might meet the fiber criterion but they should not be classified as fibers. The fiber criterion is only intended to automatically pre-classify ubiquitous textile fibers, not to characterize process-related particles. This can also be hard to differentiate in the follow-up check.

Another tip for identification is that natural fibers often appear slightly “frayed” at the ends (see Figure 8-25 and Figure 8-26 for comparison).

Note 3: Hairs should not be categorized as “fibers,” because hairs are longer and thicker than fibers. If both fibers and hairs are irrelevant for a certain application, then the typification for a hair can be modified by “hiding” the hair. This change of typification should be documented in the test report, though.

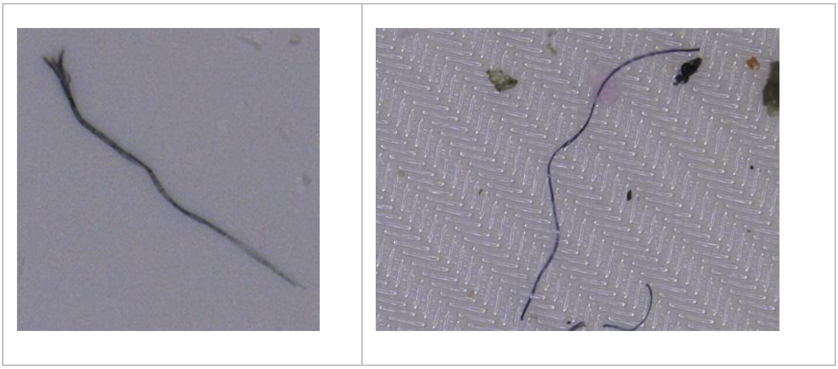


Figure 8-25: Examples of fibers

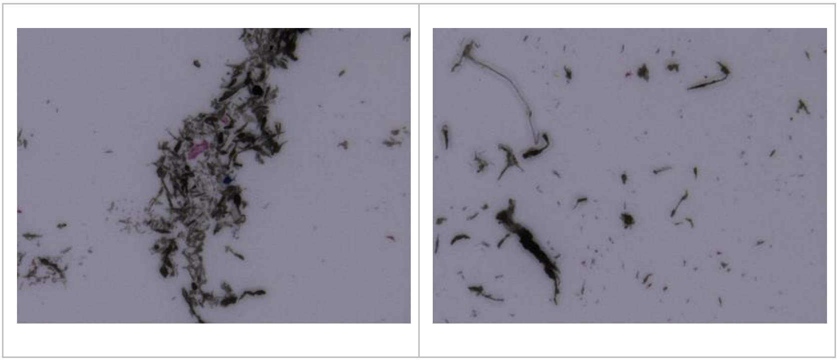


Figure 8-26: Examples of plastic debris

Where particle types cannot be clearly identified, a note must be made in the test report.

8.2.2.5 Material and equipment

The materials and equipment described here pertain to the standard analysis of analysis filters as described in Chapter 8.2.2.2.

In case of deviations from this procedure, e.g. line with free light-optical analysis, make corresponding adjustments. This also applies to the procedure described in Chapter 8.2.2.6.

1. **Light-optical system**, e.g. material microscope, zoom microscope, stereo microscope or flatbed scanner, featuring the components and characteristics described in the section “Detecting, measuring

and characterizing particles with the aid of light-optical standard analysis” in Chapter 8.2.2.1.
Light-optical systems should include options for checking results and making certain edits. Corrections made in the follow-up check must be documented and saved by the evaluation system, so that changes can be retraced later on.

2. **Reflected light illumination**: When performing automated analyses, it is essential that the entire image field is homogenously illuminated at all times irrespective of the degree of magnification selected. The degree of illumination must also remain constant during the entire procedure. In order to prevent the illumination from being altered inadvertently, it should be integrated into the light-optical analysis system. The lighting should be directed so as to avoid artifacts due to reflections, e.g. from the filaments of mesh filters.
   Any inhomogeneities occurring on illuminating the image fields can also be compensated for by the image processing system (shading correction with microscopes, white balance with flatbed scanners or other brightness balance, provided no information from the image that is relevant to the particle is altered).

3. **Sample holder:** With automated light-optical analysis, the analysis filter must be secured so that it does not slip out of place when the sampling table is moved. All areas of the analysis filter and particles contained on it must be within the range of the depth of field of the imaging lens. This is essential in order to obtain a good image and accurate analysis. To achieve this, the analysis filter can be tensioned, for example (like a drumhead) or pressed flat with a glass lid and analyzed and archived in a slide mount. With flatbed scanner systems, where the analysis filter is placed face down for the inspection, the filter must be secured with a glass plate. The clamping fixture or slide mount must be designed so that the analysis filter is in the focal plane of the scanner.

Note 1: If, for example, the analysis filter is inspected in a tensioning device without a lid, the environment must be sufficiently clean to ensure that the analysis filter is not contaminated by further particles or fibers in the specified size range during the analysis. The tensioning device may not cover any part of the effective filter surface.

Note 2: If the analysis filter is not clamped in place by a glass lid, there is a risk that large particles could shift when the sample table is moved and be counted twice, or fibers could be lost due to air currents.

Note 3: When removing a glass lid used to secure an analysis filter, it is probable that particles will adhere to the lid and be removed from the analysis filter. If the analysis filter is then subjected to an extended analysis, the use of a glass lid should either be avoided, the extended analysis be carried out beforehand. If necessary, the particles adhering to the lid be rinsed back onto the analysis filter with extreme care using a laboratory wash bottle. Note that particles can be transferred from all rinsed areas of the cover glass to the filter (appropriate level of cleanliness must be ensured beforehand).

Note 4: If an analysis filter that has translucent areas, such as the mesh of a coarser sieve cloth filter, is analyzed using a light-optical method, the sample holder should be of a similar color and brightness as the analysis filter itself. Otherwise there is a risk that dark translucent areas will be counted as particles. The easiest way to avoid this problem is to place a non-transparent filter membrane beneath the sieve cloth filter.

4. **Motorized positioning unit:** Positioning axes need to be extremely accurate for the following reasons:

    d) In an automated analysis, the effective filter surface has to be fully analyzed without it slipping out of place (see also Figure 8-28 and Figure 8-30 in the annex) and

    a) Particles have to be reliably positioned under the lens for a manual follow-up check (this is not possible with flatbed scanners because of their design).

    b) Positioning accuracy should be in the same range as the smallest particles requiring detection.

Note 5: In cases where the sampling table has a wider range of movement, filter mounts can be realized that hold several analysis filters, which can then be subsequently analyzed automatically in succession (the focal plane over horizontal distances must remain identical).

5. **Camera**: The number of pixels of the camera sensor (or of the line camera in the case of flatbed scanners) must be adapted to the optical resolution of the magnification lens. The 10-pixel criterion must be observed for the smallest particle size to be measured.
   The light sensitivity of the camera has a similar impact on the analysis image as the intensity of illumination. The camera must be operated with defined, fixable sensitivity settings. Automatic functions that correct the brightness must be disabled.

c) The cameras are typically linearly driven, i.e. without gamma correction (or gamma = 1).

6. **System control and image processing**: The programs used to control the system and analyze the images must possess the features described in the section "Detecting, measuring and characterizing particles with the aid of light-optical standard analysis" in Chapter 8.2.2.1.
   Additional software filters for processing the analysis images, such as for enhancing contrast or sharpen edges, may be useful for the viewer but should not be used in a light-optical standard analysis because their influence is often not known.

8.2.2.6 Procedure

The following procedure is to be adapted to the features of the respective light-optical analysis system.

1. Procure all resources required for the inspection

2. Secure the analysis filter in the sample holder. (Use forceps to carefully remove the analysis filter from the drying receptacle or transport container, e.g. Petri dish, and position it as required, making sure that no particles are lost.) If using a glass lid, check the condition of the lid, and clean it if necessary

   Note 1: Pre-conditioning is not required if analysis filters are inspected only by light-optical analysis and not gravimetry.

   Note 2: Unlike with gravimetry, filters for light-optical analysis do not have to be dried until weight constancy is attained. The cooling step in the desiccator is therefore not necessary. Although, in principle, wet or moist analysis filters can be inspected by light-optical analysis, there is a risk that reflections due to humidity or changes in the image may occur as the filter dries under the microscope.

3. Fix the sample holder onto sampling table (or place the sample holder in the flatbed scanner)

4. Set all parameters including illumination (if necessary, allow for warming-up time). Parameters can be set manually and/or (partially) automatically by the analysis system

5. Where appropriate, check that the sample and sampling table are

level

6. As required, focus the imaging lens on the surface of the analysis filter

   Note 3: In case of light-optical systems with a fixed focus, e.g. scanners, the filter holder must be designed so that the surface of the analysis filter is in the focus of the optical system. The same applies to particle traps and stamps.

7. Perform the automated analysis

8. Verify the analysis results as instructed in Chapter 8.2.2.4

9. Document the results

8.2.2.7 Set-up and testing of light-optical systems

For information on the set-up and testing of light-optical systems, refer to the annex (see A 8.2.2.).

8.2.2.8 Documentation

see Chapter 9 DOCUMENTATION as well as Chapter 12 CASE EXAMPLES

Annex 8.2.2 Light-optical analysis

A 8.2.2.1 Other (optional) particles widths measured using light-optical standard analysis

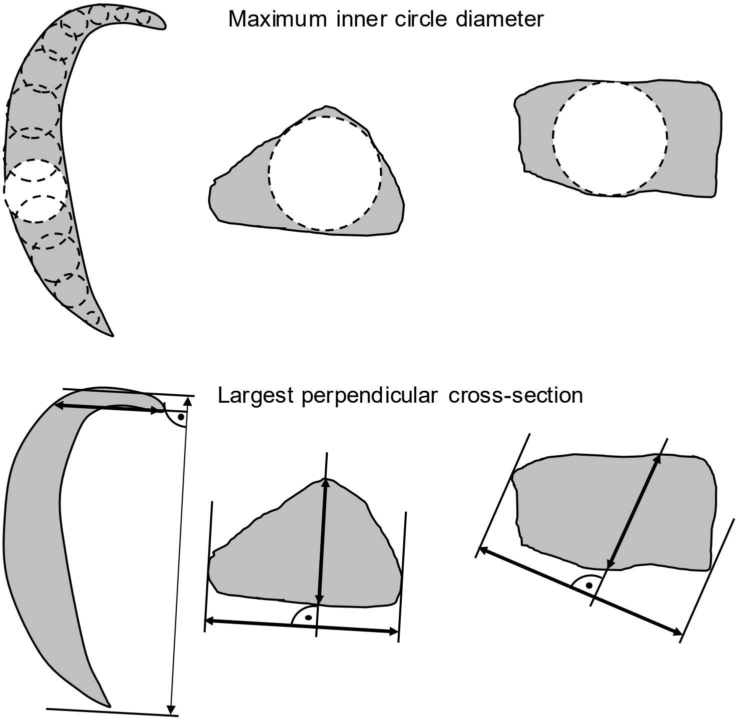


Figure 8-27: Other (optional) particles widths measured using light-optical standard analysis

Light-optical standard analysis can also be applied as an option to determine two other particle widths:

- The **maximum inner circle diameter**: this identifies the damaging potential of a particle, or the size of the narrowest channel it can still pass through.
- The **largest perpendicular cross-section**: this is determined perpendicular to the longest dimension measured and cannot be directly linked to the damaging potential of a specific particle size.

A 8.2.2.2 Terminology pertaining to analysis membranes

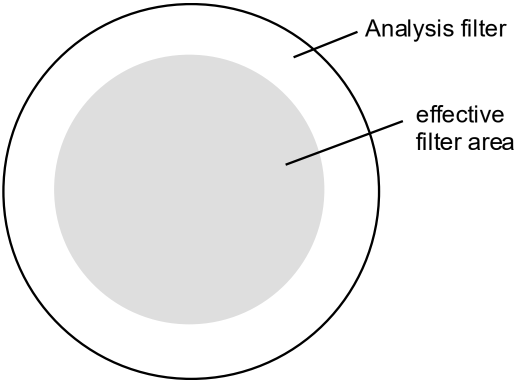


Figure 8-28: Terminology pertaining to analysis membranes (effective filter surface)

The effective filter surface is the area that is wetted during the filtration process and onto which particles are deposited.

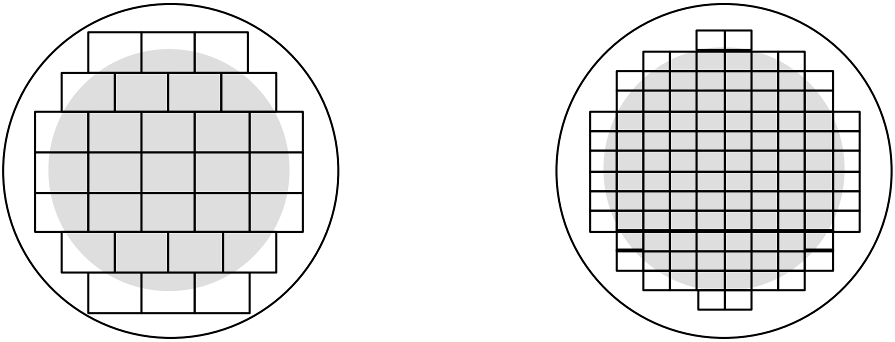


Figure 8-29: Measuring fields for evaluating the analysis filter

The locations of the measuring fields must be selected so as to enable the entire effective filter surface to be analyzed. The figure shows two examples of microscope grids: the one on the left for a lower degree of magnification and the one on the right for a higher degree of magnification. With scanners, a linear grid is formed due to the use of line cameras.

Note: Occasionally, due to errors in the filtration process or during handling, some particles may be deposited outside the effective filter surface. Where possible, these particles should also be included in the analysis.

A 8.2.2.3 Particle reconstruction

To avoid particles projecting over the edge of an image field from being excluded in the analysis, counted twice or only measured in part, the light-optical analysis system must be capable of reconstructing such “margin particles” to their full shape and of measuring and characterizing them on the basis of the complete particle. To achieve this, image analysis and the axis control unit need to cooperate with one another, the sampling table has to be accurate and motorized, and the translation axes of the sampling table and the camera must be finely adjustable. The following figure b) shows an example of “stitching,” a typical error that occurs if the translation axes of the camera and sampling table are not optimally aligned with one another, or if sizes are calibrated inaccurately – as compared to Figure a).

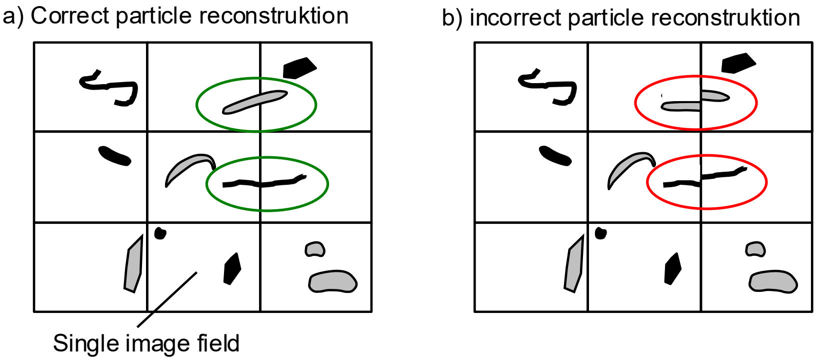


Figure 8-30: Particle reconstruction

A 8.2.2.4 Setting up and checking light-optical systems

When setting up a light-optical system, a specific unit of length in the sampling plane (object scale) is first assigned to the corresponding unit of length on the sample image (see also Figure 8-2). This setting process must be repeated for all the magnifications used to analyze the filter. Where systems have a zoom function, it must be possible to set the degrees of magnification to defined positions (e.g. lock the position at a certain magnification with a stereo microscopes).

The verification of correct magnification as the basis for accurate automated measurement of length and the orientation of the camera in relation to the sampling table as the basis for the right composition of image fields should be performed regularly using a particle standard with a known particle size distribution and permissible margin of deviation.

The “particle standards” used for this are generally glass substrates marked with defined geometric particle structures in full black/white contrast. The particle standards used must be calibrated, so that the length measurement can be traced.

If the inspection reveals excessive deviations, the first step should be to check for possible causes, rectify them as necessary and perform another inspection. If the deviations cannot be rectified in this way, the measurement system may need to be recalibrated. This can be done either by the operator or a service technician.

Note 1: VDA 19.1 does not specify any designated inspection cycles for measurement systems. A laboratory-specific specification of inspection cycles with a particle standard can be made based on a risk assessment that assessed the consequences of failure to successfully inspect the measurement system. For example, if a measurement system is only inspected every three months but measurement results are generated daily, then the number of analysis results that would have to be checked and possibly corrected will be relatively high. The customer would then have to be sent a corrected version. So it would make sense to schedule inspections more frequently. However, if a measurement system is less prone to going out of alignment due to its design and there has been corresponding experience with the measurement system, or if, for example, if the operator identifies the source of the maladjustment elsewhere (e.g. inspection of incorrectly combined particles in the follow-up check,) then it might be reasonable to check the measurement system less frequently.

The comparability of (different) light-optical analysis systems cannot be verified using particle standards with ideal geometries and contrasts only, because the aspects of brightness adjustment and binarization threshold cannot be considered with this type of verification. If it is necessary to assess the comparability of different measurement systems, this can be done by checking their precision – measure a real filter using different measurement systems (see also Table 10-1; e.g. by taking part in an interlaboratory trial).

Note 2: For a successful interlaboratory trial, the measurement conditions must be defined ahead of time (relevant particle size, settings to be used in case of deviations from standard analysis, number of follow-up checking steps to be performed, etc.), since these factors can significantly affect the measurement result.

A 8.2.2.5 Connecting separated particle structures by dilation and erosion

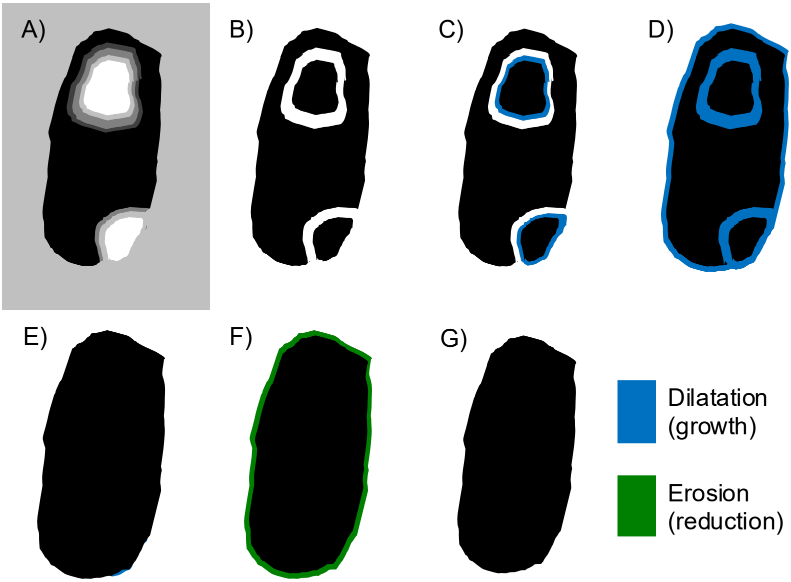


Figure 8-31: Connecting separated particle structures by dilation and erosion

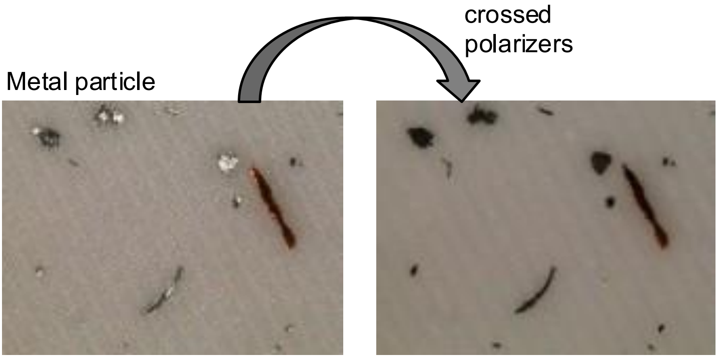
In Figure 8 11, Image A) shows an example particle with bright and dark points as well as gray value transitions. In Image B), the particle is split into three separate sections after binarization. In the first dilation step, the original light areas of the particle are first enlarged by one pixel, see Image C). In the second dilation step, all particle sections are enlarged by one pixel, and the separated structures merge, see Image D). Since the total contour of the particle has now been enlarged (see Image E),) an erosion step is performed (see Image F)) in which it is shrunk by one pixel. This produces the particle structure in Image G), which is then measured.

A 8.2.2.6 Functioning principle and limitations of light-optical analysis

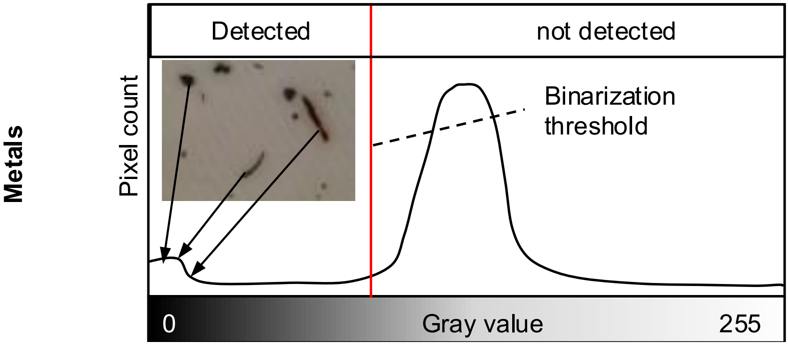
In the analysis of particles using light optical microscopes, only particle structures with values below the binarization threshold are detected (darker than the filter background).

Therefore, in order to detect metals, crossed polarizers are used; these extinguish shiny areas on particles and make the particles appear mostly darker. This generally enables effective detection (see Graph A).

Other materials, such as abrasives, plastics and textile fibers, usually have a broad spectrum of colors and levels of brightness. This makes it impossible to accurately detect bright particles or bright parts of particles (see Graphs B, C and D).



A)



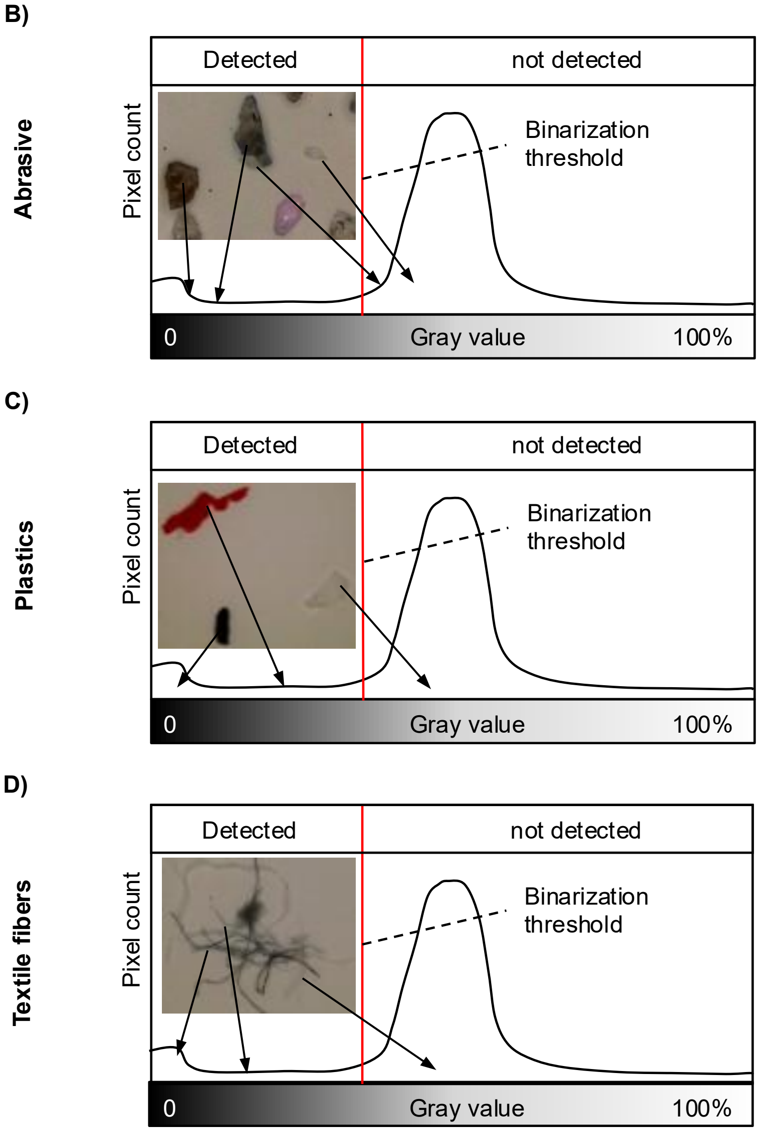


Figure 8-32: Limits of light-optical analysis

8.2.3 SEM/EDX analysis

8.2.3.1 Fundamentals and principle

SEM/EDX analysis is a combined analysis technique which counts and measures particles using a scanning electron microscope (SEM) and determines their material composition by means of energy-dispersive x-ray spectroscopy (EDX). Since this analysis method can be used to obtain element information, it is possible to perform a particle analysis that goes beyond just typification based on optical information as allowed by light-optical analysis (see also Figure 8-33).

Automated particle analysis is performed using scanning electron microscopes with the possibility of measurement in a variable vacuum or low vacuum. This is necessary in order to use carbon-based (i.e. non-conductive) analysis filters without a sputter coating (application of a thin, electrically conductive layer,) since the residual gas molecules remaining in the vacuum chamber could remove the charges generated by the electron beam.

The acceleration voltage is typically 20 kV but can also be set lower, depending on the system. The image must be recorded with a back-scattered electron detector, because this is the only type of detector that can depict the necessary material contrast. The recommendations on optical resolution are the same as for light-optical analysis (see Table 8-4).

SEM/EDX analyses can also be performed manually on individual particles or on preselected particles in the light microscope if the particle coordinates are transmitted to suitable SEM/EDX systems. At this point, we will only describe the automatic analysis of entire analysis filters (for more information, see Chapter 8.4.2).

The attribution of particles to certain material classes based on elemental composition, in conjunction with their size, makes it is possible to obtain additional information on the damage potential or origin of particles.

As with light-optical analysis, to ensure that individual critical particles are also detected, for particles ≥ 50 μm, a count is performed on the entire filter area. For particles < 50 μm, unlike in the light-optical analysis procedure, due to the sometimes very long measurement duration, a statistical evaluation (evaluation of a partial area) of the filter can be performed (two cycles completed for particle analysis). For recommendations on statistical evaluation, refer to Chapter 8.2.3.3.1.

As with light-optical, a well-prepared analysis filter on which the particles are arranged individually and without overlapping is needed as a prerequisite for accurate detection, measurement and analysis.

The imaging and detection of particles in SEM is based on material contrast, which is produced by the different detector intensity caused by the material-dependent number of backscattered electrons of the chemical elements in particles and (filter) background.

As with light-optical analysis, which image areas are detected as particles and which are part of the filter background is determined based on a threshold (binarization threshold). Due to the different contrast conditions in the SEM, the carbon-containing filter background appears dark, the particles with elements heavier than carbon appear light against it (the lighter, the heavier the elements in the particle, see Figure 8-34).

As in light-optical analysis, particle measurement is generally based on the $\text{Feret}_{\text{max}}$, while the utilized measurement systems can also output information on particle width.

Note 1: The selection of an appropriate magnification and corresponding resolution (pixel criterium) as a basis for reliable detection of particles is done as described for light-optical analysis in Table 8-4.

Attention: Due to the different detection mechanisms, which are based on different contrast, the analysis results obtained by light-optical and scanning electron microscopy are not comparable (no comparability of detected particles) (see also Figure 8-44 in the annex).

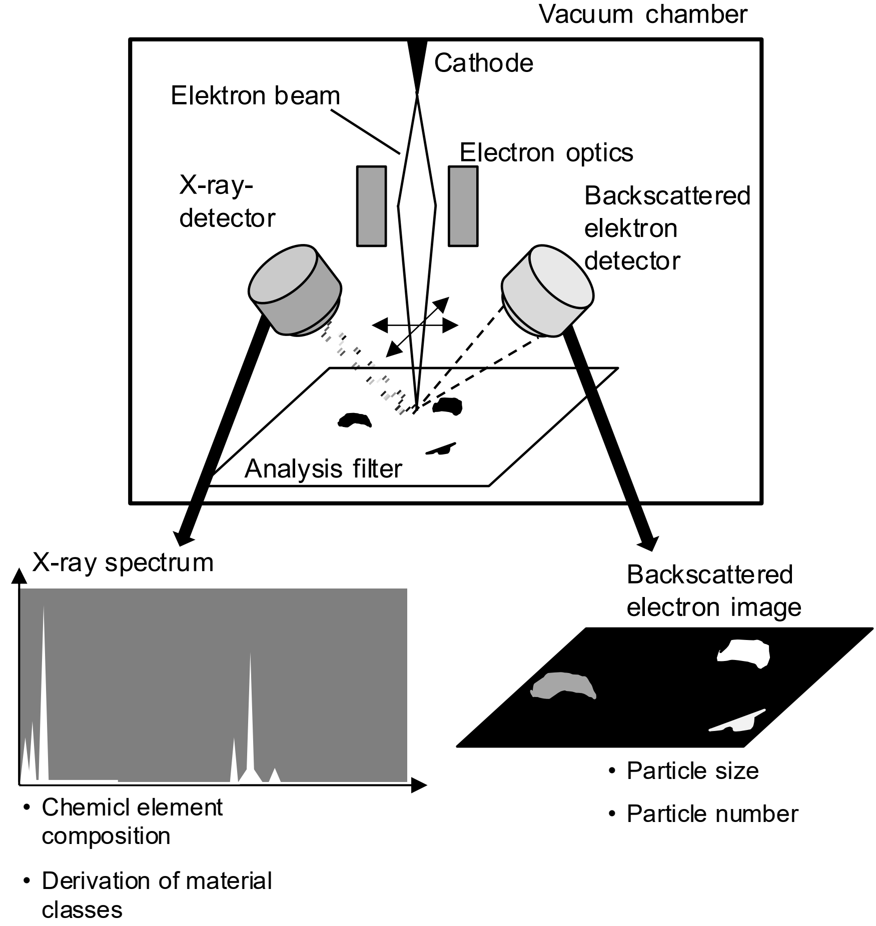


Figure 8-33: SEM/EDX schematic

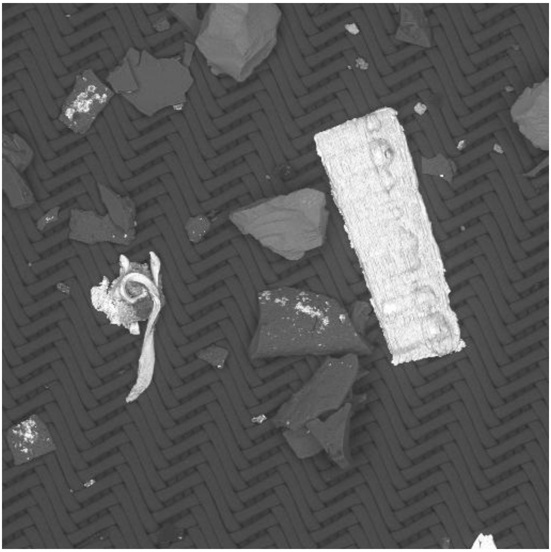


Figure 8-34: Sieve cloth filter (dark) with different particles (brighter than filter background)

In points in the image that are attributed to the particles, an EDX spectrum is recorded. The energetic location of the lines in the x-ray spectrum is characteristic of the chemical element that they originate from (Figure 8-35). The evaluation of the line spectrum also allows the elements to be quantified. Since spectral analysis can result in misinterpretations, e.g. due to line overlaps or noise and short measuring times, if possible, it is preset to only pick up the relevant elements to be included in the evaluation of the EDX spectra.

Note 2: One way of compensating for effects such as line overlapping or noise in the spectrum is “zero-element rules,” which can be used to set an element to “0” under a given condition (see A 8.2.3.2 optional zero-element rules).

Note 3: All the listed element symbols correspond to the symbols from the periodic table of elements.

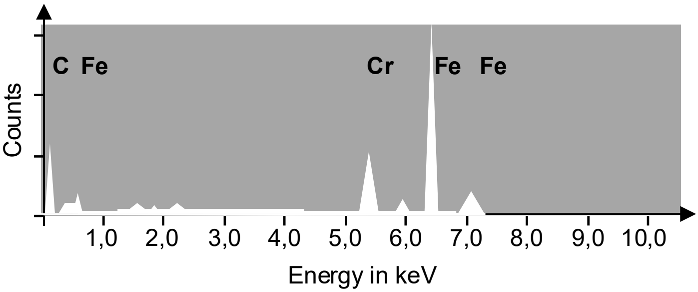
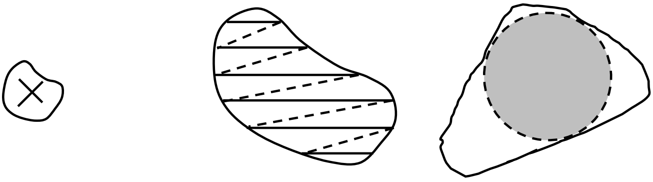


Figure 8-35: Example EDX-spectrum of a particle of high-alloyed steel

In order to characterize the elemental composition of an entire larger particle detected by material contrast as accurately as possible, in the EDX analysis, the electron beam should not stick to one point on the particle but cover as large an area of the particle as possible (Figure 8-36, right). With smaller particles, the portion of the signal from the filter background increases. So for smaller particles, an EDX punctual analysis can also be done (Figure 8-36, left).



EDS-spot-analysis: suitabe for small particles

Areal EDS-analysis (e.g. inner circle): suitable for larger particles

Figure 8-36: Area of a particle for the EDX analysis

The result of the EDX analysis enables us to draw conclusions as to the chemical composition (elemental composition) of the detected particles, and, based on a definition of certain elemental compositions, particles can additionally be assigned to material classes.

Listed below are the essential definition components that are needed in order to describe the material classes and categorize particles accordingly. These definition components must be available in the SEM/EDX system for automatic particle analysis:

- Prioritization option/sequence for material classes (sieve stack principle)

  Note: When particles are assigned to material classes, it is possible for some particles to be assigned to multiple material classes based on their elemental composition. For this reason, the classification is performed according to priority or the sieve stack principle. In the sieve stack principle, the “sieve order” represents the priority. Particles are thus assigned to the first applicable elemental composition of the “sieve stack”.

- Designation of the given element by the name, the element symbol or, if necessary, the atomic number

- Definition of elemental fractions with functions like greater than “>”, lesser than “<”, plus “+” and/or minus “-”

- Element with highest (E1) and second highest (E2) mass fraction

- “and”-linking of classification rules (both rules must be observed)

- “or”-linking of classification rules (one of the rules must be observed)

- Application of conditions under which elements are set to “0” (zero-element rules)

These definition components make it possible to define elements for the material classes with regard to their percentual proportion (mass fraction,) to link elements (that have to occur together) or exclude elements (that should not occur together,) to define rules that must apply together or alone as well as to establish an order in which the inspection should be performed, whether a certain elemental composition belongs in a certain material class. This ensures that particles with precisely defined compositions end up in the appropriate classes, as in the following example definition for high-alloyed steel and not in a “catch-all class”:

high-alloyed steel: Fe≥50 AND (Cr≥5 OR Mn≥5 OR Ni≥5)

Here, a particle is attributed to the material class “high-alloyed steel” (in accordance with the “sieve order”) if the detected iron content is over 50% and the content of chrome, manganese or nickel is additionally over 5%. This ensures that the aforementioned particles are sorted into the class “high-alloyed steel” and not into the material class “iron-rich,” which is defined only by a high iron content.

These definition options are needed for VDA 19.1 material classes, which are used in line with SEM/EDX standard analysis (see Table 8-6).

Due to the missing material contrast with the filter background, it is difficult or unreasonable to detect organic particles automatically. In addition, it is generally not possible to further classify particles due to the prevalence of carbon.

An exception to this is plastics, which, in addition to carbon, nitrogen and oxygen, also contain other elements such as halogenated plastics (chlorine in PVC, fluorine in PTFE).

For information on the measurement limits and framework conditions of an automatic SEM/EDX analysis, refer to the annex (see A 8.2.3.1).

For information on the system requirements, refer to Chapter 8.2.3.2.

The following section (see Chapter 8.2.3.2) describes SEM/EDX standard analysis. As with light-optical standard analysis, the goal of this type of analysis is comparability, and it should be given preference whenever it can reasonably be applied. Chapter 8.2.3.3 describes free SEM/EDX analysis for applications that need a procedure other than SEM/EDX standard analysis.

8.2.3.2 SEM/EDX standard analysis

Similarly to light-optical analysis, the following section describes an SEM/EDX standard analysis for particles of 50 µm and up on 5 µm PET or PA sieve cloth filters, designed to ensure comparable results when using different SEM/EDX systems or performing analyses in different laboratories.

The convention on SEM/EDX standard analysis comprises the following more detailed rules and, accordingly, these system prerequisites:

- Conventions for imaging:
    - defined REM-settings (acceleration voltage, e.g. 20 kV, low-vacuum/variables vacuum, resolution see Table 8-4)
    - A defined image adjustment is done for the analysis using two specified standard materials (polypropylene (PP) and aluminum,) which differ significantly from the gray value at the same REM settings. In the process, the brightness and contrast are adjusted, so that defined gray values result for these materials (PP: gray value

20 or 8% and aluminum: gray value 160 or 63%; see also histogram in Figure 8-37).

Note 1: Materials used for image adjustment do not have to be material standards with a specific chemical purity. The most homogenous material possible should be used. As a reference material for PP, for example, it is possible to use a PP adhesive tape (e.g. Tesafilm or Scotch tape).

- The brightness setting of the two standard materials then result in a gray value peak of the filter background. In the second step, a binarization threshold is set relative to the maximum of this gray value of the filter background at 1.5 times this value. All image structures that are brighter than this threshold are then detected as particles. Those structures that are darker are counted as part of the background (Figure 8-32).

Note 2: The relative threshold does not need to be determined individually for every measurement, but it should be determined once for the combination of measurement system and filter and, if used again, it should be confirmed by checking the gray value for the filter or verified by checking the particle detection.

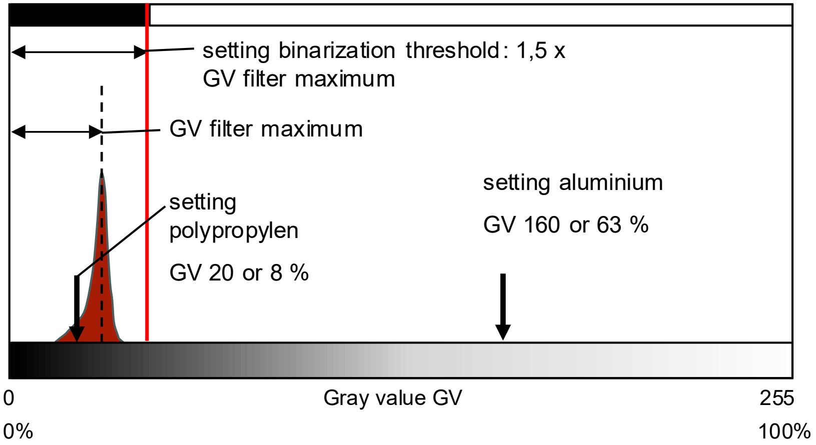


Figure 8-37: Convention on particle detection

- Convention for EDX analysis:

  - EDX settings: The quality of an EDX spectrum as a starting point for an elemental analysis is all the better, the more X-ray counts can be utilized when recording the spectrum. In order to obtain a sufficiently analyzable X-ray spectrum even with very short automatic particle analysis times (≈ 1 second/particle,) a goal of 5000 counts per particle is set. The minimum number of counts is 3000.

Note 3: The count is not determined the same way on all REM/EDX systems. Sometimes the counts are considered for the entire spectrum. Sometimes only the counts of relevant elements are considered. Where only counts of relevant elements are considered, the minimum counts of 3000 can be reduced to 1500.

- Consistent definition of material classes and the preselected elements to be considered for them in the EDX analysis.

- When using material classes, the possibility of excluding elements through “zero-element rules” when using material classes (removing oxygen in case of steels and, if necessary, removing noise due to short measurement duration or accounting for line overlaps).

Note 4: The way that particles with a low number of counts are handled varies depending on the SEM/EDX system. The total particle counts therefore cannot always be compared directly. Since the particle counts are typically relevant in specific material classes, no precise determination was made with regard to the output of particles with too few counts in the revision of VDA 19.1.

Note 5: Using an alternative filter material with additional elements, e.g. PTFE, can lead to problems with the attribution of particles to VDA 19.1 material classes, because they were conceived for carbon-based filters. They are not intended for the measurement of carbon, so as to exclude particle-size-dependent influences of the background (e.g. due to different proportions of measured carbon from the background). However, fluorine in PTFE, for example, is detected and not counted as background. In case of filters with higher oxygen contents, e.g. cellulose nitrate, the material contrast with abrasive materials such as corundum or SiC is comparably lower than for PET or PA. Accordingly, the possibility of the higher filter oxygen content affecting the EDX analysis result cannot be excluded.

As with light-optical analysis, the following prerequisites apply for a reasonable application of SEM/EDX standard analysis:

- SEM/EDX system with the corresponding prerequisites (see Chapter 8.2.3.5)

- Cleanliness specification that only covers particles ≥ 50 µm and uses the VDA 19.1 material classes

- carefully prepared analysis filter with particles distributed on it evenly and not too densely packed (see Chapter 7.1.7)

- well educated personnel, specially trained for this work

If necessary, it may be beneficial or necessary to deviate from the convention of the SEM/EDX standard analysis (see Chapter 8.2.3.3,) e.g.:

- if the cleanliness specification makes it necessary to analyze particles smaller than 50 µm,

- if the cleanliness specification covers material classes other than those of SEM/EDX standard analysis or the analysis of other materials than these and accordingly makes it necessary to select other or additional elements,

- if it is necessary or desirable to optimize the detection of certain particles through the use of contrast methods and/or parameter settings other than those of standard analysis.

These deviations must be approved and documented if they are used in the customer-supplier relationship to verify cleanliness specifications.

If a cleanliness specification meets the criteria of a SEM/EDX standard analysis and if there are no other agreements in the customer-supplier relationship, SEM/EDX standard analysis should be used~~.~~

For SEM/EDX standard analysis according to VDA 19.1, only the elements listed in Table 8-5, if detected, should be output standardized to 100% for classification. Other elements potentially detected can be excluded device-specifically by means of zero-rules, fixed preselection of an element list and/or peak deconvolution. As a result, for elements with a low proportion, standardizing the result to 100% can potentially produce higher proportions.

Table 8-5: elements to be output for standard analysis according to VDA 19.1

Elements to be considered
O, F, Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, Cr, Mn, Fe, Ni, Cu, Zn, Zr, Mo, Ag, Sn, Ba, Au, Pb

Note: If a SEM/EDX system offers the possibility of peak deconvolution, other elements, e.g. carbon, can also be included in the peak deconvolution. The elemental composition is only output for the elements indicated in Table 8-5.

When applying the SEM/EDX standard analysis, it is necessary to define the material classes listed in Table 8-6 as well as the zero-element rules listed in Table 8-7.

These are used, for example, in order to classify iron-containing particles by removing oxygen, which can be present in varying amounts due to corrosion processes and can make material classification difficult.

Table 8-6: VDA 19.1 Material classes

#	Name	Rule
1	Cr- layer	P<5 AND Fe≥10 AND E1=Cr AND (Fe+Cr)≥35 AND Zn<20 AND Cu<5 AND Mn<5 AND Ti<5
2	Zn- layer	P<5 AND Fe≥10 AND E1=Zn AND (Fe+Zn)≥35 AND Cr<20 AND Cu<5 AND Mn<5 AND Ti<5
3	Mn-phosphate	P≥5 AND Mn≥10 AND Fe≥5 AND (P+Fe+Mn) ≥50 AND Cl<5 AND K<5 AND Zn<5 AND Cu<5 AND Ti<5 AND Cr<5
4	Zn-phosphate	P≥5 AND Zn≥10 AND Fe≥5 AND Cr<2 AND (Fe+Zn+P)≥40 AND Cu<5 AND Mn<5 AND Ti<5
5	unalloyed steel	Fe≥75 AND Cr<1 AND Mn<1 AND Ni<0.5 AND Zn<5 AND Cu<5 AND Ti<3
6	low-alloy steel	Fe≥65 AND (Mn>0 OR Cr>0 OR Ni>0) AND (Cr+Mn+Ni)<5 AND Zn<5
7	high-alloy steel	Fe≥50 AND (Cr≥5 OR Mn≥5 OR Ni≥5)
8	medium-alloy steel	Fe≥65 AND (Mn<5 AND Cr<5 AND Ni<5) AND (Cr+Mn+Ni) ≥5 AND Zn<5
9	iron-rich	E1=Fe AND Fe≥30
10	Si-O	((E1=Si AND E2=O) OR (E1=O AND E2=Si)) AND O≥20 AND Ca<3 AND Mg<3 AND Al<3 AND K<3 AND Na<3
11	Si - (SiC - SiN)	E1=Si AND Al<3 AND Mg<3 AND Ca<3 AND O<20 AND K<3 AND Na<3
12	silicates (Si-XX-O)	(Si+Al+Ca+K+Na+Fe+O)≥60 AND Si≥10 AND K<50 AND Ca<50 AND Mg<5 AND Al<50 AND Na<50 AND O≥15
13	Si-Mg-O	(Si+Mg+O)≥60 AND Si≥10 AND Mg≥5 AND Mg<50 AND Ca<3 AND K<3 AND Al<3
14	Al-O	((E1=Al AND E2=O) OR (E1=O AND E2=Al)) AND Al<65 AND O≥25 AND Si<8 AND Ca<3 AND Mg<3 AND K<3 AND Cu<1 AND F<3
15	aluminum alloy	E1=Al AND Al≥30 AND O<30 AND Si<22 AND Cu<12 AND Mg<8 AND Na<3 AND (K+Ca)<5
16	zirconium-rich	E1=Zr AND Zr≥30
17	silicon-rich	Si≥25 AND Al<60
18	aluminum-rich	E1=Al AND Al≥30
19	brass	((E1=Cu AND E2=Zn) OR (E1=Zn AND E2=Cu)) AND Cu≥15 AND Zn≥15
20	copper-rich	E1=Cu AND Cu≥30
21	zinc-rich	E1=Zn AND Zn≥30
22	tin-rich	E1=Sn AND Sn≥30
23	titanium-rich	E1=Ti AND Ti≥30
24	nickel-rich	E1=Ni AND Ni≥30
25	silver-rich	E1=Ag AND Ag≥30
26	gold-rich	E1=Au AND Au≥30
27	fluorine-rich	E1=F AND F≥30
28	solid lubricants	(Mo+S+Pb+Ba)≥50
29	chlorine-rich	E1=Cl OR E2=Cl
30	P/S/Na/Mg/K/Ca	E1=P OR E2=P OR E1=S OR E2=S OR E1=Na OR E2=Na OR E1=Mg OR E2=Mg OR E1=K OR E2=K OR E1=Ca OR E2=Ca

E1: Element with highest mass fraction, E2: Element with second-highest mass fraction

Table 8-7: mandatory zero-element-rules

Zero-element rule (element “x” is set to “0”, if...)	
O	$(Al+Si)<15$
O	$O<15$
O	$Fe\geq30$

The optional zero-element rules listed in the annex (see Table 8-10) can be additionally applied to compensate for line overlaps (e.g. in measurement systems without peak deconvolution) or noise in the spectrum.

When assessing the damage potential of particles, certain material properties, e.g. hardness or conductive, may be relevant. These material properties are difficult to determine for individual particles and are thus not directly detectable in an SEM/EDX analysis.

Since particles can be attributed to a material class based on their elemental composition in an SEM/EDX standard analysis, these material classes can, in turn, be associated with material properties (see Table 8-8).

However, this association is uncertain, since particles cannot always be reliably placed in a material class based on their elemental composition alone. Moreover, very different material properties can sometimes occur within a single material class.

Example 1: For a large plastic particle with small, particles deposited on it, sometimes the detected material class is that of the deposited particles.

Example 2: A silicon particle is associated with a mineral class based on its elemental composition and thus categorized as “potentially hard”.

Example 3: Both metallic and potentially conductive titanium particles as well as non-metallic and non-conductive titanium dioxide particles are placed in the material class “titanium-rich”.

Table 8-8: Table with potential material properties and examples for the material class

#	Name	Examples/occurrence	potentially hard	potentially conductive
1	Cr- layer	Material coating system	V3	+
2	Zn- layer	Material coating system	V1	+
3	Mn-phosphate	Material coating system	V1	+
4	Zn-phosphate	Material coating system	V1	+
5	unalloyed steel	Material	V2	+
6	low-alloy steel	Material	V2	+
7	high-alloy steel	Material	V2	+
8	medium-alloy steel	Material	V2	+
9	iron-rich	General category	V2	+
10	Si-O	Processing materials, e.g. quartz, glass	V3	-
11	Si - (SiC - SiN)	Processing materials, e.g. grinding wheel materials	V3	-
12	silicates (Si-XX-O)	Processing materials, e.g. grinding wheel materials, mineral fibers (also as filler of plastics,) glass	V3	-
13	Si-Mg-O	Processing materials, e.g. talc (soft Si)	V3	-
14	Al-O	Processing materials, e.g. corundum, eloxal	V1	+
15	aluminum alloy	Material	V3	-
16	silicon-rich	General category	V1	+
17	aluminum-rich	General category	V2	-
18	zirconium-rich	Typically mineral: ceramic	V1	+
19	brass	Material	V1	+
20	copper-rich	Material	V1	+
21	zinc-rich	Material coating system, general category	V1	+
22	tin-rich	Material coating system	V2	+
23	titanium-rich	Titanium (metallic,) titanium oxide	V3	+
24	nickel-rich	Material coating system	V1	+
25	silver-rich	Material coating system, material in electronic components	V1	+
26	gold-rich	Material coating system, material in electronic components	V1	-
27	fluorine-rich	PTFE	V1	-
28	solid lubricants	Auxiliary material	V1	-
29	chlorine-rich	Salts, PVC	V1	-
30	P/S/Na/Mg/K/Ca	Salts, lime	V3	-

+: potentially conductive, -: non-conductive
V1: Vickers hardness < 400 HV, V2: Vickers hardness 400 – 1000 HV, V3: Vickers hardness > 1000 HV

The conductivity and hardness properties of particles can differ greatly from the materials in pure substance, e.g. due to oxidation, foreign substances on the surface of the particles, etc.

The attribution of the properties in Table 8-8 pertains to the pure substance. If multiple materials can be categorized in one material class (e.g. oxidized aluminum or corundum,) the indicated hardness refers to the worst-case.

Note 6: When evaluating conductivity, all metallic materials are classified as potentially electrically conductive. Material classes to which both metallic and non-metallic particles can be attributed in line with a worst-case scenario are classified as potentially conductive.

Note 7: When evaluating the hardness of the particles, categorization is based on the Vickers hardness value. The association with a material class is based on the Vickers hardness value of the hardest material in the material class.

8.2.3.3 Free SEM/EDX analysis

Under certain circumstances, the SEM/EDX standard analysis procedure described in Chapter 8.2.3.2 may only cover some of the information required in order to perform an SEM/EDX analysis.

In order to still obtain the necessary information, it may be necessary to adapt the procedure, e.g. as in the following cases:

- Detection of particles smaller than 50 µm
- Consideration of deviating particle materials and associated, potentially deviating elements
- Detection of organic particles

8.2.3.3.1 SEM/EDX analysis of particles < 50 µm

If, during an SEM/EDX REM/EDX analysis, particles < 50 µm also need to be considered, then the items listed in Table 8-9 need to be adapted as compared to standard analysis.

Table 8-9: Adapting the SEM/EDX standard analysis to detect smaller particles

	Particles ≥ 5 µm (up to 50 µm)	**Particles ≥ 50 µm (REM/EDX-standard analysis)**
utilized filter	1 µm polyamide (foamed)	5 µm PET or PA sieve cloth
utilized resolution (see Table 8-4)	≤ 1 µm/pxl	≤ 5 µm/pxl
Particle detection (image setting and threshold)	Figure 8-37	
evaluated area of the filter	statistical evaluation possible (min. 10%, see Figure 8-38)	full-surface (100%)
EDX analysis (see Figure 8-36)	single-point EDX analysis possible	areal EDX analysis

Note 1: When using the convention for the SEM/EDX standard analysis for smaller particles, a check should be done to see if interference artifacts are picked up (e.g. detection of portions of the filter background,) depending on the system. If so, the threshold should be adjusted.

For smaller particles, due to very long measurement times, it can sometimes make sense to perform a proportional evaluation and extrapolate to the whole area. Please note that a proportional evaluation that only includes a fraction over a defined measurement time, e.g. by only analyzing half the analysis filter)Figure 8-38, left,) can potentially produce results that are not representative of the whole.

To obtain a representative result, it is recommended to perform a proportional evaluation of each analysis field in which at least 10% of the area is detected (Figure 8-38, right). In order to be able to implement this proportional evaluation, the analysis filter must first have its particle density checked and a reasonable cut-off criterion must be determined (e.g. particle count/analysis field). Since a full-surface evaluation should be done for particles ≥ 50 µm, this must take place in two cycles (a full-surface cycle for particles from 50 µm and a proportional evaluation for particles < 50 µm).

Note 2: Using a 1 µm sieve cloth filter to detect particles of 5 µm and up is not recommended, since it retains fewer particles compared to a foamed filter membrane.

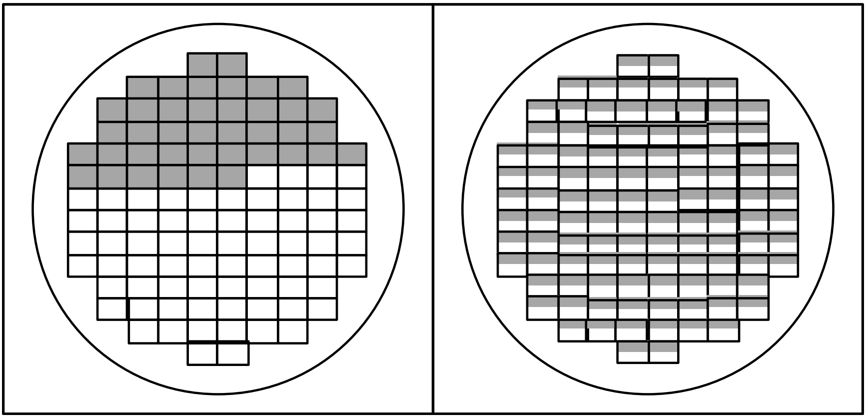


Figure 8-38: Possible statistical evaluation of particles < 50 µm

8.2.3.3.2 Treatment of deviating particle materials and/or elements

Different applications or product groups can sometimes contain materials that cannot be classified or cannot be meaningfully classified according to VDA 19.1 material classes. For this reason, before performing an SEM/EDX analysis, check if any materials or elements are needed which deviate from SEM/EDX standard analysis. If so, the material classes or elements should be adapted accordingly. When adapting the material classes or elements of the SEM/EDX standard analysis, note the following:

- When elements are added, peaks located close to other elements and peak overlaps as well as other effects like pile-up can result the peaks of a spectrum being attributed to an element less accurately. If system-specific zero-element rules are applied, it may be necessary to adapt them and check their effects on existing zero-element rules. If elements of the SEM/EDX are not relevant, they can be removed from the element selection. When doing so, check if the elements are needed for existing material class definitions and if another adjustment needs to be made.

- When adding to the existing material classes, check if the addition will have an effect on the classification of particles in the existing material classes (e.g. reasonable classification into the (sieve) order or priority) and if particles are correctly attributed to the added material class. If certain material classes are not needed, they can be left out.

Note: Products from the electronics or battery range can contain materials and elements that deviate from the SEM/EDX standard analysis. Sometimes it makes sense to create separate material classes for these.

8.2.3.3.3 Detection of organic particles

With the organic filter used in standard analysis, organic particles cannot be detected or cannot be detected reliably, because there is little or no material contrast with the filter background. If organic particles or other particles with a weak material contrast against the filter background need to be detected, the use of a metallic/metallicized filter can be considered. In this case, note that different image settings may potentially need to be selected. Since this will be an analysis of dark particles on a light background, the threshold must be adapted (contrast deviates from SEM/EDX standard analysis, see Figure 8-39).

Metal particle on organic background | **Organic particle on a silver membrane filter**

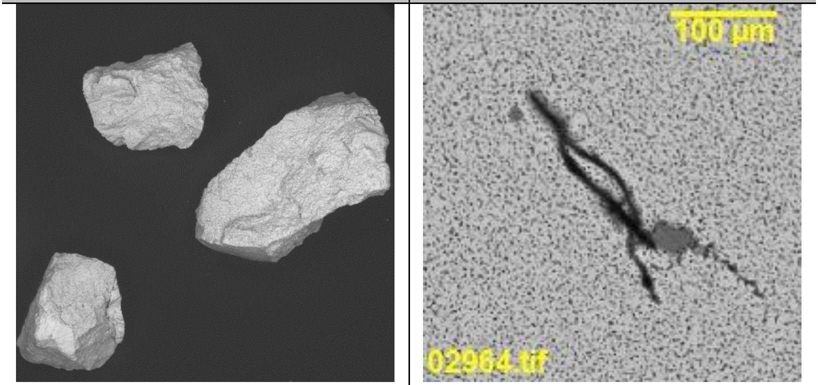


Figure 8-39: Contrast of particles against filter background

Note: Before using metal filters to detect organic particles, check their compatibility with regard to the blank value (filter condition on delivery).

8.2.3.4 Follow-up check for SEM/EDX

After an automatic evaluation, the results should be verified by double-checking the largest particles. An SEM/EDX analysis may need to be double-checked for the following reasons, among others:

1. Particle detection correction:
    - If particles overlap (e.g. superposed particles,) some particles may not be detected in full size, and the measurement may be too large or too small.
    - If material contrast is low, certain particles can potentially not be detected in full, their length being measured shorter than it is.
    - If material contrast is very high, certain particles can may be distorted by blooming, making them appear longer.
2. Correction of the attributed material class (since the correct material cannot always be reliably determined based on the elemental composition alone):
    - In case of a high carbon content, the result is skewed by failure to account for the element carbon.
    - In case of particle agglomerates, a mixed signal is produced.
    - Any organic, silicon-containing particles are detected as mineral particles with the classification rules.

The follow-up inspection can include the following steps:

- Separate particles (Figure 8-40, #4, #5)
- Connect particles (Figure 8-40, #1 - #2)
- Delete artifacts
- Repeat EDX analysis on a particle or particles after the separating or connecting them
- Reclassify particles/re-evaluated the measurement data

Note 1: If the filter has too much residue on it, as with light-optical systems, measurements may be inaccurate due to particles lying next to or on top of each other. Particles that are not detected from the material contrast (e.g. fibers) can also lead to problems if they touch other particles, causing them to be detected incompletely or as multiple fragments (see Figure 8-42).

Note 2: A reliable conformity test of specifications can only be done on the results after they have been corrected in the follow-up check.

Figure 8-40 shows examples of separating and connecting particles. If particles are separated, a new EDX analysis should be done for both of the separated particles, because the original spectrum could be a mixed spectrum of the two individual particles combined. If particles are connected, check if a new EDX analysis is necessary.

In the follow-up check, also check if particles classified as mineral really are mineral particles. Since particles are only classified based on their elemental composition, it can happen, for example, that plastic particles with mineral particles deposited on them or silicon particles are detected as mineral particles. Their damage potential is not comparable, however.

The first step can be to check if there is any reason to doubt the classification based on the visual appearance (with appropriate magnification if necessary). If there is, then the next step should be to perform a new EDX analysis to confirm the result. If the analysis shows that the particle is very likely not mineral, it can be manually placed in the material class “Other”.

It should also be noted in the test report that, based on their visual appearance, particles were attributed to a material class which was not identified based on the determined elemental composition. Figure 8-41 shows some helpful example images of various mineral particles, some of which are identifiable based on their characteristic surface structure.

Note 3: The material class Si-Mg-O (e.g. talc) is mineral but cannot be categorized as hard.

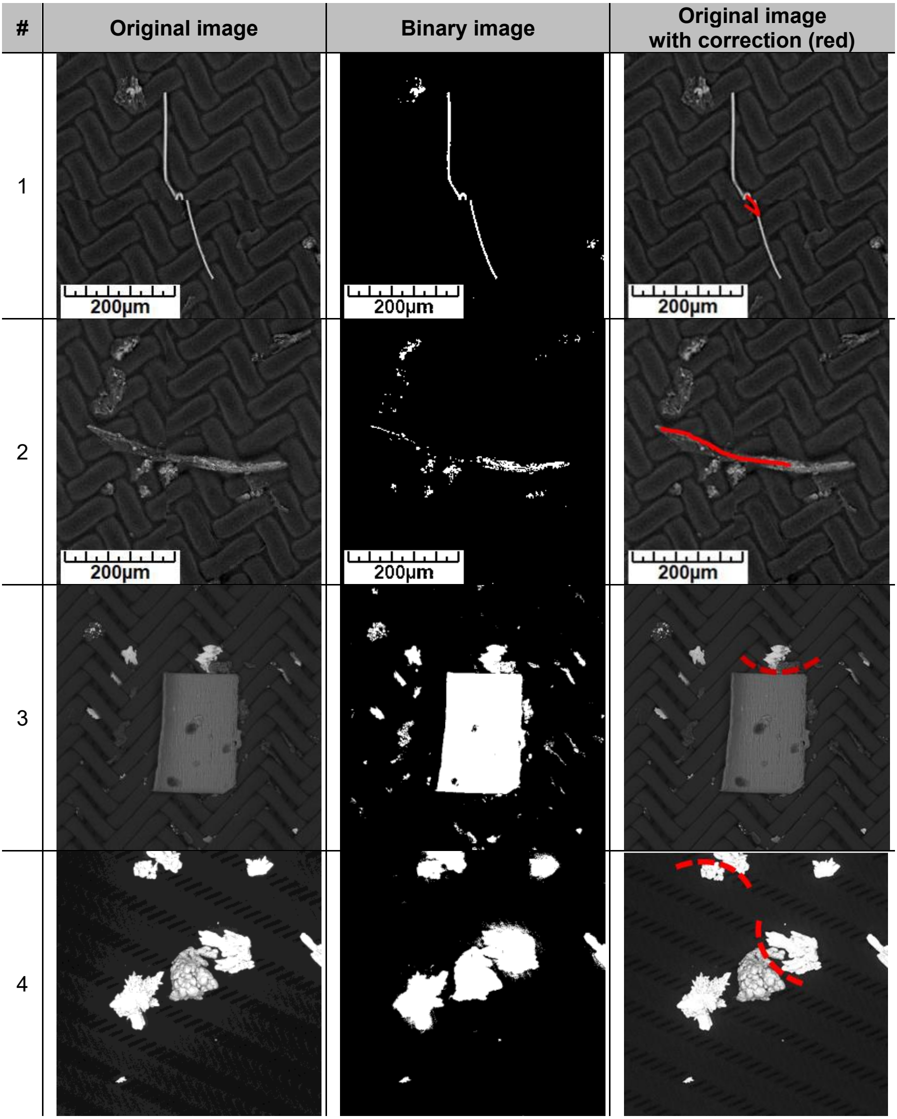
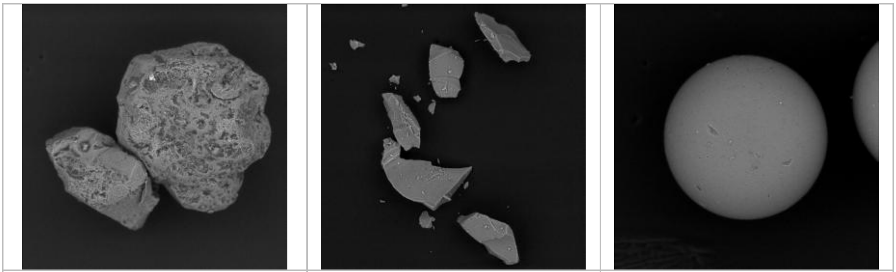
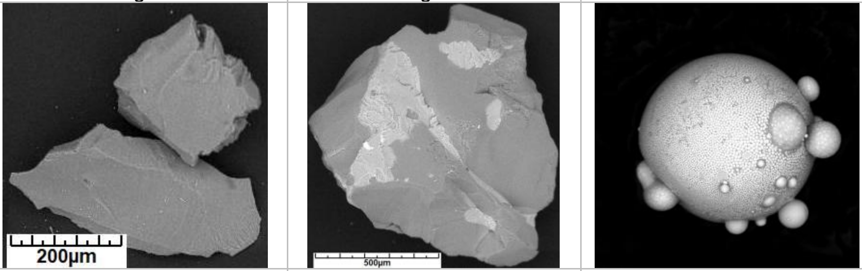


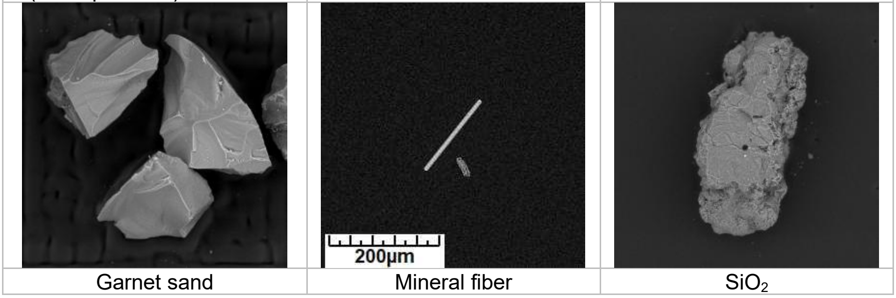
Figure 8-40: Examples of particles edited in the follow-up check



Casting sand | Glass granulate | Glass beads



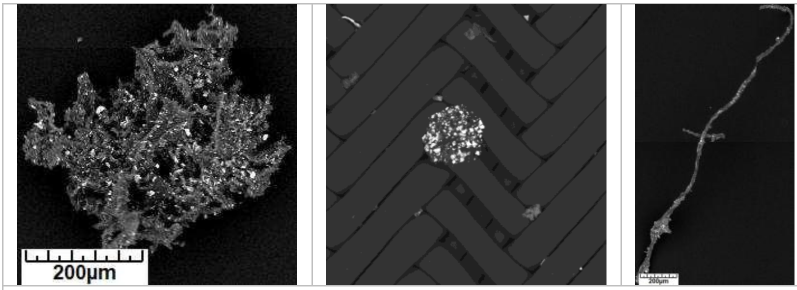
(Semi-precious) corundum | SiC | Ceramic beads



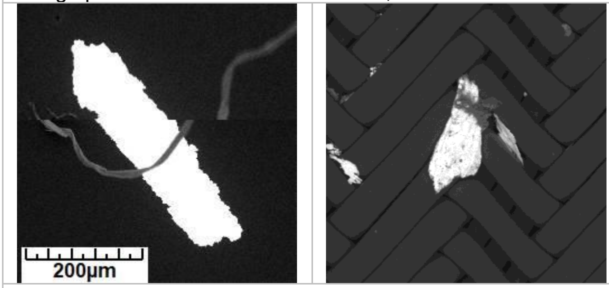
Garnet sand | Mineral fiber | SiO_2

Figure 8-41: Examples of mineral particles

Figure 8-42 shows additional examples of particles that can come up in the follow-up check and provides a recommendation for action.



Organic particles or fibers with smaller particles deposited on them:
assign particles to material class “other,” and note event in test report



Metallic particles with fibers or organic particles on them:
connect separated particle areas

Figure 8-42: Examples of deposited particles

Note 4: If particles are mostly covered by other particles or fibers, preventing reliable detection, this should be noted in the test report.

8.2.3.5 Material and equipment

The data indicated under materials and equipment refers to the SEM/EDX standard analysis. If a free SEM/EDX analysis is performed, there may be deviations from the following data.

- SEM/EDX system with:
    - option for variable vacuum/low vacuum
    - automated x-y table
    - F fixture for one or more analysis filters as well as aluminum and PP adhesive tapes for adjusting brightness and contrast and, if necessary, suitable material (e.g. copper, cobalt, etc.) for checking the EDX (Figure 8-43)

- back-scattered electron detector (BSE) to record images
- if possible, constant beam current
- Software with option:
- for evaluating images to determine particle size distribution
- for saving the elements to be included
- for saving (VDA 19.1) material classes and, if necessary, zero-element-rules
- for double-checking the results
- holder for supporting and securing one or more analysis filters
- X-ray detector with evaluation system (EDX system) for elemental analysis
- As needed: particle-fixative for binding the particles to the analysis filter membrane and dissipating charges (if particles become charged, there may be imaging errors, or particles could "jump" due to electrostatic forces and either get lost or be detected twice in the analysis)

Note 1: If particle-fixative will be used, check for compatibility with the filter.

Note 2: When using particle-fixative in an analysis of small particles (e.g. particle of 5 µm and up,) check whether the fixative interferes with the detection of the particles.

Note 3: For instructions on evaluating open-mesh filters, refer to Annex A 8.2.3.3.

Note 4: The requirements for resolving power, possibility of image composition and particle reconstruction as well as the particle dimensions to be measured are subject to the same specifications as for light-optical analysis systems.

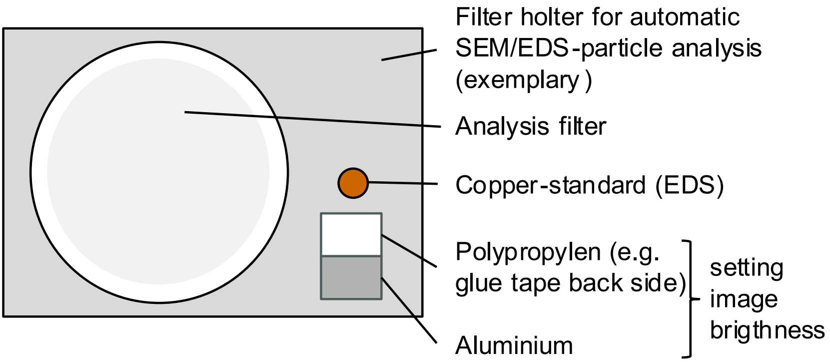


Figure 8-43: Filter holder REM/EDX

8.2.3.6 Procedure

The following procedure pertains to the SEM/EDX standard analysis and may have to be adapted to the respective SEM/EDX system. For free SEM/EDX analysis, a different procedure may be required under certain circumstances.

1. If necessary: fix the particles on the analysis filter using suitable particle-fixative (gravimetric analysis must be done before using particle-fixative)

2. Insert the analysis filter into the SEM/EDX system using a suitable filter holder, and pump out the sample chamber until a stable operating pressure is reached

3. Adjust the height of the sample table (z-position) so that the analysis filter is located at the appropriate working distance from the system (optimal distance for EDX analysis)

4. Adjust the acceleration voltage of the SEM (typically 20 kV for elemental analysis)

5. If relevant: Warm up the cathode for stabilizing the beam current

6. Set the particle detection parameters for the SEM/EDX standard analysis or other appropriate parameters:

    d) Select a suitable magnification

    a) If necessary, select a suitable overlap range for the analysis fields

    b) Set the brightness and contrast (used at same working distance as in following test run) as well as the threshold

    c) If necessary, set the basis (length, width, etc.) on which particles should be measured and what size channels should be used

Note 1: For “free SEM/EDX analysis,” the brightness and contrast of the SE image are adjusted so that all relevant elements are detected and the image processing dynamic range is well utilized.

7. Set the EDX analysis parameters for the SEM/EDX standard analysis or other appropriate parameters:

    a) Selection of elements to be considered (see Table 8-5)

    b) Saving material definitions and zero-element rules (see Table 8-6 and Table 8-7)

    c) Set the necessary target counts over measuring time or total counts (target counts 5000)

    d) If necessary, set where on the particle the SEM/EDX analysis should be done

8. Start the automated analysis

9. Verify the results in the follow-up check after the evaluation is completed

10. Document the results

Note 2: In an SEM/EDX evaluation, the individual images are typically combined into a total overview image of the filter (stitching). In the process, particles that extend past an image field are combined and then correctly detected and measured. In some measurement systems, this stitching involves working with an image field overlap.

8.2.3.7 Set-up and testing of SEM/EDX systems

For information on the set-up and testing of SEM/EDX systems, refer to the annex (see A 8.2.3.4).

8.2.3.8 Documentation

see Chapter 9 DOCUMENTATION

Annex 8.2.3 SEM/EDX

A 8.2.3.1 Conditions/limits of automatic SEM/EDX analysis

- Due to the threshold that is used, the number and size of particles in the “chlorine-rich” and “fluorine-rich” material classes are not reliably detected.

- The completed EDX analysis was not performed under the framework conditions (plane, polished, clean sample; adequate measurement duration, etc.,) that a quantitative EDX analysis should ideally be performed under. It is therefore not possible to detach the smallest alloy components. The aforementioned conditions can give rise to effects that have an influence on the accuracy of the measurement result.

- In EDX analysis, the limited energy resolution of the EDX detectors can sometimes lead to signal overlaps.

- Particles are attributed to a material class according to certain classification rules based solely on the elemental composition of the analyzed particles. If materials are analyzed that are not covered by the classification rules, they might be categorized as belonging to the material class “Other” or placed in the wrong material class.

- Particles are attributed to a material class based solely on the elemental composition. This procedure does not always allow for the desired classification (e.g. eloxal particles, like corundum particles, are also attributed to the material class “Al-O”).

- In EDX analysis, only the preselected elements are considered. If the sample contains elements that are not considered, they might be incorrectly attributed to a material class.

- Smaller particles lying next to large particles can be lying on the side turned away from the EDX detector and hidden by “shadowing” as a result. As a result, no measurement signal reaches the detector, and the composition of the particle cannot be determined in this case.

- VDA 19.1 material classes are created for organic filters with low oxygen content (e.g. PA or PET). If filters with a higher oxygen content are used, it is necessary to check if this could potentially skew the categorization of materials or impair the correct/complete detection of relevant (e.g. abrasive) particles. For filters that contain other elements (e.g. PTFE,) the material classes can be reasonably used without adjustment.

- When attributing particle characteristics such as “hard” or “conductive,” note that these characteristics cannot be determined directly in a SEM/EDX analysis. The attribution in this case is done purely on the basis of the determined chemical composition and a characteristic that may be present.

A 8.2.3.2 Comparison of contrast method of light microscope and scanning electron microscope

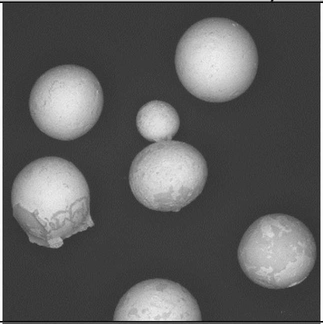
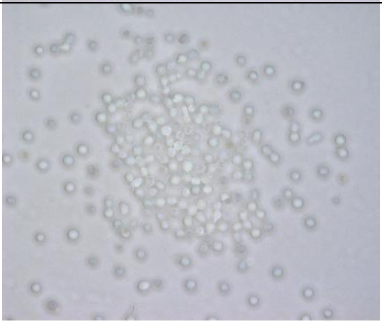
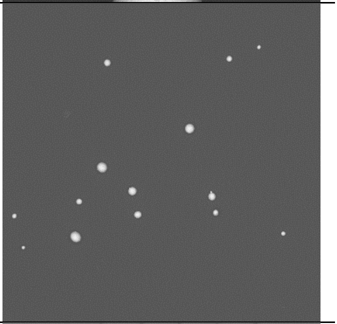
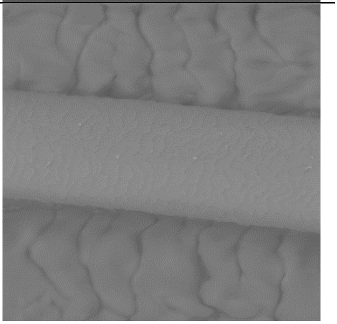
	Light microscopy image (brightness contrast)	**Scanning electron microscopy image (back-scattered electron contrast/material contrast)**
Steel particles		
Ceramic balls (white)		
Hair		

Figure 8-44: Comparison of contrast method of light microscope and scanning electron microscope

A 8.2.3.2 Optional zero-element rules

Table 8-10: Optional zero-element rules

Zero-element rule (element “x” is set to “0”, if...)	
Si	Fe≥50 AND Si≥3
Ni	Ni<1
Cu	Cu<1
S	S<3
P	P<3
Al	Al<2 AND Si<2
K	K<2
Fe	Fe<1
Zn	Zn<1
Ti	Ti<2
Ca	Ca<2
Cl	Cl<2
Ba	Ba<3 OR Ti≥25
Sn	Sn<3 OR Si≥10 OR K≥10
Mo	Mo<3 OR S<5
Sn	Ca≥20
Na	Zn≥15 OR Cu≥15 OR Na<1
F	Fe≥35
F	F<15 AND (K+F)<25
Pb	Pb<1

A 8.2.3.3 Evaluation of open-mesh filters

If filters are adhered to a glass surface (e.g. filter frame) for evaluation or placed on a metal surface, with coarser open-mesh sieve cloth filters, enough particle-fixative should be used so that light does not pass through the glass substrate or a corresponding organic support (e.g. foamed filter) should be used. Otherwise, the substrate could be detected as particles (see Figure 8-45).

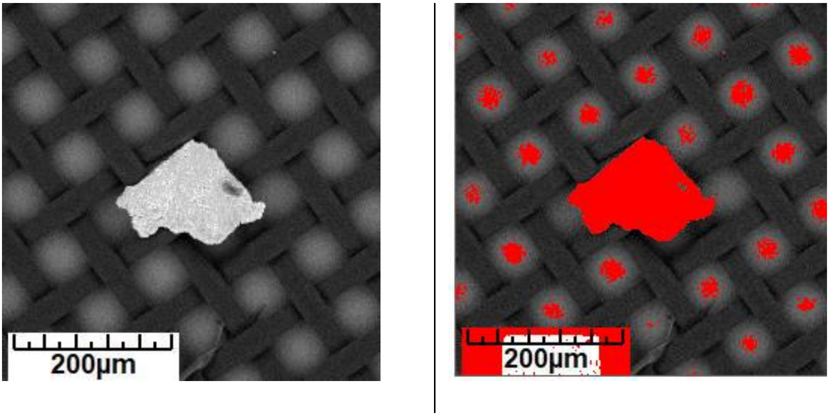


Figure 8-45: open-mesh sieve cloth filter on a glass surface

A 8.2.3.4 Set-up and test of SEM/EDX systems

When setting up an SEM/EDX system, a specific unit of length in the sampling plane (object scale) is first assigned to the corresponding unit of length on the sample image or overall image. The accuracy of this assignment in combination with the image composition (see also A 8.2.2.3) should be checked regularly with a standard for which the particle size distribution and the permitted deviation are known.

Currently available particle standards for checking the particle size and quantity in light microscopy consist of chrome oxide objects that are lithographically applied to a glass object carrier and can generally also be used for checking SEM systems. If excessive deviations are found, the first step should be to check for possible causes, rectify them as necessary and perform another inspection. If the deviations cannot be rectified in this way, the measurement system may need to be recalibrated either by the operator or a service technician.

Energy-dispersive X-ray spectroscopy (EDX) can be verified by observing the peak position (energy) of the EDX spectrum, e.g. for copper or cobalt and should be done according to device-manufacturer-specific data (procedure, regularity and, if necessary, calibration). Since the sensitivity of the EDX detector can be affected by contaminants (light elements/low-energy peaks affected more significantly,) it sometimes makes sense to test them with a corundum or nickel sample by checking for the correct ratio of aluminum to oxygen or high-energy and low-energy peaks.

As of 2025, no standard is available for checking material classes. In line with the revision of VDA 19.1, a verification of the material classes with example particles of various known materials was performed on different SEM/EDX systems. Such a test must comply with the attached (see A 8.2.3.1) conditions and limits for SEM/EDX analyses as well as the following points:

- In some cases, only example particles that vary in their composition (e.g. layer particles with different iron content than the base material) are available.

- Some of the example particles utilized can not always be reliably attributed to their “target material class” due to contaminants.

- Example particles can have a composition that is on the border between two different material class definitions and thus impossible to reliably classify (“material class jumpers”).

It would make sense to have the classification of in-house materials according to VDA 19.1 material classes verified, but this is often not feasible due to availability, especially in contract laboratories.

Table 8-11 shows an overview for testing SEM/EDX systems.

Table 8-11: Set-up and testing of SEM/EDX systems

Set-up and testing of SEM/EDX systems	Material	Frequency
A specific unit of length in the sampling plane (object scale) is assigned to the corresponding unit of length on the sample image or overall image	scale rule	at start-up (or as needed)
Verification of length measurement and image composition	(calibrated) standard	regularly
Verification of peak point (energy) of the EDX spectrum	suitable material (e.g. copper, cobalt, etc.)	regularly
Verification of the sensitivity of the EDX detector	corundum or nickel	as needed
example check of the material classes	selected example particles	upon introduction (initially)

8.3 (Process) monitoring

Inspection methods that can provide a lot of meaningful results within the shortest possible time and indicate process changes are particularly suitable for process control monitoring; see Chapter 3.3.2: (Process) monitoring as well as Figure 3-3 in the annex. They describe the basics of (process) monitoring. No further technical or methodological descriptions are included in VDA 19.1.

Note: Optical particle counters (OPC,) in which particles are counted and measured right as they flow through a measuring cell, casting shadows on a sensor, have many limitations that make them unsuitable for determining cleanliness limit values according to VDA 19.1, even though their use is established in oil or fuel cleanliness test. Only small amounts of liquid can be analyzed; due to the low flow through the measuring cell, large particles often settle before reaching the measuring cell; air bubbles and other liquid drops are accidentally counted as particles, and the particle size is determined based on a circle-equivalent diameter, not the longest length. As part of (process) monitoring, however, they can certainly be used for certain inspection purposes (e.g. testing the cleanliness of process liquids and their change over time).

8.4 Extended analysis

Extended analysis methods are used, for example, in order to narrow down the origin of particles or cause analysis in line with process optimization. Extended analyses can also be performed in response to a limit value being exceeded in order to better evaluate a particle's damaging potential. This is because these methods are more precise than the methods of cleanliness specification testing in Chapter 8.2. They use procedures that provide further information on particle shape (third dimension) and/or particle material.

If extended analysis methods are needed in order to validate cleanliness specifications, this must be agreed in the customer-supplier relationship, and the parameters of the applied methods must be defined. The implementation of extended analysis methods may involve significantly more laboratory or manual work for the analyses and/or higher costs than those associated with standard limit value analysis methods.

Material analyses in particular can essentially be done using a wide range of chromatographic, spectroscopic as well as wet-chemical methods, which would far exceed the scope of this VDA publication. So here, we will only list methods that are specifically suitable for further characterizing (microscopic) particles, not just for larger material samples or surfaces.

Moreover, we will not include any methods that require dissolving the particles. The list of methods included is not necessarily exhaustive. The methods are presented only with regard to their essential mode of operation, without precise information on materials, equipment or procedures.

8.4.1 Additional light-optical analyses

8.4.1.1 Optical characteristics

In the first step, the characterization of particles can also be performed with light-optical analysis methods (see Chapter 8.2.2) by experienced and well trained laboratory or operating personnel, with no need to resort to expensive laboratory material analyses. The shape, color and surface texture of particles already provides indications with regard to their origin and/or functionally critical properties. This can be further facilitated by using the “particle catalog,” which lists and depicts particles typically produced or released in certain production or assembly steps.

The steps for compiling a particle catalog are as follows:

- Analyze the cleanliness-related production steps with regard to characteristic particles, e.g. using:
  - VDA 19.1 cleanliness inspections on components sampled in or after the relevant production steps.
  - Evaluate particle traps set up after the relevant production step.
  - Remove particles from the production step, e.g. using particle stamps.
  - Assess process filters, e.g. in exhaust units, that are installed in the relevant process stations.
- Identification of process-typical particle and image documentation.
- Create a particle catalog (e.g. as a file or as a poster,) and make it available at the workstation for use in the implementation and evaluation of cleanliness inspections.

Note 1: A particle catalog can also be used to help with manual follow-up checks following automatic light-optical analysis, especially for evaluating the correct typification of particles.

Note 2: A particle catalog is not created as a generally applicable document for all types of production but rather individually for the specific process chains. This is typically not feasible for contract laboratories but only for factory labs of companies that produce the components themselves.

Figure 8-46 shows some example images of process-specific particles as they might be used in a particle catalog.

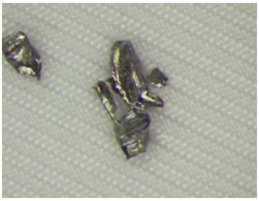
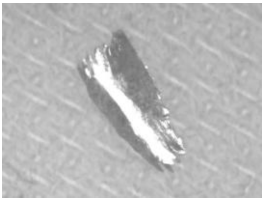
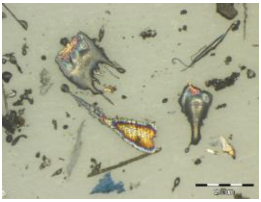
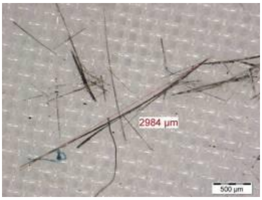
Particle catalog for process chain XX		
		
Laser cutting process	Sawing process	Drilling process
		
Rotary cutting process	Welding process	Insulation application

Figure 8-46: example particle catalog

8.4.1.2 Particle height

8.4.1.2.1 Principle

With this analysis method, the height of a particle is determined with the aid of the depth of field of a microscope lens (T). In simple terms, the depth of field can be expressed as the ratio between the wavelength (a value of 550 nm can generally be assumed here) and numerical aperture (NA) of the lens used.

$$T = \frac{550}{NA^2}$$

T	Microscope optics
NA	Numerical aperture

The numerical aperture of the utilized lens affects the lateral resolving power and its depth of field. As a rule, the numerical aperture increases if fixed lenses with mounting degrees of magnification are utilized. Therefore, as magnification increases (2.5 x -> 5 x -> 10 x -> 20 x), so also does the lateral optical resolving power, whereas the depth of field decreases, i.e. the range within which structures of different heights can be clearly visualized in a plane (focal plane).

Microscope systems with fixed, high-resolution lenses possess degrees of magnification upwards of approx. 20 x (200-fold total magnification at lens level) and a depth of field which is low enough to prevent objects with varying heights from being visualized clearly in one focal plane. As a result, there is a difference between the upper and lower focal plane. This difference indicates an object's height.

The theoretical accuracy of this method depends on the numerical aperture of the lens used and can be said to be 2 x the depth of field.

To measure height, first of all the bottom of the particle is brought into focus. Then the lens is adjusted along the z-axis until the top of the particle is in focus.
The particle height is the difference between these two focal planes, or the distance traveled by the lens in the z-direction. It is calculated indirectly via the screw pitch and stepmotor of the z-axis (see Figure 8-47).

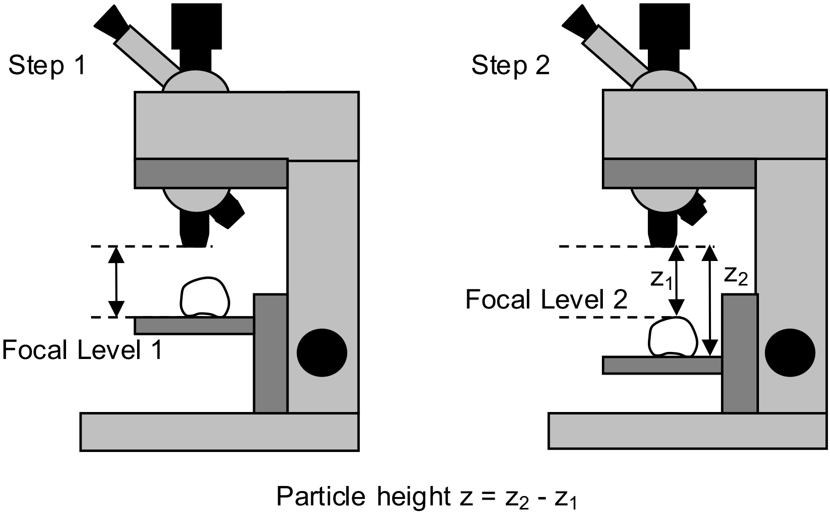


Figure 8-47: Principle of particle height determination

Note: In order to best use the method for measuring particle height via the difference between the focus positions of the filter background and the highest point of the particle, the particle should lie flat on a planar analysis filter (without being directly covered by glass). If a mesh filter is used, care is to be taken to ensure that the particle does not “protrude” into the pore structure as this would result in a lower height being measured.

8.4.2 Other SEM/EDX analyses

Back in Chapter 8.2.3 we already introduced the concept of SEM/EDX analysis for particle detection, measurement and elemental analysis with material classification. There, it is applied for the purpose of **automatic evaluation of an entire analysis filter** and for the detection and analysis of large numbers of particles. The limits of this application are as follows:

- The image evaluation is limited to detecting particles and determining their size.
- The EDX analysis times per particle are very short. The number of analyzable X-ray quanta is very limited, which restricts the precision of the elemental analysis.

In line with further analysis with the SEM/EDX system, the characterization is often done manually by the operator on individual particles. What this process allows for:

- Additional visual information can be obtained on the observed particles, e.g. shape, texture, homogeneity or material contrast. Similarly to the visual characteristics in 8.4.1.1, this allows for the particles to be characterized more precisely and can provide information as to their origin or damage potential. It is also possible to use a different magnification, other detectors or an adapted acceleration voltage for this in order to obtain the desired image information.

- The EDX analysis can be performed with significantly longer measuring times and on different locations on a particle. The spectra obtained in this manner make it possible to determine elemental composition much more precisely.

  Note: For example, if an elemental analysis shows that a particle contains aluminum and oxygen, this is not enough in order to determine whether this is an abrasive corundum particle or if it broke off of the eloxal coating. The additional evaluation of its morphology and surface structure can help with classification.

A further SEM/EDX analysis can also be performed as part of a corrective analysis in which, following an automatic light-optical analysis, the coordinates are transmitted using reference points, so that a targeted recovery and analysis of the largest particles of a filter in the SEM/EDX can be performed.

8.4.3 LIBS

Laser Induced Breakdown Spectroscopy (LIBS) is a form of emission spectroscopy that enables the elemental composition of particles to be determined. When inspecting technical cleanliness, the material composition of particles is analyzed on the filter membrane or adhesive pad on the basis of the emission lines in the spectrum. This enables analysis directly on components and, because material is removed, an in-depth analysis of samples.

The main component of the LIBS microscope is an infinity-corrected microscope (see Figure 8-49 in the annex). A laser is coupled with a mirror in front of the imaging camera, and the LIBS signal is decoupled. Typical laser wavelengths are 331 nm and 1064 nm.

Systems with an integrated microscope are capable of automated particle detection (see light microscopy) and determine the coordinates of a particle’s center of gravity. These particles are then aligned with the laser focus.

In the analysis, the lens focuses a laser pulse onto a particle. The laser pulses used typically have a wavelength ranging between 331 and 1064 nm.

The laser pulse vaporizes the material and generates plasma. Depending on the system, the observed wavelength range lies between 400 and 800 nanometers.

Pure metals generally emit a strong signal. The strength of the signal mainly depends on the point of vaporization of the material. So the more material is vaporized by the laser pulse, the stronger the signal. Because elements each have a specific spectrum, metals and inorganic materials can be clearly identified by means of a spectrum databank (see Figure 8-48).

Polymers and elastomers can only be identified if they are mixed with inorganic materials (if present). If a stronger laser pulse is used, fragments of organic molecules can be visualized, thus facilitating the classification of polymers.

Modern systems are capable of analyzing particles with a minimum size of approx. 15 µm. The quality of the signal varies significantly according to the numerical aperture of the lens and the light throughput of the spectrometer. The size of the focal point of the laser is also determined by the numerical aperture of the lens and the quality of the laser beam.

An impact crater with a diameter of 20 µm and a depth of approx. 10 µm is analyzed per particle. The analysis time is less than one second. The method is quantitative and can also be used to identify and classify alloys. Depending on the resolution of the spectrum, individual constituents of an alloy may overlay other materials in the spectrum and impair their identification.

Note: In principle, analysis directly on components is also possible and, because material is removed, an in-depth analysis of samples.

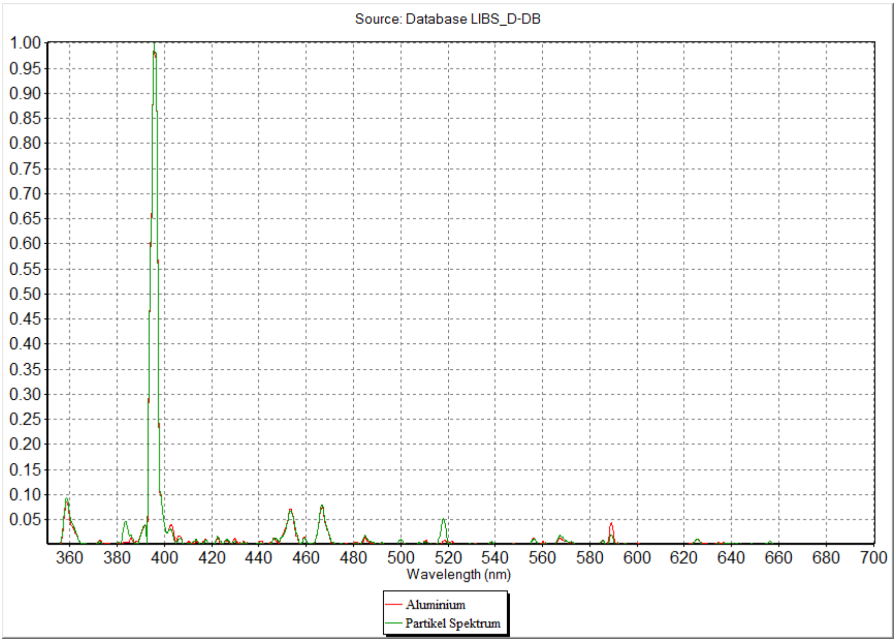


Figure 8-48: LIBS spectra – comparison of aluminum (green) with particle spectrum (red)

Annex 8.4.3 LIBS

A 8.4.3.1 Schematic diagram of a spectroscopic set-up

The schematic diagram shows a system that can be used both for the LIBS analysis and for Raman spectroscopy.

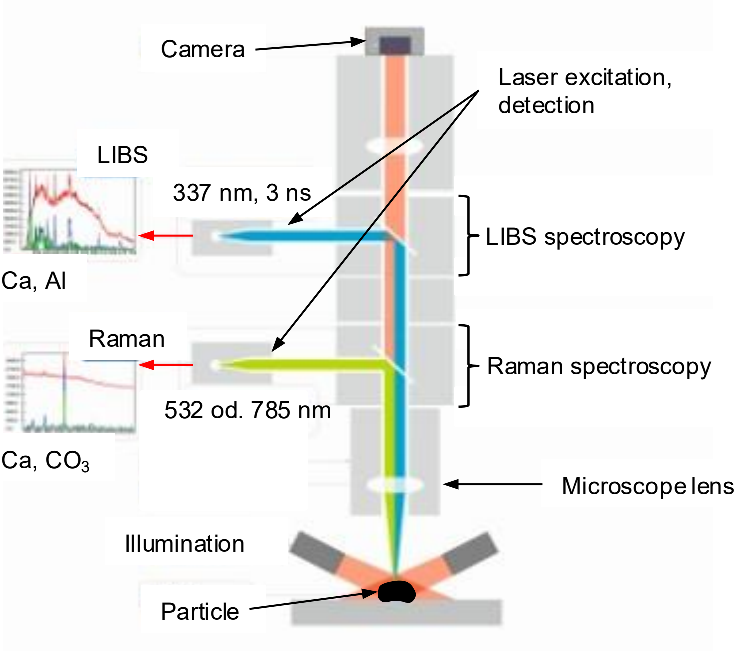


Figure 8-49: schematic design of a spectroscopic system

8.4.4 Raman

Raman spectroscopy is a form of oscillation spectroscopy, which enables the structure of a particle to be analyzed. The atoms in the molecule and their arrangement relative to one another create a specific material fingerprint.

The main component of the Raman microscope is an infinity-corrected microscope. A laser is coupled with a mirror in front of the imaging camera, and the Raman signal is decoupled. Typical laser wavelengths are 532 nm and 785 nm.

In the analysis, a laser beam is focused onto a particle by a lens. The interaction of the matter with the laser beam generates a signal that is recorded by a CCD camera (Charge Coupled Device). This signal is known as a spectrum. Depending on the system, the observed wavelength range lies between 400 and 3500 wave numbers.

The system is only capable of analyzing molecules (pure metals do not generate a signal). Organic and inorganic materials, provided they are Raman-active, can be clearly identified by a spectrum databank, because their structure generates a specific spectrum (see Figure 8-50).

The minimum size of particles for analysis depends on the factor of magnification of the analysis lens. As metals do not generate a Raman signal, they form an ideal background for detecting a specific Raman signal from a particle without any interference. Special metalized plastic mesh filters are available for this purpose. Materials from particles upwards of 0.5 µm emit clear signals if they are prepared for analysis on such filters.

47 mm or 25 mm round filters made from cellulose nitrate or polyester mesh filters can also be used with larger particles without the need for additional sample preparation. However, if this procedure is implemented, the particles should effectively screen the filter background to prevent these organic materials from contributing significantly to the Raman signal.

Typical analysis times per particle range between 30 and 60 seconds. In some cases, the laser beam can induce fluorescence in the molecules. This could overlay the Raman signal and hamper classification.

Systems with an integrated microscope are capable of automated particle detection (see light microscopy) and determine the coordinates of a particle’s center of gravity. These particles are then aligned with the laser focus.

Note: Fluorescent plastics such as well as black plastics typically provide no usable Raman signals and therefore cannot be reasonably analyzed with this method.

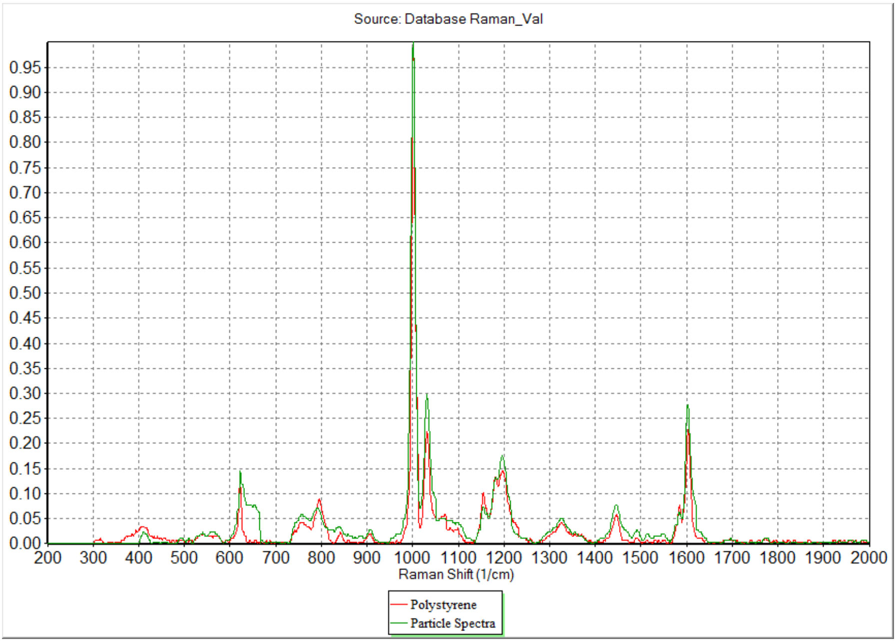


Figure 8-50: Raman spectra – comparison of polystyrene (green) with particle spectrum (red).

Figure 8-49 shows a schematic diagram of a Raman system.

8.4.5 IR (infrared spectroscopy)

If organic molecules are bombarded with electromagnetic waves in the infrared range (wave number 4000 - 400 cm^{-1} or wavelength approx. 2.5 – 25 µm,) specific energies are absorbed. The energies absorbed depend on the oscillation energy/frequency of the excited groups of atoms or complete molecule. In the process, different forms of oscillation occur, such as stretching oscillation or deformation oscillation. All symmetric forms of oscillation are Raman-active but not IR-active (see Chapter 8.4.4).

Fourier Transform infrared spectrometers are generally utilized. These feature a shorter analysis time and a better signal-interference ratio than dispersive spectrometers.

The resulting IR-spectrum is generally shown as a transmission graph: Ability of the excitation beam to penetrate the sample (expressed in percent) against the reciprocal value of the wavelength (wave number; unit cm^{-1}). As the energies absorbed by the structure or functional groups are dependent on the substances contained in the sample, the method can be used to detect all functional groups present that are infrared-active. Although individual structural elements can be identified via the absorbed energies or bands forming in the spectrum, a library search is usually carried out with the complete IR-spectrum obtained (see Figure 8-51).

Depending on the size of the available database, most organic compounds or materials can be identified. Among others, these include plastics as well as process media such as greases and oils. In order to identify as many unknown samples as possible, it is recommended that the existing databank be extended by adding all the in-house, operating and process media used.

The two common FT-IR technologies implemented for particle analysis are the ATR method (attenuated total reflexion) and transmission analysis. Both methods can be carried out using a simple IR spectrometer or an IR microscope (combined with imaging).

ATR method: The IR beam is coupled and de-coupled again via a crystal which is placed/pressed on the particle requiring characterization. Due to the functioning principle of the method, information can only be gained to a penetration depth of 1-3 µm. Placing the sample is not difficult. The method is especially suitable for investigating strongly-absorbent materials.

Transmission analysis: With this method, an IR beam passes through the particle requiring analysis (which has been pressed thin enough to enable this,) and the absorption spectrum is recorded. The spectral information originates from the complete particle volume.

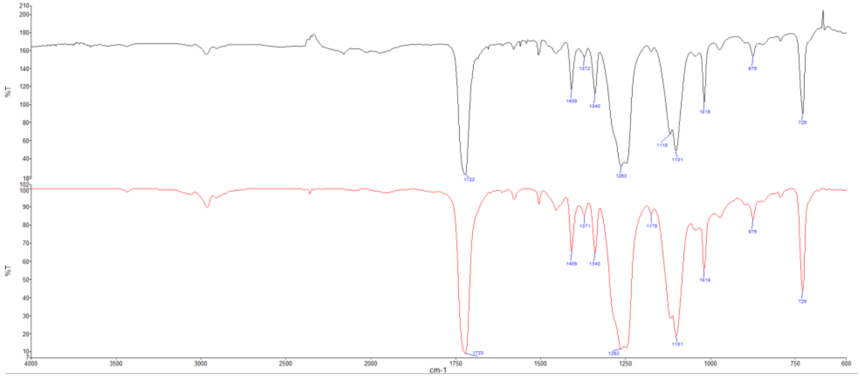


Figure 8-51: IR-spectrum of PET (black, top) and nearest match in the data library (red, bottom)

8.4.6 X-ray microtomography

8.4.6.1 Principle

With x-ray microtomography, a finely-focused x-ray beam is used to project an image of the inspected object into an x-ray camera (see Figure 8-52). During data capture, the inspected object is rotated step-by-step and an x-ray image recorded at each new angle.

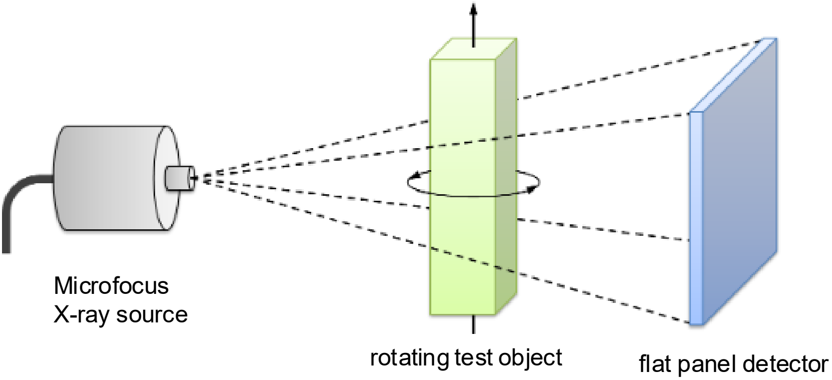


Figure 8-52: Principle of computer tomography

Using a computer-aided method according to Feldkamp, the x-ray attenuation from all the projection images is reconstructed to form a 3-D image (computer tomography). As the attenuation corresponds approximately with the density of the material, the reconstruction represents the spatial distribution of density. The reconstructed gray value gives an indication of particle density. By applying image-processing methods, the geometric structure of the inspected object can be calculated from the density distribution.

The test object analyzed is a suitably-prepared filter membrane charged with particles. By means of segmentation, particles are separated from the background and then analyzed individually. In the analysis, the geometry of a particle is measured 3-dimensionally. In addition, the analysis of the gray values also makes it possible to draw conclusions about particle density. Consequently, a differentiation can be made between lightweight and heavy materials, which may help to identify the origin of particles. However, the use of x-ray microtomography does not allow finely-resolved material analysis, such as with spectroscopic methods (EDX, IR, and Raman).

To analyze micro-particles, a high-resolution x-ray microtomography system is required (“micro CT”). The system must be equipped with a high-resolution x-ray camera and a micro-focus x-ray source. The diameter of the focal point of the x-ray corresponds to the smallest detectable particle size. In order to be able to analyze the complete filter in a single scan, a surface detector serves as the x-ray camera.

Particles can be examined singly on the analysis filter or in their entirety. If single particles are examined, they are fixed onto a piece of adhesive tape or polystyrene substrate. The analysis filter is then compacted by rolling or folding it to minimize the sample diameter. This enables a high special resolution to be achieved on the complete analysis filter.

9 DOCUMENTATION

9.1 Principles

Various documents can be produced in line with a cleanliness inspection (see Figure 9-1). Depending on the type of cleanliness inspection performed, either a qualification report or a test report is created.

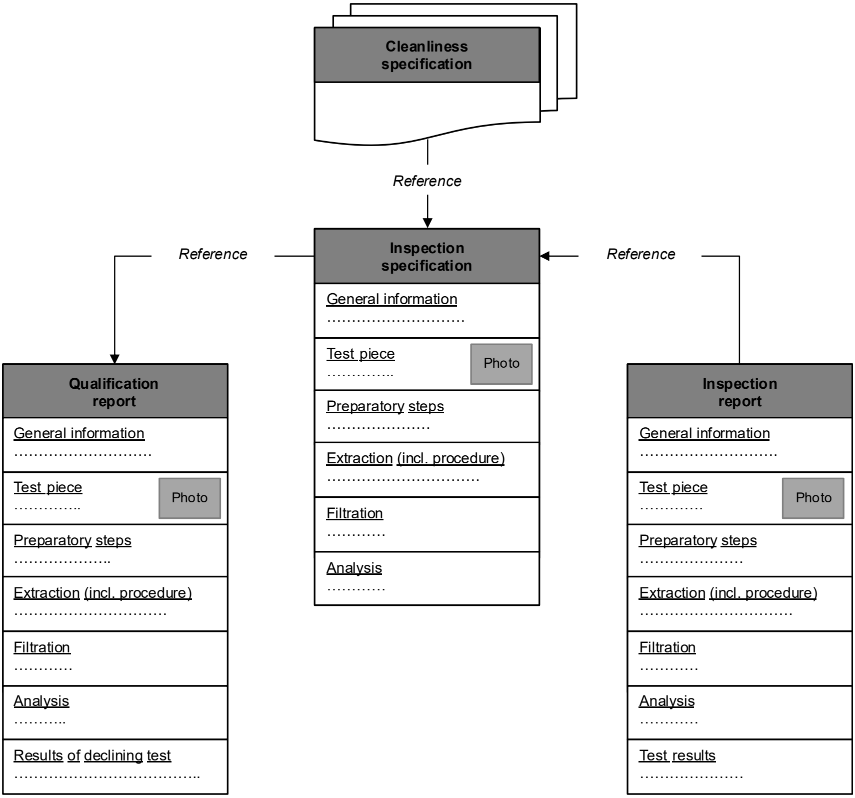


Figure 9-1: Documents from the cleanliness inspection (overview and link)

The qualification report documents the test conditions, extraction parameters and the results of the qualification test (declining series.) These are ultimately used to develop the routine inspection procedure.

The test report briefly summarizes the extraction parameters and test conditions as well as t he test results of routine inspections. The test report only needs to include information that is relevant to the completed inspection.

The third document, the inspection specification, includes information on the extraction and analysis parameters as well as a description of the inspection procedure that can be understood by third parties. The description may be a list of bullet points or more detailed and can be accompanied by photos or illustrations.

The inspection specification may contain the qualification certificate or refer to an independent document – the qualification report. Additional references (e.g. supplementary agreements) may optionally be included.

The documentation should include the information presented in the following sub-chapters. If necessary, additional information can be added, and information can also be omitted where justified.

9.2 General information

The general information includes broader details that may help with the classification and management of the document (see Table 9-1).

Table 9-1: VDA 19.1 general information

General information			
Order no.		Customer:	
Report no.:		Contact person	
Date:			
Test ordered:	☐ Routine inspection	☐ Double inspection	☐ Qualification test
Reason for test:	☐ Initial assessment	☐ Process monitoring	☐ ……………………………..

9.3 Information on the inspected object

The inspected object information allows the part to be characterized more precisely and clearly identifies it (Table 9-2). Additional information that could be helpful:

- material that the inspected object is made of,

– filmy residues on the inspected object

Table 9-2: VDA 19.1 Information on the inspected object

Inspected object					
Designation:		Condition on delivery:		Foto Anlieferung	Foto Prüfobjekt
Part number:		Inspection lot size:			
Batch number:		Test surface:			
Date removed:		A_C = … cm²			
Time removed:		V_C = … cm³			
Removed from:		Inspection specification:			
Reason for test:					

Note: In a qualification report, the inspection specification is not indicated.

9.4 Information on preparatory steps

The information on preparatory steps indicate whether or not and which additional steps are required (Table 9-3). If information on preparation is missing, test results may be evaluated or interpreted incorrectly.

Table 9-3: VDA 19.1 Information on preparatory steps

Preparatory steps	
☐ None	☐ Isolate (e.g. seal, mask) test surfaces
☐ Disassembly	☐ Preclean contaminated surfaces that are not part of the test surface
☐ Demagnetization	☐ ……………………………………………………………………..

9.5 Information on extraction

Extraction can have a lot of variance, because it greatly depends on the expertise of the inspection staff. The following extraction information reduces this variance by documenting the extraction process as thoroughly as possible (Table 9-4). The aim is to make the extraction step reproducible and improve the comparability of test results.

Because the angle or feed rate of an open jet may vary during the extraction step, this information is optional.

Table 9-4: VDA 19.1 Information on extraction

Extraction			
Scope of extraction:	☐ excl. packaging ☐ incl. packaging	Test environment:	☐ undefined ☐ clean room class 2 (ISO 14644-1) ☐ clean room class 1 (ISO 14644-1)
Extraction method:	☐ Pressure-rinsing ☐ Low-pressure rinsing ☐ Internal rinsing	☐ Ultrasonics ☐ Agitation ☐ Air jet extraction	☐ (Brush nozzle) suction ☐ Stamping test ☐ Air throughflow extraction
Dissolving:	Fluid …………	Duration ……	
Pressure-rinsing	**Low-pressure rinsing**	**Ultrasonics**	**Internal rinsing**
Chapter 9.5.1	Chapter 9.5.1	Chapter 9.5.2	Chapter 9.5.3
Agitation	**Air jet extraction**	**Throughflow extraction**	**(Brush) suction**
Chapter 9.5.4	Chapter 9.5.5	Chapter 9.5.6	Chapter 9.5.7
Stamping test			
Chapter 9.5.8			
Final rinsing - control area 1		**Final rinsing - control area 2**	
Manufacturer, extraction apparatus: Model, extraction apparatus: Type, nozzle: Dimensions, nozzle Extraction medium: Flow rate: Fluid volume: Rinse duration: Distance (inspected object - nozzle):		Manufacturer, extraction apparatus: Model, extraction apparatus: Type, nozzle: Dimensions, nozzle Extraction medium: Flow rate: Fluid volume: Rinse duration: Distance (inspected object - nozzle):	

9.5.1 Pressure-rinsing/low-pressure rinsing

Pressure-rinsing or low-pressure rinsing has highest number of influencing parameters. This should be reflected accordingly in the documentation. The extraction effect of pressure-rinsing depends on the choice of (rinsing) nozzle, among other things. Depending on the nozzle design, the following information must be provided:

- Nozzle cross-section in mm for a round (full jet) nozzle
- Spray angle in ° and equivalent nozzle cross-section in mm for the flat jet (fan) nozzle
- Nozzle cross-section in mm and number of holes for the parallel jet nozzle

Additional information can be documented, as shown in Table 9-5.

Table 9-5: VDA 19.1 Information on the (low-pressure) rinsing method of extraction

Pressure-rinsing/low-pressure rinsing	
Control area 1	**Control area 2**
Manufacturer, extraction apparatus:	Manufacturer, extraction apparatus:
Model, extraction apparatus:	Model, extraction apparatus:
Type, nozzle:	Type, nozzle:
Dimensions, nozzle	Dimensions, nozzle
Extraction medium:	Extraction medium:
Flow rate:	Flow rate:
Fluid volume:	Fluid volume:
Rinse duration:	Rinse duration:
Distance (inspected object - nozzle):	Distance (inspected object - nozzle):
Jet feed rate:	Jet feed rate:

9.5.2 Ultrasonics

For the ultrasonic extraction method, documentation is done in accordance with the information in Tabelle 9-6.

Tabelle 9-6: VDA 19.1 Information on ultrasonic extraction method

Ultrasonics	
Manufacturer, extraction apparatus:	
Model, extraction apparatus:	
Extraction medium:	
Fill level, ultrasound tank:	
Fill level, beaker:	
Frequency:	
Cavitation noise level:	
Duration of sonication:	

9.5.3 Internal rinsing

Internal rinsing can take different forms. They range from simple internal rinsing, with the (pressure-rinsing) nozzle being applied hermetically to an opening, all the way up to complex internal rinsing systems in which parameters such as direction of flow, pulsation, etc. are all adjustable. (For documentation, see Table 9-7.)

If the extraction liquid flows through the control area in one direction with a periodically changing flow rate, this is known as pulsation. Pulsation frequency is a time-dependent value and must be indicated.

Table 9-7: VDA 19.1 Information on the internal rinsing method of extraction

Internal rinsing	
Control area 1	**Control area 2**
Manufacturer, extraction apparatus:	Manufacturer, extraction apparatus:
Model, extraction apparatus:	Model, extraction apparatus:
Extraction medium:	Extraction medium:
Type, nozzle:	Type, nozzle:
Dimensions, nozzle:	Dimensions, nozzle:
Dimensions, adaptor:	Dimensions, adaptor:
Flow rate:	Flow rate:
Fluid volume:	Fluid volume:
Rinsing duration:	Rinsing duration:
Pulsation frequency:	Pulsation frequency:
Reverse flow rinse:	Reverse flow rinse:

9.5.4 Agitation

Agitation is essentially a manual extraction method. The frequency and amplitude of the arm movements can neither be fixed nor measured but must be approximated as best as possible in the documentation. (Table 9-8).

Here, the term frequency describes the up-and-down and back-and-forth movement of the inspected object.

The amplitude describes the stroke distance of this movement.

The number of fillings indicates how often the inspected object was (re-)filled during the extraction step.

Table 9-8: VDA 19.1 Information on the agitation method of extraction

Agitation	
Control area 1	**Control area 2**
Manufacturer, extraction apparatus:	Manufacturer, extraction apparatus:
Model, extraction apparatus:	Model, extraction apparatus:
Extraction medium:	Extraction medium:
Filling volume:	Filling volume:
Frequency:	Frequency:
Amplitude:	Amplitude:
Agitation duration:	Agitation duration:
Number of fillings:	Number of fillings:

9.5.5 Air jet extraction

Air jet extraction is the same as pressure-rinsing except for the fact that air is used instead of an extraction liquid. (For documentation, see Table 9-9).

Table 9-9: VDA 19.1 Information on the air jet extraction method of extraction

Air jet extraction	
Control area 1	**Control area 2**
Manufacturer, extraction apparatus:	Manufacturer, extraction apparatus:
Model, extraction apparatus:	Model, extraction apparatus:
Extraction medium:	Extraction medium:
Type, nozzle:	Type, nozzle:
Dimensions, nozzle:	Dimensions, nozzle:
Pressure/flow rate:	Pressure/flow rate:
Extraction duration:	Extraction duration:
Distance (inspected object - nozzle):	Distance (inspected object - nozzle):

9.5.6 Air throughflow extraction

Air throughflow extraction is the same as rinsing except for the fact that air is used instead of an extraction liquid. (For documentation, see Table 9-10).

Table 9-10: VDA 19.1 Information on the throughflow extraction method of extraction

Air throughflow extraction	
Control area 1	**Control area 2**
Manufacturer, extraction apparatus:	Manufacturer, extraction apparatus:
Model, extraction apparatus:	Model, extraction apparatus:
Extraction medium:	Extraction medium:
Type, nozzle:	Type, nozzle:
Dimensions, nozzle:	Dimensions, nozzle:
Printed:	Printed:
Extraction duration:	Extraction duration:
Flow rate:	Flow rate:

9.5.7 (Brush nozzle) suction

Table 9-11 lists the information to be documented for the (brush) suction method of extraction.

Table 9-11: VDA 19.1 Information on the (brush) suction method of extraction

(Brush nozzle) suction	
Control area 1	**Control area 2**
Manufacturer, extraction apparatus:	Manufacturer, extraction apparatus:
Model, extraction apparatus:	Model, extraction apparatus:
Intake area of the suction nozzle:	Intake area of the suction nozzle:
Suction nozzle with/without brush attachment:	Suction nozzle with/without brush attachment:
Suction flow rate:	Suction flow rate:
Nozzle distance:	Nozzle distance:
Suction time:	Suction time:
Separation (with/without cyclone):	Separation (with/without cyclone):
Separation (carrier used):	Separation (carrier used):

9.5.8 Stamping test

Table 9-12 contains the documentation information for the stamping test.

Table 9-12: VDA 19.1 Information on the stamping test

(Brush nozzle) suction

Control area 1	**Control area 2**
Stamp used:	Stamp used:
Version:	Version:
Flat stamp:	Flat stamp:
Number of stamps used:	Number of stamps used:
Number of stamping passes:	Number of stamping passes:

9.6 Information on filtration

In addition to documenting the actual filtration details, information on drying and any post-treatment steps should also be provided (Table 9-13).

Table 9-13: VDA 19.1 Information on analysis filtration

Filtration

Filter 1	**If necessary, additional filters**
Manufacturer:	
Type:	
Filter material:	
Diameter:	
Pore size:	

Drying
Equipment:
Temperature:
Duration:

Pre-conditioning
☐ yes ☐ no

Post-treatment
Fluid:
Fluid volume:

9.7 Information on analysis

The information on analysis includes the information and settings of the analysis systems.

If extraction and analysis are performed in different places or different room qualities, the test environment must also be documented as shown Table 9-4.

9.7.1 Gravimetric analysis

For gravimetric analysis, the information listed in Table 9-14 must be documented.

Table 9-14: VDA 19.1 Information on gravimetric analysis

Gravimetry		
Manufacturer:		☐ ± 0.1 mg
	Scale readable to:	☐ ± 0.01 mg
Model:		☐ ± 0.001 mg

9.7.2 Light-optical analysis

For light-optical analysis, the information listed in Table 9-15 must be documented.

Table 9-15: VDA 19.1 Information on light-optical analysis

Light-optical analysis		
Manufacturer:	Type of analysis:	☐ Standard analysis ☐ Free analysis
Model:	Brightness:	Indicate if different from standard analysis...
Scale/magnification:	Threshold:	
Evaluation diameter:		

9.7.3 SEM/EDX analysis

For SEM/EDX analysis, the information listed in Table 9-16 must be documented.

Table 9-16: VDA 19.1 Information on SEM/EDX analysis

SEM/EDX analysis		
Manufacturer:	Type of analysis:	☐ Standard analysis ☐ Free analysis
Model:		
Scale/magnification:		
Evaluation diameter:		
Accelerating voltage:		
Working distance:		
Vacuum mode		

9.8 Data on environmental conditions

The environmental conditions are summarized by the data in Table 9-17.

Table 9-17: environmental conditions

Environmental conditions
Test environment:
Temperature:
Air humidity:

9.9 Statement of test results

The statement of test results is only correct in conjunction with a unit of reference. Results should first be indicated for the inspection lot. In addition, they can be presented in the following standardized format:

- Number of tested components n standardized to a component
- tested area of the inspected object $A_C in\ cm^2$ standardized to 1000 cm^2
- tested volume of the inspected object $V_C in\ cm^3$ standardized to 100 cm^3

9.9.1 Gravimetric analysis

The result of a gravimetric analysis is the residue weight $M = M2 - M1$, which should be rounded up to the last decimal place. The weights M2 and M1 are read off using the full resolving capacity of the scale. The resulting particle mass G, which is calculated from the difference between the residue weight and the unit of reference, must be documented.

Mass in relation to one component

$$G_C = \frac{M}{n} in \frac{mg}{Component}$$

G_C: Particle mass in relation to component

M: Residue weight for the inspection lot n: Number of components in an inspection lot

For example, if an inspection lot of 10 parts (n = 10) is inspected, and the gravimetric analysis indicates a residue weight of 4 mg, then the resulting standardized residue weight is $G_C = 0.4$ (rounded up to at least one decimal place).

Mass in relation to standardized area

$$G_A = \frac{M * 1000}{A_C} in \frac{mg}{1000cm^2}$$

G_A: Particle mass over 1000 cm^2

M: Residue weight for the inspection lot

A_C: Sampled area of an inspection lot

For example, if a component has a wetted component surface area of $A_C = 500\ cm^2$, and the gravimetric analysis indicates a residue weight of 4 mg, then the formula gives us the standardized residue weight of $G_A = 8\frac{mg}{1000\ cm^2}$ (rounded up to at least one decimal place).

Mass in relation to standardized volume

$$G_V = \frac{M * 100}{V_C} in \frac{mg}{100cm^3}$$

G_V: Particle mass over 100 cm^3

M: Residue weight for the inspection lot

V_C: Sampled volume of an inspection lot

For example, if a component has a wetted component volume of $V_C = 500cm^3$, and the gravimetric analysis indicates a residue weight of 4 mg, then the formula gives us the standardized residue weight of $G_V = 0.8\frac{mg}{100\ cm^3}$ (rounded up to at least one decimal place).

9.9.2 Light-optical analysis

Light-optical systems determine the length and width of individual particles. The particles are also classified into a specified length/width interval (also: size class).

The result is a particle size distribution, which may contain all or only selected (particle) size classes.

Length/width intervals other than the size classes listed below should only be documented if absolutely necessary, e.g. 100 ≤ x < 200 µm, 200 ≤ x < 300 µm, etc., as this would mean doing additional work.

The size classes are listed in Table 9-18.

Table 9-18: (Particle) size classes as per VDA 19.1

Size class	Size x in µm		
B	5	≤ x <	15
C	15	≤ x <	25
D	25	≤ x <	50
E	50	≤ x <	100
F	100	≤ x <	150
G	150	≤ x <	200
H	200	≤ x <	400
I	400	≤ x <	600
J	600	≤ x <	1000
K	1000	≤ x <	1500
L	1500	≤ x <	2000
M	2000	≤ x <	3000
N	3000	≤ x	

The particle size distribution must include information on the unit of reference. The standardized particle count H is obtained from the ration of the absolute particle count h to the unit of reference.

Particle count for a component

$$H_C = \frac{h}{n} in \frac{Particle}{Component}$$

H_C: Particle count for a component

h: Absolute particle count for the inspection lot

n: Number of components in the inspection lot

For example, if an inspection lot of 5 parts (n = 5) is inspected, and it is found to contain 1 particle in the size class H (200 ≤ x < 400 μm), then the resulting standardized particle count is $H_C = 0.2$ (rounded to at least one decimal place).

Particle count in relation to standardized area

$$H_A = \frac{h * 1000}{A_C} in \frac{Particle}{1000cm^2}$$

H_A: Particle count over 1000 cm^2

h: Absolute particle count for the inspection lot

A_C: Sampled area of an inspection lot

For example, if a component has a wetted component surface area of $A_C = 263cm^2$, and it is found to contain 89 particle in the size class H (200 ≤ x < 400 μm), then the formula gives us the standardized particle count of $H_A = 338.4$ (rounded up to at least one decimal place).

The documentation type is presented in Table 9-19.

Table 9-19: VDA 19.1 Information on test results (light-optical analysis)

Inspection results														
Particle size distribution														
Length (Feret_{max}) or width (Feret_{min}) in µm		Particle count per 1000 cm²												
		B	C	D	E	F	G	H	I	J	K	L	M	N
		5	15	25	50	100	150	200	400	600	1000	1500	2000	3000
		≤ x <	≤ x <	≤ x <	≤ x <	≤ x <	≤ x <	≤ x <	≤ x <	≤ x <	≤ x <	≤ x <	≤ x <	≤ x
		15	25	50	100	150	200	400	600	1000	1500	2000	3000	
Typification	All particles without fibers													
	Particles with metallic shine													
	Fibers													
Images	Größter Partikel	Zweitgrößter Partikel	Größter metallisch glänzender Partikel	Zweitgrößter metallisch glänzender Partikel	Größte Faser	Zweitgrößte Faser	Filterbelegung [%]							

Particle count in relation to standardized volume

$$H_V = \frac{h * 100}{V_C} \, in \, \frac{Particle}{100cm^3}$$

H_V: Particle count over 100 cm^3

h: Absolute particle count for the inspection lot

V_C: Sampled volume of an inspection lot

For example, if a component has a wetted component volume of $V_C = 320cm^3$, and it is found to contain 2 particles in the size class K (1000 ≤ x < 1500 µm), then the formula gives us the standardized particle count of $H_V = 0.6$ (rounded up to at least one decimal place).

The particle counts per unit of reference are entered directly in the table fields (cf. presentation of test results). Standardization often produces decimals that need to be rounded up to a decimal place.

Indicating a decimal place acknowledges outliers that occur with limit value requirements in the higher size classes and with small absolute particle counts.

If no unit of reference is indicated, the number or the calculation of the blank value always refers to the inspection lot.

It is also possible to provide information on categories, e.g. the physical effects of reflected light are used to characterize particles more precisely. A distinction can thus be made between the category “metallic shiny” and “not (metallically) shiny” particles, and this should be documented.

However, light-optical systems do not allow particles to be categorized as soft or hard, electrically conductive or non-conductive, or magnetic or non-magnetic.

It is also standard practice to document the largest particles. Images of the longest or widest particle in each category are to be recorded with the image processing software of the light-optical system in order to be able to better assess the damaging potential of particles. There is no fixed minimum number of images to be recorded in each category.

9.9.3 SEM/EDX analysis

The way inspection results are presented depends on the method selected. For an SEM/EDX analysis, for example, a material class can also be documented.

The documentation type is presented in Table 9-20.

Table 9-20: VDA 19.1 Information on test results (SEM/EDX analysis)

Inspection results														
Particle size distribution														
Length (Feret$_{max}$) in µm		Particle count per 1000 cm²												
		B	C	D	E	F	G	H	I	J	K	L	M	N
		5	15	25	50	100	150	200	400	600	1000	1500	2000	3000
		≤ x <	≤ x <	≤ x <	≤ x <	≤ x <	≤ x <	≤ x <	≤ x <	≤ x <	≤ X <	≤ x <	≤ x <	≤ x
		15	25	50	100	150	200	400	600	1000	1500	2000	3000	
Material class	Cr-layer													
	Zn-layer													
	etc.													
Images (any relevant particle material classes)														
Partikel 1	**Partikel 2**	**Partikel 3**	**Partikel 4**	**Partikel 5**										

Note: The results of an SEM/EDX analysis can also be stated with combined size classes (e.g. ≥ 1000 µm as largest size channel without further division into size classes).

9.9.4 Optional coding (informative)

This sub-chapter deals with coding particle size distributions in accordance with ISO 16232 (as of 2007) with the original intention of abbreviating cleanliness values. The coding is an optional component in the documentation. It can only be used for particle size distributions, although it is not stated in the ISO norm whether coding may be applied to individual types of particle (fibers, metallic shiny, etc.). The norm also does not state whether particle widths can be coded or not.

Component Cleanliness Code (German: Bauteilsauberkeitscode)

Coding is used to attribute a contamination level to the particle count. The size classes are indicated in Table 9-18 and the contamination levels are indicated in Table 9-21. The resulting Component Cleanliness Code is written as follows:

$$CCC = \underbrace{A}_{\substack{Unit\,of- \\ reference}} \;(\; \underbrace{D}_{\substack{Size- \\ class}} \;\; \underbrace{20}_{\substack{Contami- \\ nation- \\ level}} \;\; \underbrace{/}_{\substack{Separ- \\ ator}} \;\; E16/F18/\ldots)$$

The unit of reference indicates whether the particle count relates to:

- $1000cm^2$ wetted surface area of the inspected object (marked: A),
- $100cm^3$ wetted volume of the inspected object (marked: V) or
- $1\,component$ (marked: N).

Table 9-21: Particle contamination levels

Particle contamination levels (Partikelkonzentrationsklassen)	Number of particles (per 100 cm³ or 1000 cm²) up to
00	0
0	1
1	2
2	4
3	8
4	16
5	32
6	64
7	130
8	250
9	500
10	1000
11	2000
12	4000
13	8000
14	16.000
15	32.000
16	64.000
17	130.000
18	250.000
19	500.000
20	1.000.000
…	…

Simplified ways of writing Component Cleanliness Codes

The following example shows the various methods permitted for documenting the CCC. The following particle size distribution is assumed (see Table 9-22).

Table 9-22: Particle size distribution example

Particle count per 1000 cm²												
B	C	D	E	F	G	H	I	J	K	L	M	N
5 ≤ x < 15	15 ≤ x < 25	25 ≤ x < 50	50 ≤ x < 100	100 ≤ x < 150	150 ≤ x < 200	200 ≤ x < 400	400 ≤ x < 600	600 ≤ x < 1000	1000 ≤ x < 1500	1500 ≤ x < 2000	2000 ≤ x < 3000	3000 ≤ x
634981	49735	36791	938	502	394	48	7	5	2	1	1	0

As particle counts are expressed in a normed way, the contamination level can be read directly from Table 9-21, resulting in the following Component Cleanliness Code:

$$CCC = A(B20/C16/D16/E10/F10/G9/H6/I3/J2/K1/L0/M0/N00)$$

If individual size classes do not need to be stated, e.g. if no specification or analysis result exists for these size classes, they are omitted in the CCC:

$$CCC = A(D16/E10/F10/G9/H6/I3/J2/K1/L0/M0/\mathrm{N}00)$$

If the contamination levels of neighboring size classes are identical, this can be abbreviated to:

$$CCC = A(B20/\underline{CD}16/\underline{EF}10/G9/H6/I3/J2/K1/\underline{LM}0/N00)$$

However, the situation changes if several different size classes are combined in the analysis (see Table 9-23).

Table 9-23: Particle size distribution example with combined size classes

Particle count per 1000 cm²							
B - D	E	F	G	H	I	J	K - N
5 ≤ x < 50	50 ≤ x < 100	100 ≤ x < 150	150 ≤ x < 200	200 ≤ x < 400	400 ≤ x < 600	600 ≤ x < 1000	1000 ≤ x
721507	938	502	394	48	7	5	4

The corresponding simplified code is then expressed as follows:

$$CCC = A(\underline{B-D}20/E10/F10/G9/H6/I3/J2/\underline{K-N}2)$$

Exceptional case, unit of reference N

The CCC *per component* may only refer to exactly 1 component. Contamination levels may not be used for this unit of reference; therefore, the particle count is adopted from the particle size distribution in a non-encoded form. Particle counts with a position after the decimal point should be rounded up.

$$CCC = N(B755840/C43720/D36791/E938/F502/G394/H48/I7/J5/K2/L1/M1/N0)$$

9.10 Conformity assessment

If an inspection report includes a conformity assessment, i.e. a verification of compliance with a limit value, the following must be considered:

- The associated limit value should be indicated in the inspection report.

- Conformity assessments are done in accordance with VDA 19.1 unless specified otherwise, without accounting for measurement uncertainty.

- The conformity assessment should use the phrasing “specification met/not met” or “specification observed/not observed”. The formulation OK/NOK should not be used in this context.

- The blank value should be considered in the conformity assessment and therefore indicated in the inspection report, especially if this is relevant for the interpretation of the results.

–

9.11 Notes on the implementation of the cleanliness inspection

The notes section can be used to add any supplementary information, e.g.

- deviations from the procedure according to VDA 19.1
- justification for the deviation from the start parameters for extraction
- condition of inspected object upon delivery not compliant with cleanliness requirements
- limited analyzability of the filter
- limitations on correction in follow-up check
- etc.

9.12 Scopes of the individual documents

The information provided in the following chapters for the various documents can be abridged as necessary for in-house use.

9.12.1 Inspection specification

The inspection specification is the main document of the cleanliness analysis. It is written after the qualification test has been completed and once inspection parameters have been derived for the routine inspection. The inspection specification comprises:

- General information
- Information on the inspected object
- Information on preparatory steps (detailed)*
- Information on extraction (detailed)*
- Information on filtration
- Information on analysis
- Location of the inspected objects

The inspection specification may contain additional information about the qualification test or refer to an independent document – the qualification report.

The inspection specification contains a clearly understandable description of the inspection procedure (especially with regard to the sections marked with *). Illustrations or photos are a helpful supplement to the description. In general, as the inspection procedure becomes more complex, the more detailed the description should be. With simple inspection procedures, a point-by-point description is sufficient. The inspection specification must enable the cleanliness inspection to be performed independently of the time, place and inspecting member of staff.

No inspection results are documented in the inspection specification except for the results of the qualification test if no qualification report is available. Cleanliness requirements or limit values may be included in an inspection specification if no independent cleanliness specification exists or if no appropriate sketches are available.

9.12.2 Qualification report

The first document prepared is the qualification report. Without the qualification of test conditions and inspection parameters, there can be no inspection specification and thus also no inspection report. The qualification report comprises:

- General information
- Information on the inspected object
- Information on preparatory steps
- Information on extraction
- Information on filtration
- Information on analysis
- Results of the declining test*
- Verification of the blank value*

- Information on routine test conditions and inspection parameters*

The qualification report contains a graph of the declining test and information on routine test conditions and parameters (marked with *). As an option, the results of a subsequent double inspection can also be included.

The routine test conditions and parameters derived from the declining test, which are contained in the qualification report, are also included in the inspection specification and inspection report. The origin of the routine test conditions and parameters remains transparent because of the mandatory reference to the inspection specification. The reference is not necessary if all the required information about the qualification test is included in the inspection specification (see preceding list).

9.12.3 Inspection report

The inspection report is the last document written (see Table 9-24 in the annex). A routine inspection can only be performed once qualified test conditions and parameters have been determined. All settings and results are documented briefly and clearly in the inspection report. The inspection report comprises:

- General information
- Information on the inspected object
- Information on preparatory steps
- Information on extraction
- Information on filtration
- Information on analysis
- Results of the routine inspection*

The most important part of the inspection report is the results. With recurrent routine inspections, these are the only things that change and all other information remains identical. To ensure that it is always clear how test conditions and parameters were determined, the inspection report must contain a reference to the inspection specification. This may be of particular interest if the declining test was not successful – i.e. in the event of an exceptional case – and in cases where no qualified inspection parameters exist.

Provided they have been archived or saved, the inspection specification and qualification report do not have to be included when handing over the inspection report.

Annex 9 Documentation

A 9.1 Example of an inspection report

Table 9-24: Example of an inspection report

Inspection report: (Standard) cleanliness inspection as per VDA 19.1 (2025)				
General information				
Order no. Report no.: Date:	Customer: Contact person:			
Test ordered:	☐ Routine inspection	☐ Double inspection	☐ Qualification test	
Reason for test:	☐ Initial assessment	☐ Process monitoring	☐ Modifications, design	☐....
Inspected object				
Designation: Part number: Batch number: Date removed: Time removed: Removed from:	Condition on delivery: Inspection lot size: Control area: $A_C = \dots\ \text{cm}^2$ $V_C = \dots\ \text{cm}^3$ Inspection specification:	Foto Anlieferung	Foto Prüfobjekt	
Preparatory steps				
☐ none	☐ Isolate (e.g. seal, mask) control areas			
☐ Disassembly	☐ Preclean contaminated surfaces not relevant to the control area			
☐ Demagnetization	☐ ……………………………………………………………			
Extraction				
Scope of extraction:	☐ excl. packaging ☐ incl. packaging	Test environment:	☐ undefined ☐ clean room class 2 (ISO 14644-1) ☐ clean room class 1 (ISO 14644-1)	
Extraction method:	☐ Pressure-rinsing ☐ Ultrasonics	☐ Internal rinsing ☐ Agitation	☐ Air jet extraction ☐ Air throughflow extraction	
Dissolving:	Fluid ………………	Duration ……………	Temperature ………	
Pressure-rinsing/low-pressure rinsing				
Control area 1	**Control area 2**			
Manufacturer, extraction apparatus:	Manufacturer, extraction apparatus:			
Model, extraction apparatus:	Model, extraction apparatus:			
Type, nozzle:	Type, nozzle:			
Dimensions, nozzle	Dimensions, nozzle			
Extraction medium:	Extraction medium:			
Flow rate:	Flow rate:			
Fluid volume:	Fluid volume:			
Rinse duration:	Rinse duration:			
Angle (inspected object, jet):	Angle (inspected object, jet):			
Distance (inspected object, nozzle):	Distance (inspected object, nozzle):			
Jet feed rate:	Jet feed rate:			

Inspection report: (Standard) cleanliness inspection as per VDA 19.1 (2025)

Filtration

Filter 1
Manufacturer:
Type:
Filter material:
Diameter:
Pore size:

If necessary, additional filters

Drying
Manufacturer:
Model:
Temperature:
Duration:

Pre-conditioning
☐ yes ☐ no

Post-treatment
Fluid:
Fluid volume:

Light-optical analysis

Manufacturer:

Model:

Scale/magnification:

Evaluation diameter:

Type of analysis: ☐ Standard analysis
☐ Free analysis

Brightness:

Threshold:

Indicate if different from standard analysis...

Inspection results

Particle size distribution

		Particle count per 1000 cm²												
Length (Feret_{max}) or width (Feret_{min}) in µm		B	C	D	E	F	G	H	I	J	K	L	M	N
		5 ≤ x < 15	15 ≤ x < 25	25 ≤ x < 50	50 ≤ x < 100	100 ≤ x < 150	150 ≤ x < 200	200 ≤ x < 400	400 ≤ x < 600	600 ≤ x < 1000	1000 ≤ x < 1500	1500 ≤ x < 2000	2000 ≤ x < 3000	3000 ≤ x
Typification	All particles without fibers													
	Particles with metallic shine													
	Fibers													

Images

Größter Partikel

Zweitgrößter Partikel

Größter metallisch glänzender Partikel

Zweitgrößter metallisch glänzender Partikel

Größte Faser

Zweitgrößte Faser

Filterbelegung [%]

10 INTERPRETATION AND REACTION

10.1 Interpretation

The technical cleanliness of components fluctuates much more than any features created specifically. This applies both to the quantities of particles (gravimetric or as counts in particle size classes) and especially the length of the largest particle.

This is due to the fact that contaminant particles are not specifically generated but are rather produced in many shapes and sizes in an uncontrolled manner. This applies to almost all forms of contamination arising in the course of the manufacturing process or during transport and storage.

In chipping processes, for example when machining metal components, chips in a wide range of lengths, widths and shapes are generated. Some of these may be found again on the component in the form of residual particulate contamination.

Note: Even with chips specially produced in the laboratory by means of precision chipping, tests have shown that lengths still fluctuate by about 20%.

Although an industrial parts cleaning plant can reduce the overall quantity of component contamination highly efficiently, the existing fluctuation mar-gin can only be reduced to a limited extent.

One of the reasons for this is the technical characteristics of filters (filtration curve). For example, a filter in a cleaning system, though which the washing or rinsing medium flows, retains particles upwards of a specific particle width or height that are orientated in the direction of flow.

However, the length of particles passing through the filter membrane may still vary significantly. This can often be seen by the major fluctuation in largest particle size in cleanliness analysis results.

This explains why standard quality assurance criteria, such as the values otherwise applying typically to the reliability of processes in the automotive and supplier industries, cannot be applied to technical cleanliness!

As explained earlier in Chapter 2, if a cleanliness limit value for a component is exceeded, this does not necessarily mean that the system in which the component is installed will fail. However, the probability of a system malfunction/fault occurring will increase. A particle determined to be critical will only cause a malfunction if is located in the sensitive area of the system at the right moment in time and possibly if it is orientated in a specific direction.

The aim of a VDA 19.1 cleanliness analysis is not primarily to detect such random events caused by strong fluctuations in cleanliness characteristics but rather to identify systematic effects on technical cleanliness throughout the entire process chain. These can be caused, for example, by:

- sub-optimal manufacturing and cleaning processes
- incorrectly-adjusted or worn tools
- unsuitable process parameters
- impure process media
- unserviced filtration systems
- transport, packaging and storage not compliant with cleanliness requirements

10.2 Reaction

For the reasons mentioned in the preceding section, when a cleanliness specification limit value is exceeded, the assessment requires a response plan between the customer and the testing organization.

To start with, a verification is performed in order to rule out the possibility that the limit value may have been exceeded due to the test conditions or testing equipment.

If this can be excluded as a possible cause, the issue is examined from the perspective of the following two questions:

- **Is this a systematically occurring an error or a spontaneous incident?** This can be done by testing other components/inspection lots from the same production run but at least by a single retesting of a component sample. Alternatively, it is possible to test several components/inspection lots (e.g. 3 or 5) at once and thus obtain a more solid foundation of information.
- **How critical is this overrun?** This decision can generally only be

made by the manufacturer or customer of the tested components, not by the person conducting the testing in the laboratory. Here are some aspects to consider:

- the degree of the overrun (particle count and/or size)
- the presence of certain particle types
- the risk class of the inspected object
- etc.

Depending on where the cleanliness inspection is performed (manufacturer, customer, contract laboratory,) there are different ways that the limit overrun can be checked, e.g. by a specialist with knowledge of the part manufacturing process or of a defined response plan (of the customer).

The actions to be taken in the event that a cleanliness limit value is exceeded are not stipulated in this VDA 19.1. Rather, they belong, for example, in an escalation plan that is agreed to in the customer-supplier relationship or as part of the process chain for checking in-house cleanliness specifications.

10.3 Method verification and measurement uncertainty (informative)

Compliance with the requirements defined in IATF 16949 (requirements for quality management systems for serial and spare parts production in the automotive industry) for a laboratory can be demonstrated with an accreditation as per DIN EN ISO IEC 17025 or similar.

This, in turn, requires verifying the inspection methods as well as determining measurement uncertainty. In the automotive industry test process capability is typically assessed according to VDA Volume 5 (Measurement and Inspection Processes: Capability, Planning and Management) and ISO 22514-7. Both the provisions of DIN EN ISO IEC 17025 and VDA Volume 5 are geared to demonstrating that an inspection method is suitable for the intended measurement/inspection task.

There are certain differences between testing for technical cleanliness as opposed performing a dimensional measurement on an inspected object. These differences give rise to certain challenges (see also Chapter 10.1.) The topic of measurement uncertainty and method verification will therefore be discussed.

One key difference as compared to a dimensional measurement is that a cleanliness inspection is a destructive test, meaning that measurement results cannot be checked by remeasuring the inspected object. Another difference is that there is no standard available for assuring the overall process of the cleanliness inspection, e.g. to easily determine the influence of sample preparation.

This chapter pertains only to the inspection process itself without looking at transport to a testing laboratory or sampling, etc. The procedure from VDA 5 as well as the requirements of DIN EN ISO IEC 17025 have essentially been integrated in the technical cleanliness inspection.

10.3.1 Method verification

A central aspect of method verification for cleanliness inspection according to VDA 19.1 is that it is not possible to formulate a generally applicable method verification procedure. This is due to the fact that the effectiveness of the extraction is component-specific, which is achieved by performing a declining test and by requiring compliance with the declining criterion of 10% and is implemented individually for each component.

Another requirement that must be checked specifically for each component is compliance with the blank value criterion. This part of the verification process can only ever be component-specific and performed at the relevant time.

The validation/verification of a method is typically performed by assessing the following process parameters:

- Correctness
- Precision
- Detection limit
- Determination limit
- Work area
- Specificity
- Robustness

- Measurement uncertainty (see Chapter 10.3.2)

Note 1: For the purpose of accreditation according to ISO 17025, the DakkS document 71 SD 4 019 describes the aforementioned process parameters for validation/verification. These terms are also used and explained in an ASTM standard (ASTM E 3411 or ASTM E 3425) on the development or validation of an automatic particle analysis on a filter membrane.

For a cleanliness inspection according to VDA 19.1, these process parameters can be used for the particle size as well as the particle count and, if necessary, the residue weight. For a more detailed explanation of the process parameters, refer to the annex (see A 10.4.1.1 through A 10.4.1.5 in Annex 10.4.1).

Table 10-1 shows some suggested process parameters to look at in line with method verification. The requirements in this table can be found in VDA 19.1 in the form of certain criteria (particle recovery, pixel criterion, etc.).

Note 2: As part of method verification, requirements must be defined for the process parameters. Some of these can be taken straight from VDA 19.1. In some cases, however, the VDA 19.1 does not have any generally applicable requirements and requirements then have to be defined independently.

Note 3: The VDA 19.1 makes no distinction between detection limit and determination limit.

Table 10-1: Recommendation on method verification

Performance characteristic	Particle quantity	Particle size	Residue weight
Correctness	Measurement of a particle standard Particle recovery (90%) Sample-specific declining criterion (10%) and blank value criterion (10%)	Measurement of a particle standard	Measurement of a reference weight Recovery (90%) Sample-specific declining criterion (10%) and blank value criterion (10%)
Precision	Repeated measurement of an analysis filter		
Detection limit, determination limit	Sample-specific via blank value criterion	Pixel criterion (10 or 5 pixels) for smallest particle size to be detected	Resolution of the scale (sample-specific via blank value criterion)
Work area	sample-specific via blank value criterion and via recommendation on filter residue	Pixel criterion (10 or 5 pixels) for smallest particle size to be detected as well as evaluation diameter	Resolution of the scale (+ sample-specific via blank value criterion) as well as weighing range of the scale
Specificity	No generally applicable test		
Robustness	No generally applicable test		

10.3.2 Measurement uncertainty

In the automotive industry test process capability is typically assessed according to VDA Volume 5 (Measurement and Inspection Processes: Capability, Planning and Management) and ISO 22514-7, and terms such as “proof of capability” (measurement system capability Q_{MS} or measurement process capability Q_{MP}) are used.

The proof of capability test is performed primarily based on the consideration of measurement uncertainty for the measurement system or for the measurement process. The capability ratio is calculated by factoring in the tolerance for the product characteristic to be measured, among other things. This procedure is essentially possible, but for a cleanliness inspection according to VDA 19.1, it only makes sense to use it for the following reasons:

- It is not necessary to differentiate between a measurement uncertainty for the measurement system and for the measurement process, because the greatest measurement uncertainty contribution can be attributed to sample preparation.

- It is difficult to set a tolerance for calculating capability ratios, because it is usually not a single value but rather a particle size distribution.

The basic principles for measurement uncertainty calculation contained in VDA Volume 5 can be applied, however, and VDA 19.1 also provides instructions/requirements for minimum criteria that can be used for a calculation.

These minimum criteria are already designed to keep measurement uncertainty in a cleanliness inspection within certain limits. These requirements from VDA 19.1 may already be considered in line with method verification, and uncertainty contributions can be derived from these requirements or additionally determined.

If a cleanliness inspection according to VDA 19.1 includes a declaration of conformity, this is usually done without accounting for measurement uncertainty. If a more detailed interpretation of the results is performed for the purpose of a response plan, it may make sense to account for measurement uncertainty to a certain extent (e.g. for limit values with a maximum permissible particle size).

10.3.2.1 Measurement uncertainty contributions

The first step of a measurement uncertainty assessment should be to list the potential measurement uncertainty contributions. The next step is to identify the relevant contributions, i.e. those with the greatest influence. Figure 10-1 shows potential influences in a cleanliness inspection according to VDA 19.1.

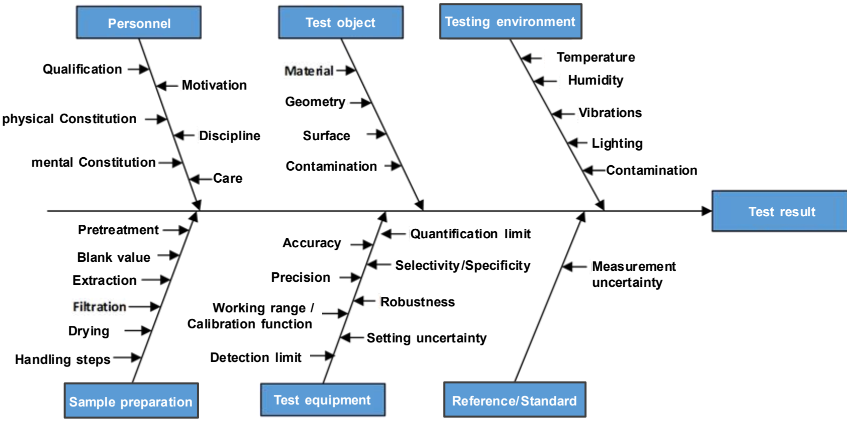


Figure 10-1: Measurement uncertainty contributions in a cleanliness inspection according to VDA 19.1

Compared to inspection methods for checking dimensional accuracy (see Figure 10-2,) a cleanliness inspection according to VDA 19.1 should also consider sample preparation as an uncertainty contribution, as this is presumably a significant measurement uncertainty contribution.

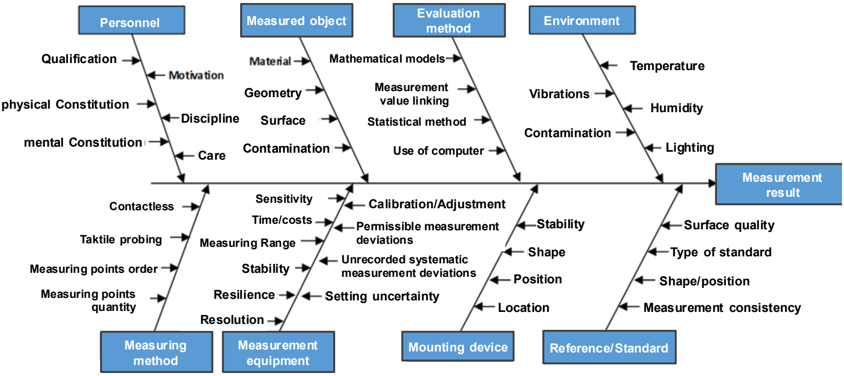


Figure 10-2: Measurement uncertainty contributions, e.g. in a dimensional measurement

The VDA 19.1 stipulates the following specific requirements for measurement uncertainty contributions to be considered:

- Particle count/residue weight:
  - Blank value criterion as a requirement for the influences on the inspection result due to personnel, environment or utilized testing equipment (10%)
  - Declining criterion as requirement for effectiveness of extraction (10%)
  - Particle recovery as a requirement for loss of already extracted particle due to utilized testing equipment (90% recovery or maximum 10% loss)
- Particle size:
  - Pixel criterion for the smallest particle size to be detected; a measurement uncertainty of 2 pixels can be assumed (see Figure 10-3)

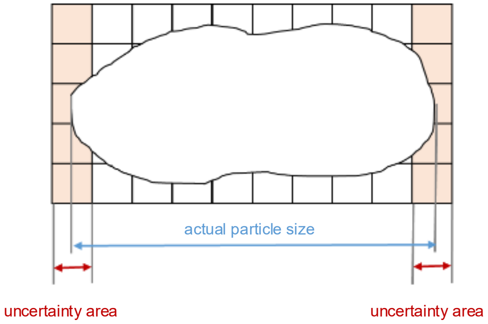


Figure 10-3: Relationship between resolution (µm/pixel) and uncertainty in particle size determination

In addition to these VDA 19.1 requirements, the following uncertainty contributions should also be considered:

- Particle count/residue weight:
  - (Measurement uncertainty contribution resulting from calibration of the measurement system)
  - Measurement uncertainty contribution resulting from the precision of the measurement system
- Particle size:
  - Measurement uncertainty contribution resulting from the calibration of the measurement system
  - Measurement uncertainty contribution due to the positioning accuracy of the microscope table to be considered for stitched particles (i.e. particles that span multiple image fields and have been combined)

In method verification, the measurement uncertainty contributions listed here are mainly examined under the aspects of accuracy and precision. In addition to the aforementioned measurement uncertainty contributions, there are also other contributions, some of which may possibly have a significant influence but which cannot be determined, e.g. the factor of staff motivation.

10.3.2.2 General calculation

Calculation of the uncertainty contributions with standard measurement uncertainty:

$$\boldsymbol{u(x_i) = a_i b_i c_i}$$

u = standard measurement uncertainty

a = half-width of distribution

b = divisor

c = sensitivity coefficient

combined measurement uncertainty of the input variables:

$$\boldsymbol{u(y) = \sqrt{\sum_{i=1}^{N} u_i^2(y)}}$$

expanded measurement uncertainty (*k* = 2, coverage probability 95 %):

$$\boldsymbol{U = ku(y)}$$

k = coverage factor

U = expanded measurement uncertainty

10.3.2.3 Calculation example

The measurement uncertainty calculation example for the particle count in Table 10-2 assumes the following uncertainty contributions: precision of measurement system (5%), effectiveness of extraction (10%), blank value proportion (10%) and particle recovery (10%). The assumed blank value and effectiveness of extraction (declining criterion) as well as the assumed particle recovery (10%) are requirements based on VDA 19.1. The other uncertainty contributions are an experimentally determined deviation (precision of microscope).

For the example calculation, this results in a measurement uncertainty of 22.4% for the particle count. The greatest uncertainty contribution is 80% and is attributed to sample preparation.

Table 10-2: Example calculation (not exhaustive) of measurement uncertainty for particle count

Value	**Estimate**		**Half-width of distribution**		**Probability distribution**	**Divisor**	**Sensitivity coefficient**	**Uncertainty contribution**	**Variance**
X_i	x_i	Unit	$s(x_i)$, $a(x_i)$, $u(x_i)$	Unit		b_i	c_i		
$N_{microscope}$	100		5	%	Artefact	1.00	1.0	5.0	25.0
$N_{recovery}$	0		10	%	Rectangle	0.58	1.0	5.8	33.3
$N_{decline}$	0		10	%	Rectangle	0.58	1.0	5.8	33.3
N_{BV}	0		10	%	Rectangle	0.58	1.0	5.8	33.3

Note: The example calculation for the measurement uncertainty of the particle count is a calculation based on the requirements of VDA 19.1 as well as an additional assumption of the precision of the measurement system based on completed repeat measurements. However, the measurement uncertainty can also be calculated sample-specifically by using the actual values for blank value, declining criterion and particle recovery. A sample-specific approach produces lower measurement uncertainty.

Calculation of the individual uncertainty contributions

1. $u(N_{Microscope}) = a_{Microscope} \times b_{Microscope} \times c_{Microscope} = 5.00 \times 1.00 \times 1.00 = 5.00$

2. $u(N_{Recovery}) = a_{Rec.} \times b_{Rec.} \times c_{Rec.} = 10.00 \times 0.58 \times 1.00 = 5.77$

3. $u(N_{Declining\ criterion}) = a_{Declining} \times b_{Declining} \times c_{Declining} = 10.00 \times 0.58 \times 1.00 = 5.77$

4. $u(N_{blank\ value}) = a_{BV} \times b_{BV} \times c_{BV} = 10.00 \times 0.58 \times 1.00 = 5.77$

Calculation of the combined measurement uncertainty

$$u(x_{total}) = \sqrt{u(N_{Microscope})^2 + u(N_{Rec.})^2 + u(N_{Declining})^2 + u(N_{BV})^2} = \sqrt{5.00^2 \times 5.77^2 \times 5.77^2 \times 5.77^2} = 11.18$$

Calculation of the extended measurement uncertainty (*k* = 2, coverage probability 95%):

$U = k \times u(x_{total}) = 2 \times 11.18 = 22.4$

Annex 10.4.1 Process parameters

A 10.4.1.1 Accuracy

Accuracy is a measure of how precisely a measured value (residue weight, particle count or particle size) matches the conventional actual value or an accepted reference value. It is very difficult to determine the accuracy of the overall process of a cleanliness inspection according to VDA 19.1 in an verification step, since there are no standard contaminated components available for comparison. Accuracy is therefore checked in multiple separate measurements.

The accuracy of a measurement system used for particle analysis according to VDA 19.1 is usually done with a reference weight (analysis scale) or a particle standard (light microscope, scanner or SEM; see following figure,) a glass substrate with a defined number of objects of known size.

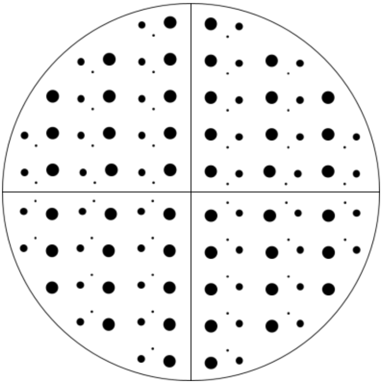


Figure 10-4: Example of a particle standard

When using such a particle standard, the following requirements must be taken into account:

- The particle standard has 2D objects on it which can be easily measured. Inspection with a particle standard thus does not account for particle detection quality, in which it must be considered that 3D objects are measured in the projection plane (2D) and only particles with sufficient contrast against the filter background can be detected in a standard analysis according to VDA 19.1.

- When the measurement system is tested with a particle standard, influencing factors related to sample preparation (personnel, testing environment, extraction, filtration) are not considered. In line with VDA 19.1, these influencing factors are accounted for via the blank value (blank value criterion 10%,) the effectiveness of extraction (declining criterion 10%) and particle recovery (90% particle recovery). While particle recovery rate can be determined for a utilized extraction apparatus using a generally valid calculation, compliance with the blank value criterion and declining criterion must be calculated based on the specific component.

Note: If the cleanliness inspection according to VDA 19.1 should include the analysis of low-contrast particles, the quality of this detection should also be assessed. This can be done as part of the follow-up check or by evaluating example particles with corresponding images. The detection is evaluated qualitatively.

A 10.4.1.2 Precision

“Precision” refers to the degree of correlation (dispersion) among a series of measurements under the prescribed conditions. In this context, we can differentiate between repeatability (precision under the same operating conditions over a short period) and reproducibility (precision between laboratories).

It is very difficult to determine the precision of the total process of a cleanliness inspection according to VDA 19.1, since this is a destructive test and no identically contaminated components are available. For this reason, it is suggested to perform a simplified test of precision that only consists of re-evaluating an analysis filter.

Note: When selecting an analysis filter for determining precision, ensure that it has enough particles of the sizes to be evaluated or that particle size channels are collected for the evaluation, if necessary. Note that the evaluation cannot be expected to produce 100% identical measurement results.

A 10.4.1.3 Detection limit, determination limit and operating range

The detection limit is the smallest particle count and particle size or particle mass that can be detected in a cleanliness inspection but does not necessarily have to be quantified as an exact value.

The quantification limit is the smallest particle count and particle size or particle mass that can be determined with adequate accuracy and precision in a cleanliness inspection.

Note: Generally, the detection limit is assumed to be the average of the blank value, plus three times the standard deviation of the blank value. The determination limit is assumed to be the average of the blank value, plus ten times the standard deviation of the blank value. When performing a cleanliness inspection according to VDA 19.1, note that blank values often fluctuate greatly in relation to the particle count and can also vary between different components. A generally valid specification for the detection or determination limit can be helpful for assessing the testability of clean components, but a current inspection must be performed due to potential changes in the condition of testing equipment.

In the cleanliness inspection according to VDA 19.1, no distinction is made between the detection limit and determination limit in relation to particle count and size. In relation to particle count, it indicates the detection/determination limit using the blank value criterion, and, in relation to particle size, using the pixel criterion to be met for the smallest particle size to be determined.

The operating range of an analysis method is the range between the lower and upper limit for which it has been demonstrated that the analysis method has the necessary degree of accuracy, precision and linearity. The operating range of a cleanliness inspection according to VDA 19.1 in relation to particle count and size is determined by the determination limit (blank value or pixel criterion) and the filter residue or the theoretically maximum evaluable particle size (evaluation diameter).

A 10.4.1.4 Specificity

"Specificity" refers to the ability of an analysis method to determine the particle count and particle size or the residue weight in the presence of other potentially expected components.

In some cases, there may not be a specificity if chemical residues are present on an analysis filter and contribute to the residue weight or are present as specks detected in image processing. With regard to filmy residues that are not detected as particles or residue weight, VDA 19.1 recommends using a suitable liquid for the post-treatment of the filter membrane.

The aspect of specificity can also pertain to the particle typification. The problem with particle typification is that it can vary significantly depending on the sample, there is no standard definition available for the typification of metallically shiny particles and the operator can still influence the result in the follow-up check.

For these reasons, no generally valid test of specificity is possible in line with a cleanliness inspection according to VDA 19.1.

A 10.4.1.5 Robustness

The robustness of an analysis method is a measure of its ability to remain uninfluenced by small but deliberate variations in the method parameters and gives us an indication of its reliability in normal application. This pertains both to the evaluation of the analysis membrane and the sample preparation.

It is very difficult to determine the robustness of the total process of a cleanliness inspection according to VDA 19.1, since this is a destructive test and no identically contaminated components are available. For this reason, testing is only possible for aspects such as:

- Performance of a declining test by different operators
- Determination of particle recovery by different operators
- Repeated evaluation of an analysis membrane in different orientation
- Evaluation of an analysis membrane with different brightness setting with the same relative threshold
- Evaluation with different resolution

Note: The robustness of the evaluation of analysis filters in different orientation or with different brightness settings and the same relative threshold was tested as an example in line with the last revision to VDA 19.1. In this example, the influence in relation to the total particle count was found to be no greater than with a repeated measurement of a filter membrane.

10.3.3 References

- GUM
- VDA 5
- ISO 22514-7
- E 3411 Standard Practice for Validation of Automated Membrane Microscopy Test Methods for the Counting and Sizing of Particulate Matter Present in Parenteral Pharmaceutical Manufacturing Processes and Final Drug Products
- E 3425 Standard Guide for Development of Automated Membrane Microscopy Test Methods for the Counting and Sizing of Particulate Matter Present in Parenteral Pharmaceutical Manufacturing Processes and Final Drug Products
- E1169 Practice for Conducting Ruggedness Tests
- ICH Q2 Validation of Analytical Procedure—Scientific Guideline
- ISO 13322-1:2014 Particle size analysis—Image analysis methods—Part 1: Static image analysis methods
- USP <1058> Analytical Method Qualification
- VDI 2083 Part 21 Cleanliness of Medical Devices in the Manufacturing Process
- 71 SD 4 019 Validation and verification of inspection procedures as per the requirements of DIN EN ISO/IEC 17025 for test laboratories in the area of chemical and chemical-physical analysis in the area of department 4 (consumer health protection | agricultural sector | chemistry | environment)

11 WORK SAFETY AND THE ENVIRONMENT

According to the rules of work safety, the operating company is required to create a hazard assessment in order to determine different hazard factors and, if necessary, implement mitigating actions.

This chapter deals exclusively with the aspect of using solvents.

11.1 General instructions

The application of these guidelines concerns materials, equipment and facilities which pose potential hazards to people and the environment. The guidelines are not claimed to cover and exclude all risks associated with the application. The operating company is responsible for implementing measures related to safety and health and complying with legal requirements.

In this context, we wish to briefly point out the potential danger from live components, e.g. batteries, or if a controller is needed for the extraction of inspected objects.

Note 1: When using water-based extraction liquids, e.g. aqueous neutral cleaner, biological hazards, e.g. due to bacterial contamination, must also be considered.

Note 2: Old facilities may not be technologically up to date with regard to safety. In addition to the obligations of the manufacturer (CE Certification) there are also obligations of the operating company, e.g. explosion protection, etc.

Note 3: Safety instructions in device-specific operating manuals, substance-specific safety data sheets, etc. must be observed.

11.2 Hazards involved in tests using solvents

The sphere of responsibility of a person running a cleanliness laboratory/testing area includes assessing risks associated with the tasks carried out therein.

This section of the book helps operators to assess the typical risks involved, especially those associated with handling solvents when performing an extraction step as part of a cleanliness inspection.

The main hazards associated with solvents are:

- Hazards due to inhalation or skin contact:
  - Vapors or aerosols can be inhaled via the respiratory tract
  - Degreasing effect on the skin
- Hazards associated with physical-chemical characteristics:
  - Fire
  - Dangerous explosive atmosphere

As the majority of non-aromatic cold cleaners used in cleanliness analyses have a flashpoint > 60°C and have only a low probability of forming vapors at room temperature (low vapor pressure at RT,) there is generally no risk of explosion due to the formation of vapors. Aside from vapors, however, an explosion hazard can also arise due to the formation of aerosols, which could form in an extraction process, for example, under certain parameters.

In this context, if the lower explosion limit (typical values for cold cleaners 0.6-0.7%) is exceeded, an explosive atmosphere will be formed. The typical workplace limit value for vapors from cold cleaners is 600mg/m³. Provided this value is observed at all times, there is no risk of explosion because the lower explosion limit is well below the workplace limit value. Please note that the workplace limit value must be measured in the location where aerosols/vapors can form.

Figure 11-1 below presents the remaining hazards – contact with liquid, inhalation and risk of explosion – and matches them with various tasks typically performed in a cleanliness laboratory.

Note: The utilized equipment must be designed for this application (intended use, e.g. for use in potentially explosive zones). If any modifications are made to the equipment, a safety assessment must be performed.

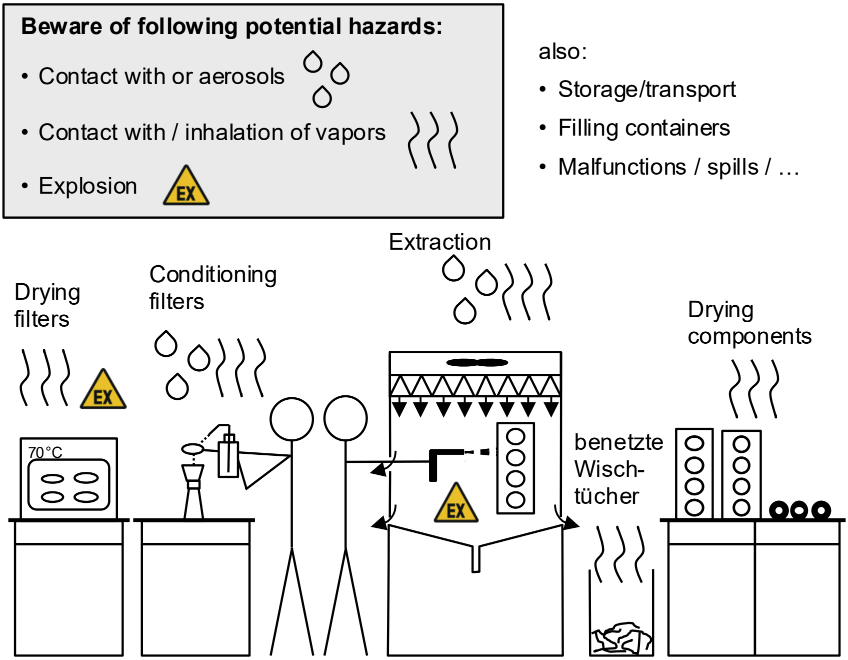


Figure 11-1: Hazards in the cleanliness laboratory associated with solvents

Additional hazards may be created through the use of ultrasonics, e.g. when warming an extraction liquid in the bath (see Chapter 6.4.3). The temperature should be kept adequately below the flash point, and the ultrasonics must be evaluated as a potential source of ignition (EN 1127:2019).

The storage of solvents is subject to the directive TRGS 510, and the directive TRGS 900 provides information on workplace limit values.

If the risk assessment in the cleanliness laboratory identifies potential hazards, protective measures must be taken to minimize them. They are listed as follows in order of priority (with No. 1 being given the highest priority).

The other points listed are merely non-prioritized examples of measures that could be taken to reduce or eliminate hazards.

1. Substitution (examples):
   - Replace with aqueous cleaning media (provided extraction efficacy is not impaired).
   - Use solvents (e.g. hydrocarbons) with a flashpoint > 60 °C.
   - Substitute solvent mixtures with non-aromatic isoparaffins as pure substances.
   - Replace pressure-rinsing extraction from inner surfaces (with associated risk of aerosol formation) with an rinsing process using a contained extraction medium.
   - etc.
2. Technical measures (examples):
   - Adequate ventilation in the room
   - Use vacuum, e.g. for filter drying
   - Enclosed extraction workstations
   - Extraction workstations with air exhaust
   - Extraction equipment designed with explosion-protection
   - Component drying stations with air exhaust
   - Lower the temperature for analysis filter drying
   - Appropriate, closed waste containers for wiping cloths soaked in solvents, etc. (for containers > 10 L, provide grounding)
   - Monitor temperature in ultrasound baths; automatic shutdown if critical temperatures are reached
   - Exclude sources of ignition in extraction chambers
   - Equipotential bonding

    - Only use round jet nozzles, and use rinsing pressures below 0.7 bar at nozzle (according to EN 12921-3:2005 +A1:2008, lower risk of aerosol formation) (see also Figure 6-6 in the annex)

    - etc.

    Note: If an exhaust fan is used, it must be suitable (six-cornered symbol,) and the ambient air concept should be designed accordingly.

3. Organizational measures (examples):

    - Keep component-drying processes separate from other workspaces

    - Remove wiping cloths soaked in solvent from the laboratory at regular intervals; if necessary, ventilation outside the laboratory out of doors

    - etc.

4. Personal protection measures (examples):

    - Breathing protection (this may not be a permanent measure, for example)

    - Face mask

    - Solvent-proof protective clothing

    - etc.

Note: This list of key points to aid risk assessment does not claim to be complete. It does not release operators of cleanliness laboratories from their duty to obtain comprehensive information about all valid regulations, laws, guidelines and hazards and to take them appropriately into account in risk assessments.

The Annex (see Figure 11-2) contains examples of different types of chamber for use in conjunction with pressure-rinsing extraction as well as the respective points to be considered in risk assessments. In particular, completely open pressure-rinsing chambers represent a major risk. In such cases, technical protective measures are to be taken to avoid the need for personal protective gear to be worn constantly. See also TRGS 900.

Annex 11 Work safety and environment

A 11.1 Potential hazards associated with extraction steps using solvents (examples)

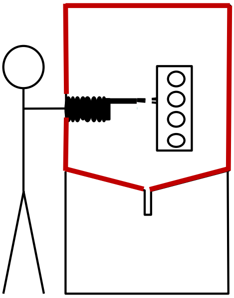
A) Fully-closed pressure rinsing chamber:

On opening after extraction step, assess

- exposure to aerosols
- occupational exposure limits

During extraction and opening, asses

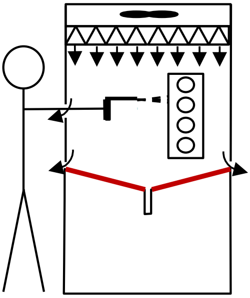
- explosion hazard



B) Leckagen Closed pressure-rinsing chamber with air supply and leaks:

During extraction (and after), asses

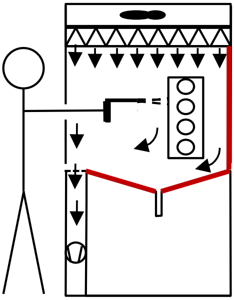
- occupational exposure limits
- explosion hazard



C) Closed pressure-rinsing chamber with air supply, leaks and air removal:

Asses

- Explosion hazard in air exhaust system

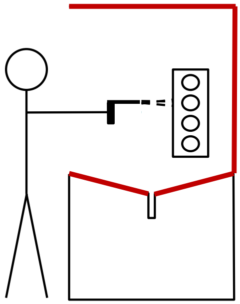


🟥 wetted area of the extraction chamber

D) Open pressure-rinsing chamber (no longer state of the art):

- Assess occupational exposure limits and
- Explosion hazard.
- Exposure to aerosols cannot be reliably avoided !
- Contact with solvent highly probable

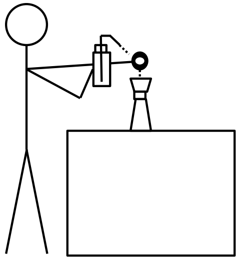
Only permitted if personal protection gear is worn and if not performed for prolonged periods of time



E) Manual pressure-rinsing extraction step without chamber:

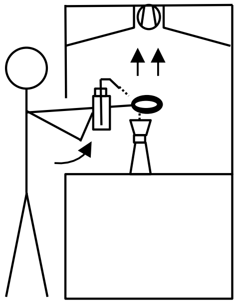
Risks as in D) but lower due to small quantities and lower rinsing pressure

- Assess occupational exposure limits
- Exposure to aerosols cannot be reliably avoided
- Contact with solvent probable



F) Manual pressure-rinsing extraction step under hood:

- Very low risks
- Contact with solvent possible
- Observe blank value because of airflow from environment to the inside



▬ wetted area of the extraction chamber

Figure 11-2: Potential hazards associated with extraction steps using solvents (examples)

Note: When work is performed under a laboratory fume hood, due to the negative pressure generated by the exhaust system contaminants can be sucked up from the environment or from the operator into the operating range of the laboratory fume hood, thus influencing the blank value.

12 CASE EXAMPLES

12.1 Overview

This chapter presents six case examples to facilitate the use of the VDA 19.1, especially for anyone who is new to technical cleanliness inspection. Specific inspected objects and cleanliness specifications are used to present the extraction, filtration, analysis, inspection procedure qualification and results interpretation steps with various focus areas. All descriptions are purely fictitious and not intended for application to actual inspected objects, cleanliness specifications or procedures. The many references are provided in order to make it easier for the reader to find the relevant information in the chapters of the guideline. The following case examples are presented:

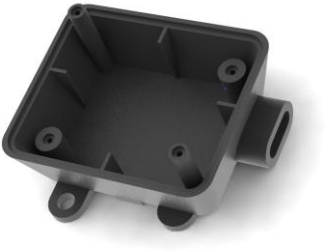
Example/ inspected object	Extraction method	Analysis method	Objective
12.2 Plastic housing	Pressure-rinsing	Light microscope (automated)	Creating an inspection specification, declining test
12.3 Piston rings, coated	Ultrasonics, pressure-rinsing	Light microscope (automated)	Creating an inspection specification, failed declining test and optimization of extraction procedure
12.4 Hydraulic cylinder	Pressure-rinsing	Gravimetry, Light microscope (automated)	Creating an inspection specification, declining test, interpreting the analysis results
12.5 Optical sensor	Low-pressure rinsing		Creating an inspection specification, for small components with stringent cleanliness requirements
12.6 Crankshaft	Pressure-rinsing + Internal rinsing	Light microscope (automated)	Creating two extraction procedures for different functional areas of a component
12.7 Battery and drive electronics	Suction	Light microscope (automatic), evaluating multiple filters from filter cascade	Developing a dry extraction procedure for large components that are reused

12.2 Example 1 – plastic housing

12.2.1 Task

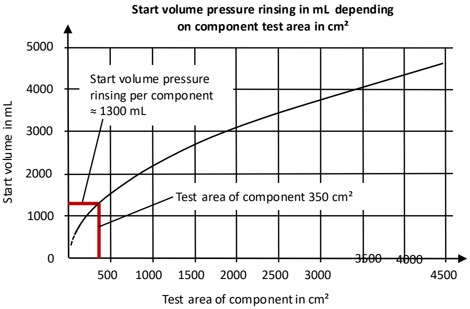
Based on the following inspected object data and cleanliness specification or limit, we can derive an inspection procedure for a plastic housing.

Fibers are not considered in the specification and are omitted from the inspection.

<table>
<tr><th colspan="4">Component data</th></tr>
<tr><td>Component type</td><td colspan="2">Plastic housing</td><td rowspan="9">approx. 10 cm x 10 cm
</td></tr>
<tr><td>Surface – control area</td><td colspan="2">350 cm²</td></tr>
<tr><td rowspan="6">Limit value Particle</td><td>Size class in µm</td><td>Particle count</td></tr>
<tr><td>$50 \leq x < 100$</td><td>500</td></tr>
<tr><td>$100 \leq x < 150$</td><td>200</td></tr>
<tr><td>$150 \leq x < 200$</td><td>20</td></tr>
<tr><td>$200 \leq x < 400$</td><td>2</td></tr>
<tr><td>$400 \leq x$</td><td>0</td></tr>
<tr><td>Limit value Gravimetry</td><td colspan="2">-</td></tr>
</table>

12.2.2 Extraction method selection

In the first step of processing the task, the extraction method is selected based on the size, geometry and position of the relevant component surfaces and the material.

<table>
<tr><th colspan="3">Extraction method selection</th><th>Chapter</th></tr>
<tr><td>Extraction method</td><td colspan="2">Due to the size and accessibility of the entire surface, the plastic housing is suitable for the pressure-rinsing method of extraction.</td><td>3.1.1.2
3.1.3.2
Table 3-4</td></tr>
<tr><td>Extraction medium</td><td colspan="2">Aqueous cleaners due to compatibility with the plastic material (if compatibility with other cleaners is tested, they can also be used)</td><td>Table 6-2</td></tr>
<tr><td rowspan="4">Start parameters</td><td>Nozzle</td><td>2.5 mm round jet nozzle</td><td rowspan="4">Table 6-3</td></tr>
<tr><td>Volume flow</td><td>1.5 l/min</td></tr>
<tr><td>Distance from component</td><td>max. 15 cm</td></tr>
<tr><td>Start quantity per cm²</td><td>$V_{St/A} = 5\frac{mL}{cm^2} \times \sqrt{\frac{200\ cm^2}{A_{cp}}}$</td></tr>
<tr><td>Start volume</td><td colspan="2">

V_{St} = 1300 mL</td><td>Figure 6-8</td></tr>
</table>

12.2.3 Selecting the filtration

The selection of the analysis filter is based on the smallest particle size to be detected (see also Chapter 7.1.1 and Figure 7-3). Since the lower limit is at 50 µm and there is no other information that needs to be considered for filter selection, **the 5 µm PET mesh** standard filter should be used.

12.2.4 Selecting the analysis method

The selection of the analysis method likewise depends on the cleanliness specification. In this example, a particle size distribution starting at 50 µm is specified. There is no gravimetric limit value and no other information on particle materials or low-contrast particles. The analysis can thus be performed as a light-optical standard analysis. The appropriate microscopes or scanners, the necessary optical resolution and the required parameters for image brightness and threshold are indicated in Chapter 8.2.2.2.

12.2.5 Qualification of the inspection procedure

The permissible blank value for the inspection is taken directly from the cleanliness specification of the component (see also Chapter 5.3 and Table 5-3).

	Size channel in microns				
	50 ≤x< 100	100 ≤x< 150	150 ≤x< 200	200 ≤x< 400	x≥ 400
Limit value per component	500	200	20	2	0
permissible blank value	50	20	2	0	0

To determine the necessary extraction time, a declining test is performed using the rinsing parameters and rinsing volume selected in 12.2.2. The results of the individual declining steps (extractions 1 to 6) are listed in der following table. The declining value in the last column is calculated by adding up all the particles > 50 µm (second-to-last column). The calculation is performed as described in Chapter 5.2.3.1 and Figure 5-1.

Declining test	Size channel in microns						**Declining values**
	50 ≤x< 100	100 ≤x< 150	150 ≤x< 200	200 ≤x< 400	x≥ 400	∑ ≥ 50µm	
Extraction 1	245	90	6	0	0	341	
Extraction 2	98	43	4	1	0	146	0.30
Extraction 3	65	24	1	0	0	90	0.16
Extraction 4	41	17	2	0	0	60	0.09
Extraction 5	32	12	1	0	0	45	0.07
Extraction 6	18	9	0	0	0	27	0.04

12.2.6 Deriving the routine inspection

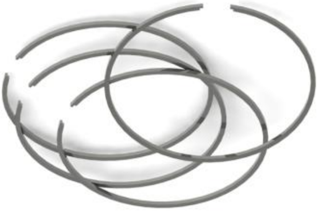
As shown in the last step, the declining criterion is reached in the fourth step, i.e. the original start volume for the declining test, in this case 1300 mL (obtained in 12.2.2,) must be at least tripled (see Chapter 5.2.3.2,) resulting in a total extraction volume of 3900 mL for the routine inspection of this component.

12.3 Example 2 - piston rings

12.3.1 Task

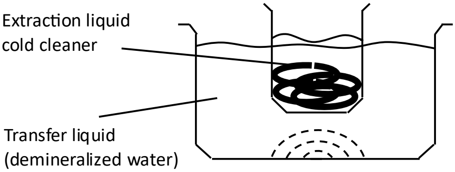
Based on the following inspected object data (without cleanliness specification or limit value,) we can derive an inspection procedure to determine a particle size distribution of 50 µm and up and a standard analysis.

Fibers are not considered in the specification and are omitted from the inspection.

Component data		
Component type	Piston rings, steel coated	approx. 10 cm diameter 
Surface – control area	50 cm²	
Limit value Particle	-	
Limit value Gravimetry	-	

12.3.2 Extraction method selection

In the first step, the extraction method is selected based on the size, geometry and position of the relevant component surfaces and the material.

<table>
<tr><th colspan="3">Extraction method selection</th><th>Chapter</th></tr>
<tr><td>Extraction method</td><td colspan="2">Due to the size and accessibility of the entire surface, the piston rings are suitable for the **ultrasonic** method of extraction.</td><td>3.1.1.2
3.1.3.2
Table 3-4</td></tr>
<tr><td>Extraction medium</td><td colspan="2">Since this is a steel component that also comes in contact with fuel when used in the engine, it is solvent-resistant; a cold cleaner is selected (solvent unpolar).
 </td><td>Table 6-2</td></tr>
<tr><td>Inspection lot size</td><td colspan="2">With smaller components, it is recommended to select a minimum test surface of 200 cm², which corresponds to **four components**.</td><td>6.4.3.2</td></tr>
<tr><td rowspan="3">Start parameters</td><td>Ultrasonic frequence</td><td>38 kHz</td><td rowspan="3">Table 6-7</td></tr>
<tr><td>cavitation noise level</td><td>≥ 206 dB</td></tr>
<tr><td>Duration</td><td>30 s</td></tr>
</table>

12.3.3 Selecting the filtration

A standard analysis should be performed. There the **5 µm PET sieve cloth filter** should be used (see also Chapter 7.1.1 and Figure 7-3).

12.3.4 Selecting the analysis method

The analysis should be performed as a light-optical standard analysis. The appropriate microscopes or scanners, the necessary optical resolution and the required parameters for image brightness and threshold are indicated in Chapter 8.2.2.2.

12.3.5 Qualification of the inspection procedure

To determine the necessary extraction time, a declining test is performed using the ultrasound parameters and starting extraction time selected in 12.3.2. The results of the individual declining steps (extractions 1 to 6) are listed in der following table. The declining value in the last column is calculated by adding up all the particles > 50 µm (second-to-last column). The calculation is performed as described in Chapter 5.2.3.1 and Figure 5-1.

Declining test	**Size channel in microns**								**Declining values**
	50 ≤x< 100	100 ≤x< 150	150 ≤x< 200	200 ≤x< 400	400 ≤x< 600	600 ≤x< 1000	x≥ 1000	∑ x≥ 50µm	
Extraction 1	3593	746	272	129	12	4	2	4758	-
Extraction 2	889	180	64	33	7	2	0	1175	0.20
Extraction 3	1031	224	70	27	7	0	0	1359	0.19
Extraction 4	1208	349	126	59	2	1	0	1745	0.19
Extraction 5	875	204	80	34	4	0	0	1197	0.12
Extraction 6	1157	242	78	28	2	0	0	1507	0.13

Conclusion: Within six extractions, no decline below the 10% criterion could be reached, i.e. the extraction procedure is not suitable this way; the routine inspection procedure cannot be derived.

The extraction parameters have to be adjusted appropriately, or a different extraction method must be selected, and the declining test must be repeated with **a new inspection lot** (see also Chapter 5.2.3.1 and Figure 5-4 in the annex).

12.3.6 Selecting an alternative extraction method

Given the failed declining test, the high number of particles detached in every extraction step and the fact that the components are coated, it seems likely that the cavitation effect of the ultrasonics has damaged the coating. This damage results in a release of particles that does not diminish.

To redo the declining test with a new inspection lot of piston rings, rinsing is selected as the extraction method.

<table>
<tr><th colspan="3">Selecting an alternative extraction method</th><th>Chapter</th></tr>
<tr><td>Extraction method</td><td colspan="2">Due to the size and accessibility of the entire surface, the piston rings are also suitable for the **rinsing** method of extraction.</td><td>3.1.1.2
3.1.3.2
Table 3-4</td></tr>
<tr><td>Extraction medium</td><td colspan="2">Cold cleaner is kept as the extraction medium
</td><td>Table 6-2</td></tr>
<tr><td>Inspection lot size</td><td colspan="2">With smaller components, it is recommended to select a minimum test surface of 200 cm², which corresponds to **four components**.</td><td>6.4.2.2</td></tr>
<tr><td rowspan="4">Start parameters</td><td>Nozzle</td><td>2.5 mm round jet nozzle</td><td rowspan="4">Table 6-3</td></tr>
<tr><td>Volume flow</td><td>1.5 l/min</td></tr>
<tr><td>Distance from component</td><td>max. 15 cm</td></tr>
<tr><td>Start quantity per cm²</td><td>$V_{St/A} = 5\frac{mL}{cm^2} \times \sqrt{\frac{200\ cm^2}{A_{cp}}}$</td></tr>
<tr><td>Start volume per component</td><td colspan="2">$V_{St} = 5\frac{mL}{cm^2} \times \sqrt{200cm^2 \times A_{cp}}$
with A_{cp} = 50 cm² follows
$V_{St} = 5\frac{mL}{cm^2} \times \sqrt{200cm^2 \times 50cm^2} = 500$ mL</td><td>6.4.2.2</td></tr>
<tr><td>Start volume per inspection lot</td><td colspan="2">V_{St} = 500 mL x 4 = 2000 mL</td><td>6.4.2.2</td></tr>
</table>

12.3.7 Repeating the qualification measurement

A new declining test is performed with the rinsing parameters selected in 12.3.6 and the starting extraction time calculated based on the component surface and number of components in the inspection lot. The results of the individual declining steps (extractions 1 to 6) are listed in der following table.

Declining test	**Size channel in microns**								**Declin-ing values**
	50 ≤x< 100	100 ≤x< 150	150 ≤x< 200	200 ≤x< 400	400 ≤x< 600	600 ≤x< 1000	x≥ 1000	∑ ≥ 50µm	
Extraction 1	1121	191	113	47	21	6	0	1499	-
Extraction 2	180	35	22	8	0	0	0	245	0.14
Extraction 3	349	23	11	11	1	0	0	395	0.18
Extraction 4	101	34	19	7	0	0	0	161	0.07
Extraction 5	79	21	7	3	0	0	0	110	0.05
Extraction 6	87	31	9	4	1	0	0	132	0.05

12.3.8 Deriving the routine inspection

As shown in the preceding section, the declining criterion can now be met with the rinsing extraction method despite the sensitive coating in the fourth step. So the original start volume for the declining test, in this case 2000 mL (obtained in 12.3.6,) must be at least tripled (see Chapter 5.2.3.2,) resulting in a total extraction volume of 6000 mL for the routine inspection of these components.

12.4 Example 3 - hydraulic cylinder

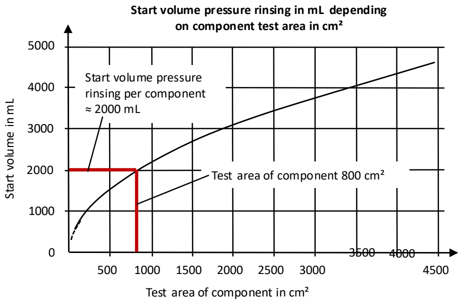
12.4.1 Task

Based on the following inspected object data and cleanliness specification or limit value for the interior of the component, we can derive an inspection procedure. Fibers are not considered in the specification and are omitted from the inspection.

<table>
<tr><th colspan="4">Component data</th></tr>
<tr><td>Component type</td><td colspan="2">Hydraulic cylinder, steel, interior lapped with oil</td><td rowspan="9">Length approx. 30 cm,
Diameter approx. 10 cm
</td></tr>
<tr><td>Surface – control area</td><td colspan="2">800 cm² (inside)</td></tr>
<tr><td rowspan="6">Limit value Particles/1000 cm²</td><td>Size class in µm</td><td>Particle quantity</td></tr>
<tr><td>$100 \le x < 150$</td><td>250</td></tr>
<tr><td>$150 \le x < 200$</td><td>80</td></tr>
<tr><td>$200 \le x < 400$</td><td>18</td></tr>
<tr><td>$400 \le x < 600$</td><td>3</td></tr>
<tr><td>$600 \le x$</td><td>0</td></tr>
<tr><td>Limit value Gravimetry/1000 cm²</td><td colspan="2">4 mg</td></tr>
</table>

12.4.2 Extraction method selection

In the first step, the extraction method is selected based on the size, geometry and position of the relevant component surfaces, the material and the expected accompanying contamination (oil, see component data).

Extraction method selection			**Chapter**
Extraction method	Due to its size and the large opening, the hydraulic cylinder is suitable for the **rinsing** extraction method, even though the specification applies to the interior.		3.1.1.2 3.1.3.2 Table 3-4
Extraction medium	Since this is a steel component and accompanying contamination with oil is expected, a **cold cleaner** is selected (solvent unpolar).		Table 6-1 Table 6-2
Start parameters	Nozzle	2.5 mm round jet nozzle	Table 6-3
	Volume flow	1.5 l/min	
	Distance from component	max. 15 cm	
	Start quantity per cm²	$V_{St/A} = 5\frac{mL}{cm^2} \times \sqrt{\frac{200\ cm^2}{A_{cp}}}$	
Start volume	 V_{St} = 2000 mL		Figure 6-8

12.4.3 Selecting the filtration

Since only particles > 50 µm are specified and there is no other information that needs to be considered for filter selection, the 5 µm PET mesh standard filter can be used (see also Chapter 7.1.1 and Figure 7-3).

12.4.4 Selecting the analysis method

The selection of the analysis method likewise depends on the cleanliness specification. In this example, a particle size distribution starting at 100 µm is specified, and there is a gravimetric limit value but no other information on particle materials or low-contrast particles. The analysis can thus be performed as a light-optical standard analysis. The appropriate microscopes or scanners, the necessary optical resolution and the parameters for image brightness and threshold are indicated in Chapter 8.2.2.2. For gravimetric analysis (see Chapter 8.2.1), the laboratory only has a four-digit scale available, i.e. readable to 0.1 mg. The consequences on the detectability of the limit value and the blank value are explained in the following section.

12.4.5 Qualification of the inspection procedure

Since, in this example, the cleanliness specification pertains to an area of 1000 cm^2 but the relevant component surface is only 800 cm^2, the first step is to recalculate the cleanliness specification for the component. This is shown in the following table: The values contained in the “limit value per component” line result from the values of the “limit value per 1000 cm^2” line divided by 1000 and multiplied by the component area of 800 cm^2. From these values per component, we then obtain the permissible blank value for the inspection by dividing by 10 (blank value may only be 10% of cleanliness value of the component) and rounding to the whole particle numbers (see also Chapter 5.3 and Table 5-3).

	Size channel in microns						**Residue weight in mg**
	100 ≤x< 150	150 ≤x< 200	200 ≤x< 400	400 ≤x< 600	600 ≤x< 1000	x≥ 1000	
Limit value per 1000 cm^2	250	80	18	3	0	0	4.0
Limit value per component	200	64	14	2	0	0	3.2
required blank value	20	6	1	0	0	0	0.32

At this point, we already run into a problem with gravimetric analysis. Since only a four-digit scale with a detection limit of one milligram is available (the last decimal place of the scale is used for rounding, not for measuring,) the blank value cannot be determined with this scale (see also Annex A 8.2.1).

To determine the necessary extraction time, a declining test is performed using the rinsing parameters and rinsing volume selected in 12.4.2. The results of the individual declining steps (extractions 1 to 6) are listed in der following table. The declining value in the last column is calculated by adding up all the particles > 100 µm (second-to-last column). The calculation is performed as described in Chapter 5.2.3.1 and Figure 5-4 in the annex.

Declining measurement	**Size channel in microns**						**Declining values**
	100 ≤x< 150	150 ≤x< 200	200 ≤x< 400	400 ≤x< 600	600 ≤x< 1000	∑ ≥ 100µm	
Extraction 1	310	120	25	4	2	461	
Extraction 2	48	19	4	1	0	72	0.14
Extraction 3	15	7	2	0	0	24	0.04
Extraction 4	16	9	1	0	0	26	0.04
Extraction 5	12	6	2	1	0	21	0.03
Extraction 6	13	7	1	0	0	21	0.03

Declining test	**Residue weight in mg**	
	Scale reading	Correctly indicated measured value
Extraction 1	2.4	3
Extraction 2	0.6	< 1
Extraction 3	0.3	< 1
Extraction 4	0.5	< 1
Extraction 5	0.2	< 1
Extraction 6	0.4	< 1

The gravimetric evaluation of the declining test reveals that, in the second declining step, the value is too low for the four-digit scale to detect (see also Chapter 8.2.1.4) and remains too low to detect in the subsequent declining steps. So it is possible to use the declining test based on the light-optical standard analysis and particle size distribution determination, which is permissible, as described in Chapter 5.2.3.

12.4.6 Deriving the routine inspection

As shown in the last step, the declining criterion is reached in the third step, i.e. the original start volume for the declining test, in this case 2000 mL (obtained in 12.4.2,) must be at least doubled (see Chapter 5.2.3.2,) resulting in a total extraction volume of 4000 mL for the routine inspection of this component.

12.4.7 Performing the routine inspection and checking the final rinsing procedure

In the following routine inspection procedure, the optimized extraction procedure is applied to a new component in order to check if the cleanliness specification is observed. Before and after this first routine inspection, a blank value is determined (see also Chapter 5.3 and Chapter 5.2.3.4).

The blank value determination before the routine inspection shows that the extraction apparatus is suitable and conditioned so as to be suitable for testing this component with the associated cleanliness specification.

The blank value after the first routine inspection shows whether or not the final rinsing procedure is able to adequately clean out the particles brought into the extraction apparatus during the extraction of this component and rinse them onto the analysis filter.

This second blank value, which is only mandatory once after the first routine inspection, is thus used to qualify the final rinsing procedure.

Routine inspection	**Size channel in microns**						**Residue weight in mg**	
	100 ≤x< 150	150 ≤x< 200	200 ≤x< 400	400 ≤x< 600	600 ≤x< 1000	x≥ 1000	Scale reading	Correctly indicated value
Target blank value	20	6	1	0	0	0	0.32	0.32
Blank value before	10	2	0	0	0	0	0.4	< 1
Cleanliness specification	200	64	14	2	0	0	3.2	3.2
Result of routing inspection	350	140	30	4	1	0	2.6	< 3
Blank value after	45	19	4	1	0	0	0.5	< 1

The result shows that:

- The blank value which is determined before the test by particle size distribution is OK. The extraction apparatus is suitable and sufficiently clean following conditioning.
- The inspected object cannot meet the cleanliness specification with regard to particle size distribution. This was already shown in the declining test in Section 12.4.5; the first declining step had already produced particle counts that are above the specification as well as one particle > 600 µm, which is not permissible.
- The inspected object cannot meet the gravimetric specification. This can be stated confidently, even though the blank value can no longer be determined sufficiently precisely with the four-decimal scale.

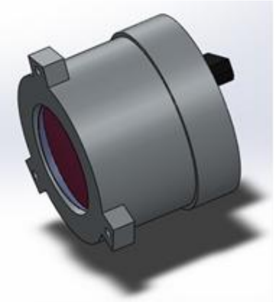
- The blank value after the routine inspection is above the permissible value and therefore not OK. This shows that the final rinsing procedure is not sufficient and needs to be optimized. It will then need to be checked whether or not the gravimetric cleanliness specification is still met by the optimized final rinsing procedure.

12.5 Example 4 – optical sensor

12.5.1 Task

Based on the following inspected object data and cleanliness specification or limit, we can derive an inspection procedure.

Fibers are not considered in the specification and are omitted from the inspection.

<table>
<tr><th colspan="4">Component data</th></tr>
<tr><td>Component type</td><td colspan="2">Optical sensor,
metal, glass, electronics,
plastic</td><td rowspan="9">Length approx. 3 cm,
diameter approx. 3 cm
</td></tr>
<tr><td>Surface – control area</td><td colspan="2">45 cm²</td></tr>
<tr><td rowspan="6">Limit value Particle</td><td>Size class in µm</td><td>Particle count</td></tr>
<tr><td>$15 \le x < 25$</td><td>200</td></tr>
<tr><td>$25 \le x < 50$</td><td>40</td></tr>
<tr><td>$50 \le x < 100$</td><td>10</td></tr>
<tr><td>$100 \le x < 200$</td><td>1</td></tr>
<tr><td>$200 \le x$</td><td>0</td></tr>
<tr><td>Limit value Gravimetry</td><td colspan="2">-</td></tr>
</table>

12.5.2 Extraction method selection

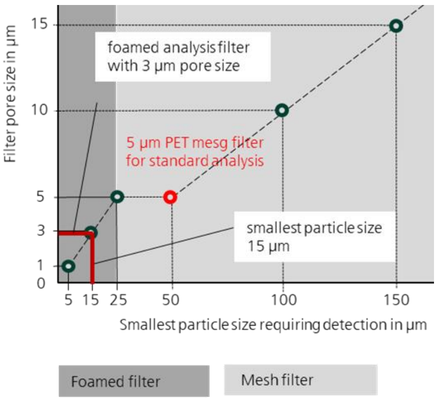
In the first step, the extraction method is selected based on the size, geometry and position of the relevant component surfaces and the material.

<table>
<tr><th colspan="3">Extraction method selection</th><th>Chapter</th></tr>
<tr><td>Extraction method</td><td colspan="2">Since the part includes electronic and optical components and is therefore very sensitive, ultrasonics and pressure-rinsing are excluded as extraction methods. This leaves us with **low-pressure rinsing** in a beaker (low blank values) as the extraction method and extraction apparatus.</td><td>3.1.1.2
3.1.3.2
Table 3-4</td></tr>
<tr><td>Extraction medium</td><td colspan="2">**Aqueous cleaner** due to compatibility with material mix of metal, plastic, glass and electronics</td><td>Table 6-2</td></tr>
<tr><td rowspan="4">Start parameters</td><td>Nozzle</td><td>2.5 mm round jet nozzle</td><td rowspan="4">Table 6-4</td></tr>
<tr><td>Volume flow</td><td>0.5 l/min</td></tr>
<tr><td>Distance from component</td><td>max. 5-10 cm</td></tr>
<tr><td>Start quantity per cm²</td><td>$V_{St/A} = 5\frac{mL}{cm^2} \times \sqrt{\frac{200\ cm^2}{A_{cp}}}$</td></tr>
<tr><td>Start volume</td><td colspan="2">Only one component is available for the qualification of the inspection procedure and for the routine inspection. This is not enough to obtain the recommended minimum test area of 200 cm².
The start quantity for the declining test is calculated using the formula:
$V_{St} = 5\frac{mL}{cm^2} \times \sqrt{200cm^2 \times A_{cp}}$
with A_{cp} = 45 cm² follows
$V_{St} = 5\frac{mL}{cm^2} \times \sqrt{200cm^2 \times 45cm^2}$ =475 mL</td><td>6.4.2.2</td></tr>
</table>

12.5.3 Selecting the filtration

A **foamed 3 µm polyamide filter** is selected. The pore size results from the lower particle limit of 15 µm.

A foamed filter is used due to the smooth surface structure, which is advantageous for the light-optical analysis at high magnification (see also Chapter 7.1.1 and Figure 7-3).



12.5.4 Selecting the analysis method

The selection of the analysis method likewise depends on the cleanliness specification.

Particle size	Optical resolution
≥ 50 µm	≤ 5,0 µm/pxl
≥ 25 µm	≤ 2,5 µm/pxl
≥ 15 µm	≤ 2,5 µm/pxl
≥ 5 µm	≤ 1,0 µm/pxl

In this example, a particle size distribution starting at 15 µm is specified. There is no gravimetric limit value and no other information on particle materials or low-contrast particles.

So the analysis can be done as a free light-optical analysis (see Chapter 8.2.2.3). The appropriate microscopes or scanners and the necessary optical resolution are indicated in Chapter 8.2.2.1; the required parameters for image brightness and threshold can be taken from the standard analysis (see Chapter 8.2.2.2).

12.5.5 Declining test and definition of the routine inspection procedure

This example does not explicitly describe the implementation of the declining test or the derivation of the fluid volume required for the routine inspection. For the remaining elements, note only that the declining test was successful and the extraction liquid needs to be doubled to 950 ml.

12.5.6 Performing a routine inspection

When performing cleanliness inspections on small parts with very strict cleanliness requirements, as in this example, even with a lot of effort and special highly clean extraction apparatuses, it can be difficult to comply with the blank value criterion, as seen in the following results.

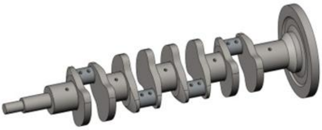
Routine inspection	**Size channel in microns**				
	15 ≤x< 25	25 ≤x< 50	50 ≤x< 100	100 ≤x< 150	x≥ 150
Limit value per component	200	40	10	1	0
required blank value	20	4	0	0	0
Result Routine inspection	175	35	5	1	0
Result of blank value determination	48	8	2	0	0

Even if the blank value cannot be observed due to strict cleanliness requirements, it is still possible to demonstrate that the part is within the specification (see also Chapter 5.3.5).

12.6 Example 5 – crankshaft

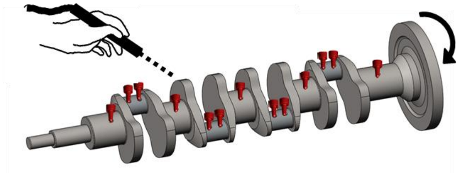
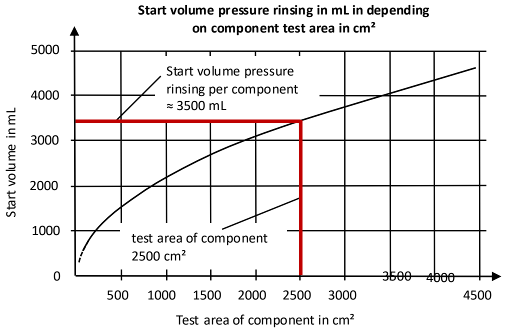
12.6.1 Task

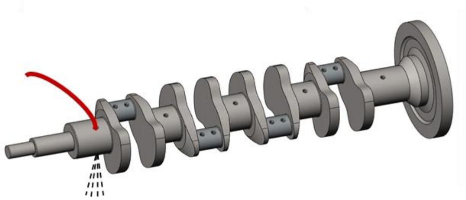
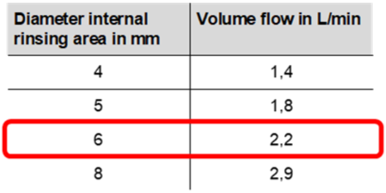
The following example describes an inspected object that has two different functional areas with separate cleanliness specifications. A preliminary extraction procedure needs to be developed for performing the declining tests. Fibers are not considered in the specification and are omitted from the inspection.

Component data			
Component type	Crankshaft: steel with oil-based corrosion protection		Length approx. 55 cm, diameter approx. 14 cm 
Inspected areas	Outside: 2500 cm²	Oil bores: Diameter 6 mm	
Limit values	Residue weight: max. 10 mg	no particles over 600 µm, no abrasives > 50µm permissible	

12.6.2 Extraction method selection

In the first step, the extraction methods are selected based on the size, geometry and position of the relevant component surfaces and the material. Since there are two control areas with different cleanliness requirements, these areas need to be extracted separately from one another. To the extent possible, carry-over between the control areas must be avoided.

<table>
<tr><th colspan="3">Outside: Extraction method selection</th><th>Chapter</th></tr>
<tr><td>Extraction method</td><td colspan="2">Due to its accessibility and size, the outside of the crankshaft is suitable for the **pressure-rinsing** method of extraction. Important: The oil channels that need to be sampled in a second extraction step must be sealed (red plugs).
</td><td>3.1.1.2
3.1.3.2
Table 3-4
6.3.3</td></tr>
<tr><td>Extraction medium</td><td colspan="2">Since this is a steel component with oil-based corrosion protection as accompanying contamination, a **cold cleaner** is selected (solvent unpolar).</td><td>Table 6-1</td></tr>
<tr><td rowspan="4">Start parameters</td><td>Nozzle</td><td>2.5 mm round jet nozzle</td><td rowspan="4">Table 6-3</td></tr>
<tr><td>Volume flow</td><td>1.5 l/min</td></tr>
<tr><td>Distance from component</td><td>max. 15 cm</td></tr>
<tr><td>Start quantity per cm²</td><td>$V_{St/A} = 5\frac{mL}{cm^2} \times \sqrt{\frac{200\,cm^2}{A_{cp}}}$</td></tr>
<tr><td>Start volume</td><td colspan="2">
V_{St} = 3500 mL</td><td>Figure 6-8</td></tr>
</table>

<table>
<tr><th colspan="2">Oil bores: Extraction method selection</th><th>Chapter</th></tr>
<tr><td>Extraction method</td><td>Due to their geometry and size, the oil channels are suitable for internal rinsing. The individual oil channels are connected to a rinsing hose (red) and rinsed out one after the other. The discharged internal rinsing liquid runs down into the collector of the extraction apparatus without pressure. Since the outside was extracted beforehand, the risk of carry-over is minimized.
</td><td>3.1.1.2
3.1.3.2
Table 3-4</td></tr>
<tr><td>Extraction medium</td><td>Cold cleaner as before with pressure-rinsing</td><td>Table 6-1</td></tr>
<tr><td>Start parameters</td><td>The flow rate depends on the diameter of the channels to be rinsed and can be calculated or read from a table for the cold cleaner.</td><td>6.4.4.2</td></tr>
<tr><td>Start volume flow and start duration</td><td><table><tr><th>Diameter internal rinsing area in mm</th><th>Volume flow in L/min</th></tr><tr><td>4</td><td>1,4</td></tr><tr><td>5</td><td>1,8</td></tr><tr><td>6</td><td>2,2</td></tr><tr><td>8</td><td>2,9</td></tr></table>Start volume flow = 2.2 l/min
30 seconds are selected as a plausible and manageable starting duration, resulting in 1.1 liters of extraction liquid per borehole.</td><td>Table 6-11</td></tr>
</table>

12.6.3 Selecting the filtration

Since a gravimetric cleanliness requirement is specified for the outside of the crankshaft, the standard filter, i.e. the **5 µm PET sieve cloth filter**, should be used (see also Chapter 7.1.1 and Figure 7-3).

In the specification for the oil channels, the largest permissible particle of 600 µm must be retained as well as (abrasive) particle of 50 µm and up. The **5 µm PET sieve cloth filter** is suitable for these requirements, too, and should be used. Since the inspection will be done on abrasive particles in the SEM/EDX, it might also make sense to use a **5 µm PA sieve cloth filter** in this case, since it has better material contrast against the low-contrast abrasives, e.g. corundum or silicon carbide, than PET. It is important that the inspection be done separately and consecutively for the two functional areas and, accordingly, that two separate analysis filters are used.

12.6.4 Selecting the analysis method

The gravimetric requirement of 10 mg for the outside of the crankshaft and the corresponding blank value of 1 mg can be checked with a four-digit scale (see Chapter 8.2.1).

The “no abrasive particles > 50 µm” requirement can be checked in the SEM/EDX standard analysis (Chapter 8.2.3.2) using the material database defined there. Here, it is possible to detect mineral particles that are designated as potentially hard, or we can search directly for special abrasives such as corundum or silicon carbide if they are used in the associated production process. It is important to perform a meticulous manual follow-up check if particles are classified in the automatic analysis as potentially hard or abrasive, because the categorization of the particles is done based on their elemental composition, which cannot be clearly associated with a material or particle property. To further evaluate the particles, we can look at their shape, for example.

The largest permissible particle of 600 µm can also be checked through automatic SEM/EDX analysis. However, due to the lack of material contrast, no organic particles such as plastics or wood can be detected. In case of doubt, this requirement should be checked (again) with a light-optical analysis system.

12.7 Example 6 – battery and drive electronics

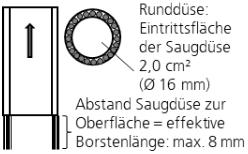
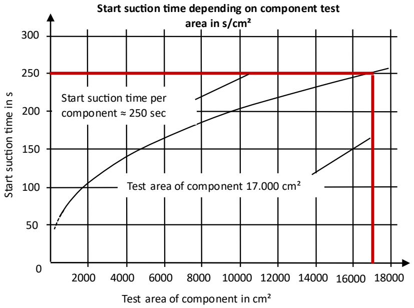
12.7.1 Task

Based on the following inspected object data and cleanliness specification or limit, we can derive an inspection procedure. Fibers are not considered in the specification and are omitted from the inspection.

<table>
<tr><th colspan="4">Component data</th></tr>
<tr><td>Component type</td><td colspan="2">Battery and drive electronics: metal electronics, plastic</td><td rowspan="8">Length approx. 120 cm
Width approx. 60 cm
Height approx. 25 cm
Weight approx. 30 kg
</td></tr>
<tr><td>Surface – control area</td><td colspan="2">17,000 cm²</td></tr>
<tr><td rowspan="5">Limit value Particle</td><td>Size class in µm</td><td>Particle count</td></tr>
<tr><td>200 ≤ x < 400</td><td>1000</td></tr>
<tr><td>400 ≤ x < 600</td><td>500</td></tr>
<tr><td>600 ≤ x < 1000</td><td>130</td></tr>
<tr><td>1000 ≤ x</td><td>0</td></tr>
<tr><td>Limit value Gravimetry</td><td colspan="2">-</td></tr>
</table>

12.7.2 Extraction method selection

In the first step, the extraction method is selected based on the size, geometry and position of the relevant component surfaces and the material. Since it is very expensive, the assembly should be reused after the extraction. So it must not be damaged by the extraction process. This excludes liquid extraction methods as an option, since the complex structure of the electronics prevent quick and residue-free drying, and there is a high risk of damage due to the extraction liquid. Out of the dry extraction methods, the stamping method is also disqualified due to the complex structure.

<table>
<tr><th colspan="3">Extraction method selection</th><th>Chapter</th></tr>
<tr><td>Extraction method</td><td colspan="2">The remaining potentially suitable dry extraction methods are (brush) suction and air jet extraction, which are both suitable based on the geometry and accessibility of the relevant component surfaces. The following consideration and calculations in this example pertain to (brush) suction.
Air jet extraction can be done using equivalent starting conditions, in accordance with Chapter 6.5.1.</td><td>3.1.1.2
3.1.3.2
Table 3-5</td></tr>
<tr><td>Extraction medium</td><td colspan="2">Air</td><td></td></tr>
<tr><td rowspan="4">Start parameters</td><td>Suction nozzle with brush attachment</td><td>
</td><td rowspan="4">Table 6-15</td></tr>
<tr><td>Volume flow</td><td>≥ 20 m³/h</td></tr>
<tr><td>Suction distance</td><td>Brush with pressureless component contact</td></tr>
<tr><td>Start suction time per cm²</td><td>$t_{St/A} = \frac{(60 \times A_{cp})^{0,4}}{A_{cp}}$</td></tr>
<tr><td>Start suction time</td><td colspan="2">

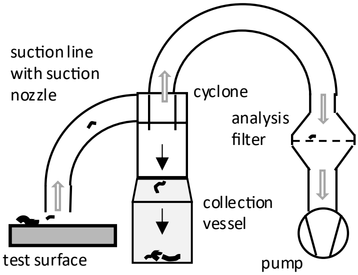
$t_{St} = 3 \times 250\ \text{s} = 750\ \text{s}$
Since the inspected object structure is not even but instead very complex, the determined start suction time is tripled</td><td>Figure 6-21</td></tr>
</table>

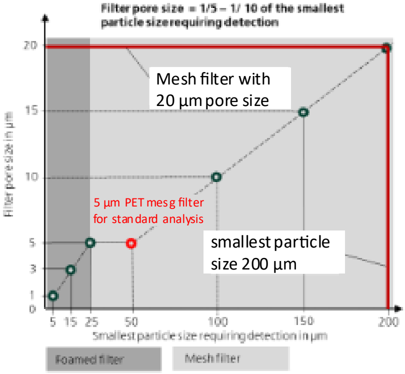
12.7.3 Selecting the filtration

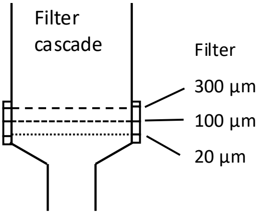
Due to the size of the component, we can expect a large quantity of particles. Accordingly, instead of being filtered directly on an analysis filter in the suction step, the particles are instead first separated out into a sampling bottle using a cyclone separator.

In the next step, the contents of the sampling bottle is washed out with fluid and filtered through a **filter cascade** with three filters. The **20 µm pore size** of the finest **sieve cloth filter** (bottom filter of the cascade) results from the smallest particle size of the cleanliness specification (see Chapter 7.1.1 and Figure 7-3).

The two larger sieve cloth filters are selected in the sizes **100 µm and 300 µm**. An additional filter is place on the suction side of the cyclone separator to be on the safe side, in case some particles are not separated out by the cyclone separator. Due to the cleanliness specification, a 20 µm filter is also used in this case.







12.7.4 Selecting the analysis method

For the analysis, **all four filters** (three in the cascade, one on the suction side of the cyclone separator) are **evaluated**, and the analysis results are added up. In this example, a particle size distribution starting at 200 µm is specified. There is no gravimetric limit value and no other information on particle materials or low-contrast particles. The analysis can therefore be performed as a light-optical standard analysis. The appropriate microscopes or scanners, the necessary optical resolution and the required parameters for image brightness and threshold are indicated in Chapter 8.2.2.2.

13 DEFINITIONS, ABBREVIATIONS AND SYMBOLS

13.1 Terms and definitions

A

Aerosol formation: atomization of a liquid to create small droplets, e.g. in pressure-rinsing due to the shape of nozzles or impaction of the pressure-rinsing jet on a surface

Agglomerate: collection of solid matter to form a larger structure

Agitation: extraction method implemented for internal surfaces; its cleaning effect is based on the turbulent change in direction of the extraction liquid inside the component

Air cleanliness class: specification of air quality based on the concentration of particles in a defined volume of air (according to ISO 14644-1)

Analysis filter: a thin membrane, either meshed or foamed, possessing defined deposition properties that cause particles of a specific size to be retained during filtration

Analysis liquid: liquid containing the particle load to be analyzed

Analysis parameters: settings on an analysis system that are used in the analysis step

Analysis scale: scale with a high (10^{-4} g) to very high (10^{-5} g) resolution capable of weighing minute quantities of particulate residue

Analysis system: device to measure and/or characterize particles

B

Binarization: process in which the color or gray scale images are converted into digital binary images composed of black and white pixels (basis of image analysis)

Binarization threshold: criterion, e.g. threshold, used for binarization.

Blank value: particle load accruing during a cleanliness inspection that does not originate from the inspected object but rather proportionately from the extraction, the equipment, the environment or the personnel

Blank value criterion: maximum value that may not be exceeded when determining the blank value, i.e. max. 10% of the required or anticipated cleanliness value

Blank value determination/blank value verification: determining the blank value using the designated blank value procedure

Blank value procedure: procedure (based on the relevant components of the test equipment, etc.) for determining the blank value

C

Calibration: An operation which, under specified conditions, in a first step establishes a relationship between the variables provided by standards with measurement uncertainties and the corresponding indications with their associated measurement uncertainties and in a second step, uses this information to establish a relation for obtaining a measurement result from an indication

Cavitation: formation and subsequent collapse of vapor bubbles as a result of high sound pressures

Cleaning: removal of (particulate) contaminants from a surface

Cleanliness inspection: inspection of technical cleanliness including documentation

Cleanliness Level: a number (coded) assigned to a specific particle count that is numerically incorporated into the CCC

Cleanliness specification: documentation of permissible particle features and quantities for a component

Cleanliness state (also component cleanliness): cleanliness value(s) of a component that may change over time due to external influences

Cleanliness value: a single value specifying the cleanliness of a component, e.g. residue weight, longest particle or particle count

Collecting container (also: collecting tray/vessel): container to collect the extraction liquid for later filtration

Component Cleanliness Code (CCC): alphanumeric character sequence containing information about the particle size distribution in coded form

Component family: Group of components that share similar design characteristics (geometric characteristics,) a similar manufacturing process and similar material or surface properties.

Conditioning: cleaning the testing equipment up to the required test capability, i.e. to the necessary blank value that is required for the subsequent cleanliness inspection

Conformity assessment: verification that defined requirements pertaining to the inspected object are met (based on ISO/IEC 17000)

Control area: general term for an inspection surface or control volume of an inspected object from which residues are to be extracted

D

Damaging particle: particle that can potentially damage the component due to its geometrical dimensions or its chemical-physical properties

Decline: a decrease in the contamination level of a component during a declining test

Declining criterion: parameter that shows whether a decline has occurred

Declining test: procedure used to verify the efficacy and suitability of extraction parameters in which the extraction step is repeated six times on the same inspected object in an identical manner

Declining value: quotient of the cleanliness value under consideration and the sum of all preceding cleanliness values (including that under consideration,) expressed in percent

Desiccator: laboratory device for cooling the analysis filter in a completely dry atmosphere

Direct inspection: analysis method capable of detecting contamination directly on the component surface without the need for an extraction or filtration step

Double inspection: procedure in which two identical extraction steps are performed in order to confirm the efficacy and suitability of qualified extraction parameters. The declining criterion is set at 30%

E

Effective filter surface area: area of the analysis filter membrane through which analysis liquid flows during the filtration step

Element analysis (EDX): Energy Dispersive X-ray spectroscopy capable of analyzing elements based on their characteristic x-ray spectra

Extraction (also: sampling): procedure used to detach particulate residues from an inspected object with the aid of an extraction fluid

Extraction apparatus: equipment used to perform the extraction

Extraction parameters: totality of all physical parameters influencing the extraction which can be set on or calculated from the extraction apparatus

Extraction procedure: complete sequence of all extraction steps performed.

Extraction step (also: sampling step): single work step forming part of the extraction procedure that is performed either in a declining test or when sampling several control areas

Extraction method: Procedure for removing the particle load from the inspected object

F

Fiber: long, thin structure which is defined by the following: Ratio between stretched length and maximum inner circle diameter is greater than 20; the width measured via maximum inner circle diameter is lower or equal to 50 µm

Filter membrane: see analysis filter

Filter occupancy: surface area of the analysis filter covered by particles, expressed in percent

Filter pore size: for mesh filters, this equates to the nominal mesh width; for foamed analysis filters, it corresponds with the equivalent mesh width measured by means of the bubble point test.

Filter housing: housing that holds a filter for the purpose of direct filtration (integrated component of an extraction apparatus)

Filtration unit: device for holding a filter in order to perform a separate filtration

Filter background: color of the analysis filter

Filtration: process in which particles are deposited on the analysis filter

Final rinsing: Final step of extraction, in which particles removed from the component are transferred from the extraction apparatus (or, in the ultrasonic method, particles that have resettled on the component as sediments) onto the analysis filter

Final rinsing procedure: procedure for final rinsing

Final rinsing liquid: liquid used after the extraction step to remove any particulate residues from the surfaces of the extraction apparatus and deposit them on the analysis filter

Fixative: liquid used to fix particles on the analysis filter to prevent their loss though electrostatic charging

Flat jet nozzle (also: fan nozzle): nozzle that generates a linear jet on impaction on a smooth surface (jet width and equivalent bore diameter as relevant parameters)

Free jet (also: jet): a fluid flowing freely into the environment from a nozzle

G

Gravimetry: analysis method used to determine the mass of all residues present on the analysis filter by measuring differences in weight

H

Hydrophone: Device for converting waterborne sound into an electrical voltage corresponding to the sound pressure (used to determine the cavitation noise level in ultrasonic baths)

I

Inspection/inspection procedure: term used to describe the full sequence of all work steps (preparatory steps, extraction, filtration, analysis) carried out in the course of a cleanliness inspection

Inspection lot: all inspected objects from which the combined particle load is measured in a cleanliness inspection

Inspection lot size: number of inspected objects in an inspection lot

Inspection packaging: packaging that differs from the series packaging and allows the inspected object to be delivered in accordance with cleanliness requirements

Inspection record: documentation of the materials, equipment and parameters etc. used in the inspection. (For contents, see Chapter 9)

Inspection report: document containing clear, summarized, general information together with details on the inspected object and the extraction, filtration and analysis steps as well as a representation of the inspection results

Inspection specification (also: inspection guideline): detailed description of the inspection procedure (where appropriate, also with the inclusion of illustrations, etc., to provide assistance)

Inspection/test medium: general term for an extraction liquid or air utilized to detach contamination from the inspected object

Internal rinsing: extraction method with a cleaning effect that is based on a turbulent flow of liquid inside the component

Internal rinsing apparatus: technical construction consisting of a media supply and a fixture for holding the inspected object, which is tested by internal rinsing only, e.g. an adapted test bench for hydraulic components.

Isolation: screening of areas of the inspected object that do not form part of the control area and which should not come into contact with the extraction fluid; sealing or masking are examples of isolation methods

L

Limit value: maximum permissible value for the residue weight, particle dimension (length, width, height) or particle quantity, which may not be exceeded

M

Material analysis: general term for analyses that accurately characterize a material by means of chemical, spectroscopic, mechanical or metallographic methods

Material classification: assignment of elemental composition to a material class based on the percentages of individual elements identified

Measurement uncertainty: non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used [ISO/IEC Guide 99:2007]

Microscope: device used to magnify and visualize small objects, often containing an integrated camera system with image-processing

Monitoring: inspection of cleanliness at regular intervals with the purpose of evaluating processes relevant to cleanliness

O

Optical particle counter (OPC): inspection device used to count particles in clear liquids and measure their size; function based on the principle of scattered light or extinction

P

Particle: tiny structure made from solid organic or inorganic matter

Particle load: totality of all particles present on a surface or in a liquid

Particle size: geometric feature of a particle that is stated in the cleanliness specification. If this is not stated, the particle size corresponds with the longest dimension ($\text{Feret}_{\text{max}}$)

Particle size class (also: size class): particle size range with an upper and lower class limit

Particle size distribution (also: size distribution): particle count grouped into particle size classes

Particle standard: substrate marked with objects of a known shape and size used to verify that optical analysis systems are correctly calibrated

Particle overlap: particles overlying one another, which prevents them from being optically recorded as single particles.

Post-treatment liquid: liquid used after the filtration step to remove any filmy contaminants from the analysis filter that were not dissolved by the extraction fluid, e.g. anti-corrosives, oils or cooling lubricants

Pre-conditioning: preparation step in which the analysis filter is pressure-rinsed, dried and dehumidified before its tare weight is weighed

Preparatory steps: totality of all measures carried out after delivery of the component and before execution of the extraction procedure in order to enable all particles present solely on the control area to be detached during the extraction step (examples: disassembly, demagnetization, isolation or pre-cleaning)

Pressure-rinsing: extraction method with a cleaning effect that is generated by the kinetic energy of an open jet (impulse)

Purify: process to make a liquid, object or extraction apparatus as clean as required

Q

Qualification report: document forming part of the inspection specification that only covers the results of the declining test, or an independent document containing general information together with information on the inspected object and the extraction, filtration and analysis steps as well as on the routine inspection parameters

Qualification test: inspection procedure for recurrent routine inspections that is determined by carrying out experiments

R

Routine inspection: cleanliness inspection performed with qualified extraction parameters (recurrent)

Residue weight: mass of the particle load determined as the weight difference using the method of gravimetric analysis

S

Sampling: see extraction

Spray nozzle geometry: geometric features affecting the shape of the jet and pressure-rinsing pattern

Start parameters: parameter set defined for the extraction method which should preferably (if reasonable) be used to perform a declining test

T

Test conditions: circumstances under which the cleanliness inspection is performed

Test object (also: inspected object or component): single component, assembly or system inspected for cleanliness

Threshold: see binarization threshold

Turbulent flow: a flow of fluid with a cleaning effect generated by turbulences that is used to extract contaminants from internal component geometries. An effective turbulent flow prevails in a liquid if the following applies: Reynolds number ≥ 4000

U

Ultrasonics: extraction method with a cleaning effect based on cavitation

Ultrasound bath/tank/basin: technical device used to clean components by means of ultrasonics

V

Verification: Provision of objective evidence that a unit of observation fulfills specified requirements [ISO/IEC Guide 99:2007, 2.44]

Volumetric measurement: flow rate determined by the measurement of a volume of liquid in a set time

W

Wetted surface area/wetted volume: control area, expressed as surface area in cm^2/volume in cm^3, coming into contact with the extraction liquid during the extraction step

Z

Zero-element rule: In line with the definition of material classes for the SEM/EDX analysis, under certain conditions, an element can be set to the value “0”.

13.2 Abbreviations and symbols

A:	Unit of reference per 1000 cm2 when specifying the CCC
A_C:	Wetted surface of all inspected objects in an inspection lot
A_{CP}:	Sampled area of the inspected object in cm²
A_i:	Component-specific weighting factors in the determination of component cleanliness specifications
ATR:	Attenuated Total Reflexion
B, C, …:	Other additive contaminant amounts in the determination of component cleanliness specifications
C_n:	Cleanliness value currently under consideration
C_i:	Cleanliness value of the extraction step
CCC:	Component Cleanliness Code
CCD:	Charge coupled device
CT:	Computer tomography
d:	Internal pipe diameter
EDX:	Energy Dispersive X-ray spectroscopy (engl.: Energy Dispersive X-ray spectroscopy)
F_{sys}:	(media-contacting) surface area of the system when determining component cleanliness specifications
F_{part}:	(media-contacting) surface area of the component i when determining component cleanliness specifications
FT-IR:	Fourier transformation infrared spectrometer
G_C:	Particle mass in relation to component
G_A:	Particle mass over 1000 cm^2
G_V:	Particle mass over 100 cm^3
LV_{tot}:	Total limit value of the system when determining component cleanliness specifications
LV_{comp}:	Limit value of the component i when determining component cleanliness specifications
h	Absolute particle count for the inspection lot
H_C:	Particle count for a component
H_A:	Particle count over 1000 cm^2

H_V:	Particle count over 100 cm^3
IR:	Infrared
HC:	Hydrocarbon
LIBS:	Laser-induced breakdown spectroscopy (engl.: laser-induced breakdown spectroscopy)
λ:	Wavelength
M:	Residue weight of the particle load for the inspection lot
M1:	Tare weight of analysis filter
M2:	Total weight of occupied analysis filter
n:	Number of components in an inspection lot
N:	Unit of reference per component when specifying the CCC
NA:	Numerical aperture
v:	Kinematic viscosity in mm^2/s
OPC:	Optical particle counter
PET:	Polyethylene terephthalate
Re:	Reynolds Number, $Re = w * d / \nu$
SEM:	Scanning Electron Microscope SEM)
DOF:	Depth of field of a microscope lens
t_{st}	(Brush) suction start time per component
$t_{St/A}$:	Area-specific start volume in mL/cm^2
US:	Ultrasonics
V:	Unit of reference per 100 cm^3 when specifying the CCC
V_C:	Sampled volume of all inspected objects in an inspection lot
V_{St}:	Start volume in mL
$V_{St/A}$:	Area-specific start volume in mL/cm^2
w:	Velocity of the liquid in m/s
x:	Variable for the particle size, e.g. $150\ \mu m \leq x < 200\ \mu m$
X:	Maximum permissible particle size
z:	Particle height

14 INDUSTRIAL ALLIANCE TECSA (INFORMATIVE)

Background

Since the anti-blocking system (ABS) came onto the market and especially since diesel direct injection systems became popular in the second half of the 90's, technical cleanliness has fully established itself as a quality criterion in the automotive and supplier industries. Not only major efforts on the part of large concerns in the cleaning technology industry but also generally in the field of clean manufacturing have led to a growing demand for a standardized method for inspecting particulate contamination. As a result, in 2001 the industrial alliance TecSa was founded through which, in the course of a two-year cooperation, the first VDA Volume 19 on the "inspection of the technical cleanliness of functionally-relevant automotive components" was written. Under the expert guidance of Fraunhofer IPA and in collaboration with 25 companies predominantly active in the automotive and supplier industries, the world's first standard on this subject was created.

The first revision

Ever since the publication of VDA Volume 19 in January 2005, the topic of technical cleanliness has constantly gained in importance. A new profession has also evolved – that of the "technical cleanliness inspector". In 2011, component cleanliness was being tested as a quality characteristic in approximately 1000 laboratories in the automotive and supplier industries. In 2012, as a result of the experience acquired in this area over the years as well as numerous innovations and improvements in cleanliness inspection technology, VDA Volume 19 needed to be revised. Between 2012 and 2014, the second, revised version of the guideline was produced through the collaboration of 41 companies, 3 associations and Fraunhofer IPA. It was published in 2015 as VDA 19.1.

TecSa 3.0 industrial alliance

As with the last revision, the aims of this latest revision of VDA 19.1 centered on the comparability of analysis results, new technological possibilities and detailing and expansion of methods. Due to the shift towards electric mobility and autonomous driving, technical cleanliness has again gained in importance and is specified as a quality characteristic in nearly all new projects. This third and comprehensively revised version of VDA 19.1 was once again produced by an industrial alliance of 44 companies, with Fraunhofer IPA acting as a neutral expert coordinator, from 2023 to 2025. The contents of the new edition were developed, discussed and tested and approved as necessary over the course of approx. 30 sessions by four sub-task forces with different focus areas. For the first time, this revision included topics from a group of Chinese counterparts to German companies. The fundamental methods described in the first VDA 19, such as extraction, filtration and analysis, as well as the qualification of declining tests, have proved in practice to be highly effective and have been further optimized. The changes are summarized briefly in Chapter 1.

We would like to thank all the people involved for their motivation, constructive and helpful support, fine teamwork and faith in the work carried out by Fraunhofer IPA.

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Quality Management in the Automotive Industry

The current versions of the VDA publications covering quality management in the automotive industry (QAI) can be found on the Internet at http://www.vda-qmc.de.

You may also order via this homepage.

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