VDA | Verband der Automobilindustrie

19

Quality Management In the Automotive Industry

Inspection of Technical Cleanliness

Part 1

- Particulate contamination of functionally-relevant automotive components -

2nd Revised Edition, March2015
(former title: VDA volume 19)

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PREFACE CONCERNING THE SECOND REVISED AND EXTENDED VERSION

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 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.

At the same time, numbering was also made consistent: the guideline on “The “Inspection of Technical Cleanliness” is now called VDA 19.1 or VDA 19 Part 1. This brings it into line with the second volume titled “Technical Cleanliness in Assembly”, which is numbered VDA 19.2 or VDA 19 Part 2.

The main reasons behind its comprehensive revision (December 2012 till June 2014) were to:

- improve the comparability of cleanliness analysis results
- include new (extraction and analysis) techniques
- consider work protection within the scope of the guideline
- provide information on how to define cleanliness specifications and explain how to react when cleanliness limit values are exceeded.

The basic methods and techniques of component cleanliness analysis that were described in the first edition have proved to be very effective and are therefore included in full in the revised version in a highly-precise and more detailed form.

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The second revised and extended edition comprises the following topics and contents:

- A new informative **Chapter 2: Cleanliness specification,** in which the procedure for defining cleanliness specifications is described, taking technical requirements and the aspects of technical and economic feasibility into account.
- An extended informative **Chapter 3: Selecting the inspection method**, which explains how to choose suitable extraction procedures, analysis filtration methods and analysis techniques. Tables and graphs provide assistance in selecting the best extraction method and also show the suitability of specific analysis methods for assessing different contaminant features and cleanliness specifications.
- An abbreviated **Chapter 4: Handling test components cleanly**. The section “Preparatory steps and post-treatment of test components” that was previously located here can now be found in a more appropriate place in the chapter “Extraction”. Chapter 4 also contains a reference to VDA 19 Part 2 in which numerous aspects of this subject are addressed in detail. A new paragraph has been added to this chapter that regulates the criteria which exclude components from a cleanliness inspection.
- An extended and more precise **Chapter 5: Qualification tests and blank value**, which especially describes in a clearer and more binding manner how to perform and interpret declining tests, e.g. by specifying six mandatory declining steps.
- In the **Chapter 6: Extraction methods**, the proven methods for sampling with liquid (pressure-rinsing, ultrasonics, internal rinsing and agitation) have been supplemented, where possible, by so-called start parameters; these aim to narrow down parameter diversity in a meaningful way and thus make it easier to compare different extraction procedures. A prior dissolving step is also described that can be used on components which, due to the presence of conservation agents for example, exhibit a delayed declining behavior.

  The chapter also describes two new extraction methods using air as an extraction medium – air throughflow extraction and air jet extraction. These techniques are suitable, for example, for components that may not come into contact with liquids during their manufacture or operation.

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- A completely new **Chapter 7** is devoted to the topic of **filtration**. Correctly-selected and carefully-prepared analysis filters are an absolute necessity in order to attain error-free results from optical analysis methods. The chapter contains more detailed information about the selection and suitability of analysis filters.

- **Chapter 8: Analysis** is now divided into three sections: the first one is concerned with so-called standard analysis with gravimetry and/or light-optical analysis (microscope and new flatbed scanner). Conventions for systems and settings have now been fixed to improve the comparability of analysis results. Width has been added as a new feature for characterizing particles, and a standardized criterion for defining fibers is now also included.

  The second section describes the extended analysis method (process optimization, cause research), which can be used to identify materials or determine 3-D geometric shapes (only to be used to validate cleanliness specifications if specifically arranged because the effort and costs involved are significantly higher than with standard analysis). As well as SEM/EDX analysis, which was already discussed in the first edition, other methods such as LIBS, Raman and IR-spectroscopy, light-optical determination of particle height and microcomputer tomography can now be found.

  The third section deals with the shortened analysis method that does not include a filtration step. This enables analysis results to be obtained much faster and may prove useful in cases where monitoring is data-intensive. Liquid particle counters are discussed here again, together with a new system based on the optical recognition and measurement of particles occupying an analysis filter in the media flow. Due to the diverse detection principles, the results obtained from a shortened analysis cannot be directly compared with those of light-optical standard analysis. They are more intended to be used to validate cleanliness specifications if this is explicitly stated in the customer-supplier agreement.

- All the information and tables for documenting cleanliness specifications, inspection specifications and inspection reports that were listed in the appropriate chapters in the first edition of VDA 19 are now grouped together in **Chapter 9 Documentation**. This gives the new edition a clearer structure and makes it easier to read.

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The particle size classes for documenting specifications or test results have now been increased by three sizes from the previous 1000 µm um to 3000 µm.

- The new **Chapter 10 Interpretation and reaction** describes the procedure to be taken when the result of a cleanliness analysis exceeds the permissible value stated in the cleanliness specification.
- **Work safety and protection of the environment** is addressed in a new **Chapter 11**, which especially considers the aspect of cold cleaners that are generally used for the extraction process. The chapter should make it easier for operators of cleanliness laboratories to make structured risk assessments for tasks carried out in the laboratory.
- **Chapter 12: Case examples** has been completely redesigned and uses examples to show how to qualify, perform and document cleanliness inspections. On the basis of practical examples, the chapter aims to give especially newcomers to the field of inspecting technical cleanliness a better understanding of the numerous topics contained in the guideline, and facilitate their implementation.
- **Chapter 13 definitions, abbreviations and equation symbols, and Chapter 14 TecSa industrial alliance** have been updated. The **Bibliography** chapter has been deleted.

Due to the restructuring and extension of the revised second edition of VDA 19, the guideline can be utilized not only to design, perform and document cleanliness inspections in the laboratory but is also suitable for use in other disciplines such as quality assurance, construction and development or supplier management to give a brief introduction to the subject. We recommend reading Chapters 2 and 3 to obtain a rough overview of technical cleanliness and understand how to inspect it.

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1 SCOPE OF APPLICATION AND VALIDITY

1.1 Introduction

The guideline describes requirements for applying and documenting methods for determining particulate contamination on functionally-relevant components (cleanliness inspection).

A cleanliness inspection forms the basis of an assessment of technical cleanliness, which is performed, for example, under the following circumstances:

- Initial inspection and evaluation
- Inspection of incoming and outgoing components
- Quality control or monitoring of manufacturing processes relevant to cleanliness (e.g. cleaning, surface treatment and assembly processes).

The guideline enhances the informative quality and comparability of test results; it also regulates the standardized expression of cleanliness specifications and cleanliness test results in the quality chain of the automotive industry.

Information concerning references:

If an inspection of technical cleanliness has been carried out in accordance with this guideline, the following reference is made in such documents as catalogues, specifications and reports:

"*Standard cleanliness inspection according to VDA 19.1"* in cases where standard analysis methods and parameters are used and no other agreements regarding methods and parameters have been made within the scope of the customer-supplier relationship.

"*Extended cleanliness inspection according to VDA 19.1*" in cases where more detailed analysis methods have been defined, implemented, parameterized and documented within the scope of the customer-supplier relationship, or in the event that modified or extended standard analysis methods are implemented, which have also been agreed upon and documented.

"Shortened cleanliness inspection according to VDA 19.1" in cases where shortened analysis methods are implemented and whose application, pa-

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rameterization and documentation are defined within the scope the customer-supplier relationship.

1.2 Exclusions

The following points are not discussed:

1. Detection of filmy contamination (grease, oils, etc.)
2. Application of non-quantifiable particulate detection methods on test components (e.g. visual assessment, wipe test with clean cloth, etc.)
3. Characterization of operating fluids (fuel, oils, coolants, 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. Cleanliness specifications should only be undertaken by specialists who not only know the component concerned but also the system it is built in to, the later conditions of use, technically-feasible practices and possible consequences for manufacturing processes and the supply chain. Tips for deriving limit values can be found in the guideline in Chapter 2: Cleanliness specifications.

1.3 Cleanliness inspection

The purpose of a cleanliness inspection is to detect as best as possible the particulate contamination generated by the manufacturing process which is present on the relevant surfaces of a test component.

In contrast with other inspections, which can generally be performed directly on a test component, e.g. optical or tactile (contact) tests, the inspection of technical cleanliness is an indirect test that requires a sampling step. The relevant surfaces of functionally-critical components utilized in the automotive industry are often located inside pipes, channels, casings, tanks, pumps, valves or similar components. Fluids often flow through such components and these are capable of transporting particles to sensitive areas of a system. The inner surfaces cannot generally be accessed to allow a 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.

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Consequently, in order to analyze technical cleanliness, first of all a so-called extraction (or sampling) step is necessary. Here, the particles present are first removed from the component by means of a laboratory cleaning process. The complete extraction medium is then filtered, the particles extracted from the component deposited on an analysis filter and then subjected to analysis.

This also means that **it is impossible to repeat the cleanliness inspection on the same test component** because its cleanliness state has been altered 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 particles present on the surface are removed during the extraction step. As real test components with a defined level of contamination do not exist to enable the efficacy of extraction procedures to be assessed, extraction procedures first have to be qualified before technical cleanliness can be assessed:

Qualification of the extraction procedure: the appropriate extraction procedure for a test component is determined by performing qualification tests. The qualification criteria are stated in this guideline. They serve to ensure that as many particles are removed from the test component as possible. The qualification results are then documented together with the general requirements and parameters of the extraction procedure chosen.

Blank value: the cleaner a test component is (i.e. the lower the number of particles expected to be determined in a cleanliness inspection), the higher the risk that external contamination introduced into the test procedure will falsify results. The quantity of foreign particles permitted in a test is stated in the guideline. This so-called permissible blank value is orientated towards the cleanliness requirements of the respective test component.

The cleanliness inspection (see Fig. 1-1) is made up of the following steps:

1. Receipt of the test component
2. Removal of the particles from the test component (extraction)
3. Filtration of the particles (except with shortened analysis)
4. Analysis of the particles
5. Documentation of the test and results

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In order to perform technical cleanliness inspections, special equipment, suitable premises and skilled, experienced and motivated staff are required.

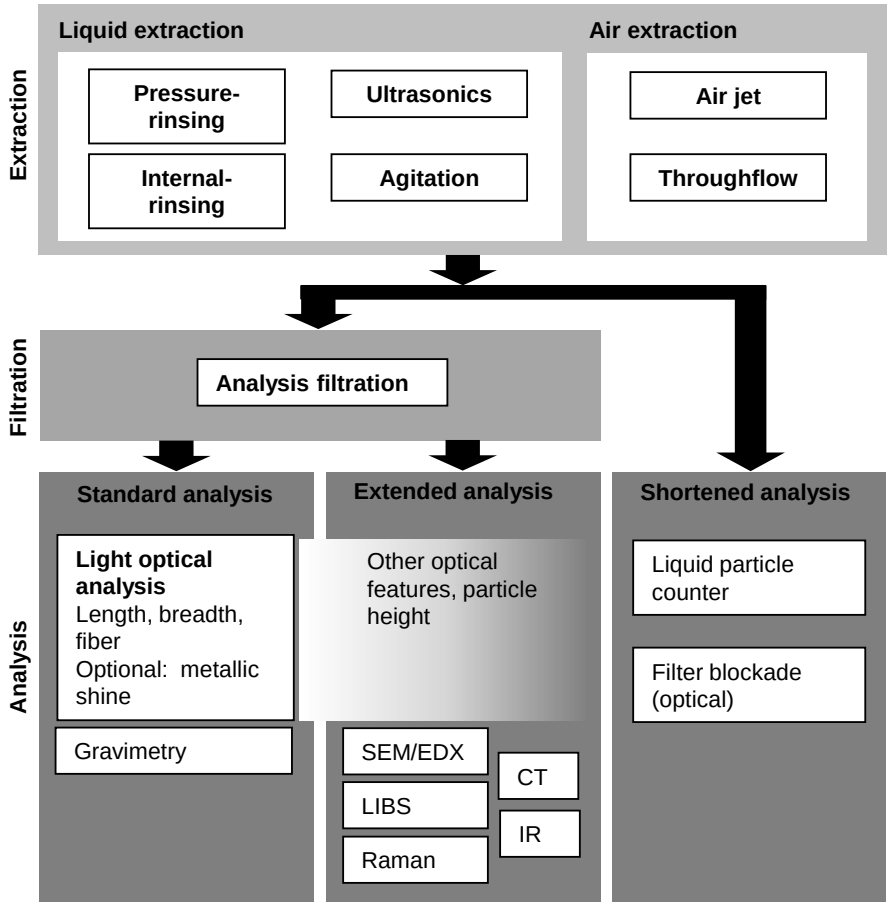


Fig. 1-1: Inspection methods according to VDA 19.1

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2 CLEANLINESS SPECIFICATION (INFORMATIVE)

2.1 Principles

A cleanliness specification (or cleanliness limit value) is stated in cases where there is a significant risk that the function of a system or component could be damaged by particulate contamination. If no risk is present, a cleanliness specification should not be made.

In general, cleanliness limit values represent control limits and not tolerance limits. 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).

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 and is to reduce particle generation in the manufacturing process. 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 contradict with the agreed cleanliness specifications. This may concern a suitable form of packaging, or the person responsible 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.

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2.2 Deriving cleanliness limit values for systems

In many cases, fluid systems (liquids and gases) often contain one or more components sensitive to particles (see annex for examples of damaging mechanisms). As particles inside such systems are generally mobile, this “weakest link in the chain” usually determines the degree of cleanliness necessary for the whole system. Examples of typical fluid systems found in the automotive industry include:

- Fuel systems
- Lubricating and hydraulic oils (engine and gearbox)
- Braking systems
- Steering
- Air-conditioning and cooling systems
- Air intake systems and exhaust tracts
- Systems for post-treating exhaust gases

Note: Components may also form part of more than one fluid system. In such cases, different cleanliness specifications may apply to different sections of the same component, with the consequence that each section may need to be sampled individually in the cleanliness inspection.

The first step towards deriving a cleanliness specification is to identify the areas which are sensitive to particles, e.g. with the aid of 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 defect occurring, e.g. during a changeable state such as a valve closing
- (temporary) local concentration in the system

Where possible, the points listed in the left-hand section of Fig. 2-1 are to be taken into account.

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In a next step, the requirements determined have to be examined to find out if they can be fulfilled using state-of-the-art technologies on taking the sub-points listed in the right-hand section of Fig. 2-1 into account.

Only after taking both sections into consideration (necessity and feasibility), can a meaningful cleanliness specification be drawn up for the respective system.

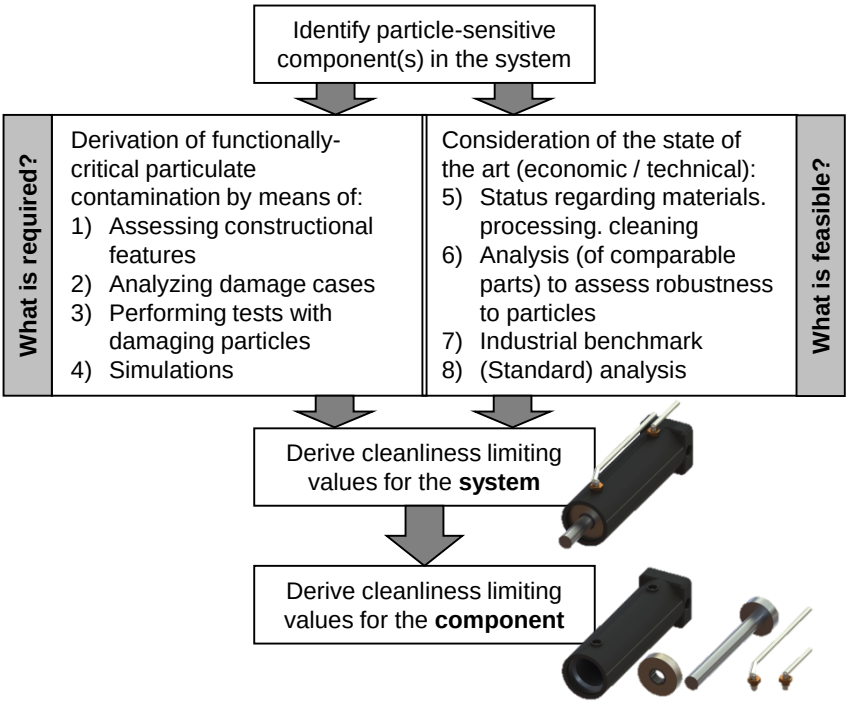


Fig. 2-1: Procedure for deriving cleanliness specifications

About 1) Assessing constructional features. In a first step, the geometric particle size that could be functionally-critical for a component in the fluid system is determined based on the system's constructional features, e.g. gap dimensions, valve stroke, filter mesh size, etc. At the same time, the direction of flow and orientation of particles in the flow is also considered. 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 in the case of electronic systems, conductivity may be relevant.

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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 functional impairments that arose can be taken into consideration when defining the 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 critical 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 analyzed. For example, particles can be injected into the system whilst being operated under realistic conditions (pressure, temperature, revolutions, etc.) or (with heat-soluble liquid grease, etc.) before it is assembled. In such tests, the sizes, types and counts of particles can be determined 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.

Test components 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) Carrying out simulations. A further method of evaluating the ability of fluid systems to withstand particles is to use modified software programs to simulate particle-charged flows. This enables particle transport to be simulated and visualized.

Note: 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) 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 aluminium component manufactured in three-shift operation cannot be cleaned as thoroughly as a polished stainless 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

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post-treatment efforts (see graph in the annex). Before fixing final cleanliness specifications, the state of machining and cleaning technology should be known.

Note: With current technologies, it is impossible to realize cleanliness limit values for compact particles in automotive fluid systems in the two-digit micrometer range (e.g. no particles > 50 µm permitted). The presence of (textile) fibers is still also to be reckoned with.

About 6) Analysis of particulate loads (comparable parts). In order to gain a rough idea about the level of technical cleanliness that can be attained with current manufacturing methods, cleanliness analyses according to VDA 19 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 may also identify any existing potentials for improving cleanliness levels.

About 7) Industrial benchmark. In the automotive and supplier industries, in order to obtain relatively standardized cleanliness specifications for comparable components with comparable conditions of use in a vehicle, it may make sense to reach a cross-company agreement on these limit values. For example, the supplier could agree to provide a standardized level of technical cleanliness for specific product groups, or the customer may demand a standardized level of cleanliness for comparable parts, thus enabling supplier processes and costs to be planned.

About 8) Analysis. Using the analysis method described in VDA 19.1, it has to be possible to validate the cleanliness specifications derived from Points 1 to 7. Even the best-founded cleanliness specification makes no sense if the supplier is unable to validate it 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 are evaluated using the standard analysis described in VDA 19.1.

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2.3 Deriving cleanliness limit values for components

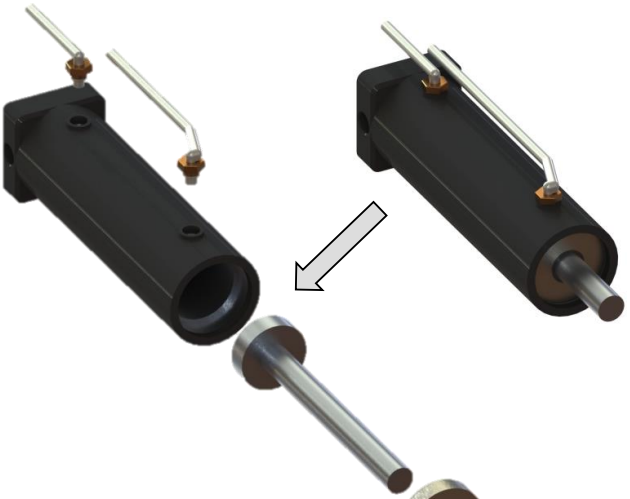
When deriving cleanliness limit values for components from cleanliness limit values for systems, a differentiation is made between the following:

1) The cleanliness limit value for a system is expressed as a rejection criterion, e.g. no particles larger than X µm (not including fibers) are permitted in the system. In this simple case, the cleanliness specification applies to all components relevant to the system (component surfaces coming into contact with media).

2) A specific quantity of contamination is permitted for the overall system, e.g. a gravimetric value or a particle size class. This total quantity of contamination is the sum (*i*=1-n) of the contaminants on the components forming the system, i.e. the sum of the limit values of the components *i* is the limit value of the system (see first line in Fig. 2-2). As large components are generally responsible for more contamination in a system than small ones, in a first step the amount of contamination in the system can be divided among the components in relation to their surface area (in contact with media) (see second line in Fig. 2-2). In practice, it makes more sense to apply a modified surface reference. Here, to start with, the surface reference remains the same, i.e. 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 modified approach, individual component limit values are scaled by weighting factors A_i whilst keeping the system's total particle count the same. This enables information regarding cleanability or other facts relevant to cleanliness to be included in the scaling process. As a result, components such as small low-cost parts which cannot be cleaned cost-effectively, complex components difficult to deburr, or coated parts are assigned weighting factors $A > 1$ (i.e. higher component limit values) and large components, which are easy to clean and deburr, are assigned weighting factors $A < 1$ (i.e. lower component limit values). Further factors relevant to cleanliness can also be integrated into overall system cleanliness by including additional summands $B, C, etc.$, for example the particulate load of an oil poured into the system, or the amount of contamination generated during assembly (see third line in Fig. 2-2).

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

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

(Individual) limiting value for Component *n*

$$LV_{tot} = A_1 * \frac{LV_{tot}}{SA_{tot}} * SA_{comp1} + \cdots + A_n * \frac{LV_{tot}}{SA_{tot}} * SA_{compn} + B + C + \cdots$$

LV_{total}: total limit value of the system

SA_{total}: total surface area of the system (in contact with media)

$LV_{Comp\ i}$: limit value of Component *i*

$SA_{Comp\ i}$: surface area of Component *i* (in contact with media)

A_i: component-specific weighting factors

B, C, ...: further additive quantities of contamination

Fig. 2-2: Deriving cleanliness specifications for components

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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. 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.
- Inspections should always be performed by skilled members of staff (laboratory experience or training with a laboratory background is advisable).
- Frequent staff changes should be avoided because the results of cleanliness analyses are highly dependent upon staff experience and consistent inspection procedures.
- 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. reproducibility) (see also example of inspection costs in the annex). 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 INTERPRETATION and REACTION in Chapter 10)
- 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: A technical cleanliness inspection does not necessarily have to be performed in a cleanroom. The cleanliness grade of the test 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).

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2.4.2 Impact on production

Cleanliness specifications should always be derived on bearing in mind the aspects of technical feasibility and economic viability. High cleanliness demands can lead to immense costs regarding the manufacture and further processing of components along the complete supply chain. For example, higher costs can be incurred due to:

- The selection of materials or surface coatings
- Processing and deburring
- Cleaning (see also Annex 2.2)
- Logistics
- 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 Part 2 “Technical Cleanliness in Assembly”.

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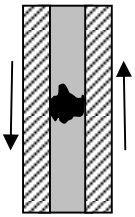
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Annex 2 Cleanliness specification

A 2.1 Examples of damage mechanisms

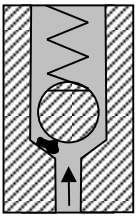
Jamming of bearings or sliding surfaces

- Turbochargers
- Crankshaft bearings
- Dispensing pumps
- Cylinder linings



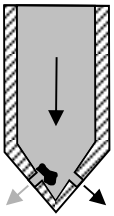
Jamming of valves

- Anti-blocking systems
- Hydraulics
- Brake servos



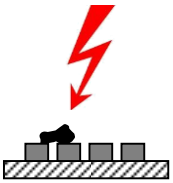
Blockage of nozzles or filters

- Injectors
- Fuel lines



Shorting of contacts

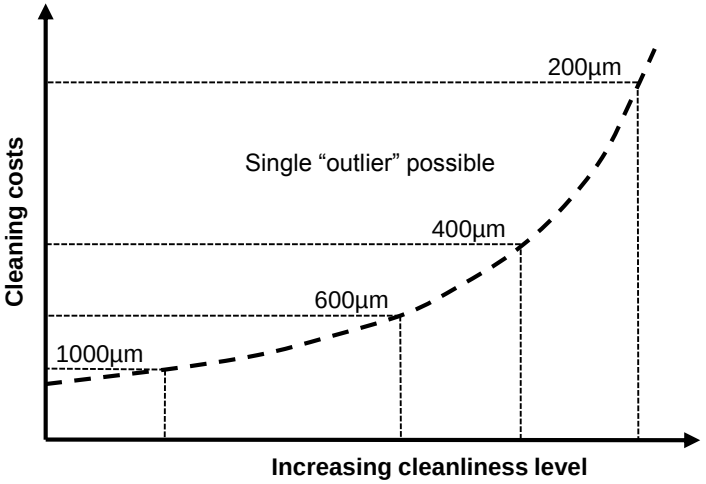
- Control electronics



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A 2.2 Rise in cleaning costs as cleanliness limit values increase



Factors affecting rising cleaning costs include:

- Higher new investments
- Bath care/filtration
- Longer cleaning times
- Lower filling quantities
- Better quality washing frames/baskets
- Maintenance
- Environment
- Trained staff

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A 2.3 Example of deriving a cleanliness specification

Note: This is not a real example. Particle sizes and counts, as well as observations made and conclusions drawn, are purely exemplary and could be totally different in practice. The example only serves to illustrate how a cleanliness specification can be derived on taking several different aspects and disciplines into account.

The component in the example is an electronic subassembly fitted with contacts.

Development:

Malfunctions may occur if conductive particles bridge and short the contacts on the subassembly.

The distance between the contacts of this new product is 400 µm.

⇨ With this information, the developer initially derived the following cleanliness specification: no conductive particles ≥ 400µm permitted for the component

Consultation with quality assurance:

Malfunctions caused by conductive particles also occurred sporadically with similar subassemblies in the past. Metallic particles > 600 µm were found in the cleanliness analyses.

It should always be possible to validate a cleanliness specification using a standard analysis method because the component concerned may be manufactured at a location unable to perform extended analysis methods.

Consultation with production:

A new cleaning system was purchased to clean the components. The cleanliness specification is defined in such a way so that fluctuations in cleanliness levels, and thus the state of the cleaning system, can be determined if cleanliness inspections are performed on a regular basis.

Action taken by quality assurance:

Cleanliness levels of similar components manufactured with the same processes were analyzed. To do this, extended analysis methods were also implemented in the company's central laboratory to obtain additional information about materials and 3-D shapes. The following was determined:

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- Not only metallic particles were found but also non-metallic particles from the housing material that, due to their geometry, only caused a malfunction in the installed relay if they were approx. 1000 µm or larger in size. The cleanliness specification should therefore take this fact into consideration.
- The metallic particles generated during the manufacturing process (solder beads, stamping burrs from plug connectors) were shaped in such a way that, despite a measured $Feret_{max}$ length of sometimes over 400 µm, their complete length never touched the surface and thus did not cause shorting. Only particles upwards of 600 µm represented a shorting hazard.

Action taken by development:

Test series were carried out to subject the subassemblies to particles of different sizes, different metals and originating from different production processes (e.g. on a vibration tester to simulate running conditions). The electrical function of the components was evaluated simultaneously.

The results showed that malfunctions repeatedly occurred due to metallic particles. The size of the metal particles responsible for this depended on the type of particle concerned. Thus, aluminium particles only started to cause problems upwards of 1000 µm (possibly due to the oxide skin on the surface). Tin chippings already caused malfunctions if they had a size of 600 µm or more.

The cleanliness specification

After taking into consideration the three areas of development, quality assurance and production, the following cleanliness specification was drawn up based on these requirements and this information:

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Particle Size Class	All particles (excluding fibers)	Metallic shiny particles
x > 1000 µm	0	0
600 < x ≤ 1000 µm	2	0
400 < x ≤ 600 µm	6	2
200 < x ≤ 400 µm	20	8
150 < x ≤ 200 µm	40	Not specified
100 < x ≤ 150 µm	60	Not specified
50 < x ≤ 100 µm	150	Not specified

The following points are taken into account in the cleanliness specification:

- Textile fibers not regulated because they are not critical to function. However, they have to be identified in the analysis in order to separate them from other particles.
- Particles upwards of 50 µm are specified because they can be tested using the standard analysis procedure.
- Particle size classes with smaller particle sizes (< 150 µm) are used to recognize fluctuations in the manufacturing process (cleaning system) at an early stage; this is not possible with large particles because of their scarcity.
- No particles larger than 1000 µm are permitted because these are considered to be functionally-critical, even if they are non-metallic.
- No metallic shiny particles larger than 600 µm are permitted because the tests were unable to confirm that the originally-derived size of 400 µm is functionally-critical.
- Using light-optical standard analysis, it cannot be concluded without a doubt that metallic shiny particles are conductive (further material analyses would be required to determine this). Nevertheless, metallic shine can be utilized as a typing indicator if the automated analysis is subsequently double-checked by a skilled inspector.
- As the smaller particles (< 150 µm) are used to monitor trends rather than characterize the damaging potential of individual parti-

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cles, these size classes are not typed (metallic shine) in the specification. This makes sense because the cost of manually confirming particle types rises as the number of smaller particles increases. Moreover, typing becomes less reliable as particle sizes decrease, and it the comparison of different light-optical analysis systems also become more difficult.

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3 SELECTING THE INSPECTION METHOD (INFORMATIVE)

A cleanliness inspection is made up of three steps:

- Particle extraction: particles are detached from the component by means of a test medium in a cleaning process. The extraction method is determined by the features of the test component (components), such as size, shape, accessibility to the surfaces requiring inspection, component material and type and adhesion of the contamination to be removed.
- Particle filtration: particles with a size relevant to the analysis are deposited on an analysis filter. The type of analysis filter is selected according to the size and quantity of the particles requiring analysis as stated, for example, in the cleanliness specification.
- Particle analysis: relevant particle features are analyzed in accordance with the information stated in the cleanliness specification, for example. Such features include aspects such as size, quantity, material composition and properties. Where no specific features are stated, the so-called standard analysis procedure is to be applied.

Note: In the so-called shortened analysis (see diagram of the structure of VDA 19.1 in Chapter 1), there is no filtration step: Once detached by the test medium, particles are advanced directly for analysis, e.g. with a liquid particle counter.

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 (Fig. 3-2), the following parameters influence the extraction result:

- **test medium** (chemical cleaning aspect)
- **temperature**
- **cleaning mechanism** (extraction method with parameters)
- **time** (time the component surface is exposed to the extraction method)

A particle bonded to a component surface by forces of adhesion serves as a model for the cleaning task to be solved. The particle could adhere, for example, because of van of the Waals forces, or alternatively capillary forces subsequent to the presence of humidity in the air or process media.

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(coolants, lubricants or anti-corrosives). The task of the extraction method is to overcome these forces and detach the particle.

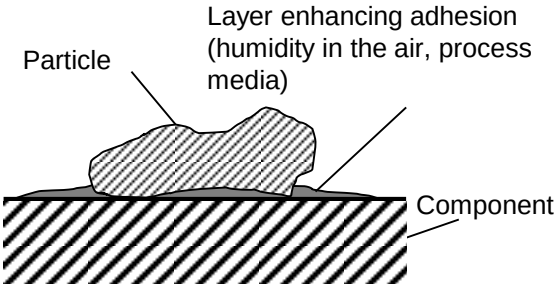


Fig. 3-1: Particle bonded to the component surface by forces of adhesion

Note: Burrs may become detached from the component during the extraction procedure, which are then also included in the cleanliness analysis. To avoid this, only components that have been carefully deburred beforehand should be analyzed. If this is not possible, an agreement must be reached to determine the procedure for analyzing and documenting detached particles.

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 room for maneuver regarding the specific parameters that can be chosen, e.g. diameter of the spray nozzle, volume flow, ultrasound frequency, etc. In order to obtain comparable extraction (and thus also analysis) results, it is advisable to commence qualification tests using the VDA 19.1 start parameters recommended for the various methods. See Chapter 6: Extraction Methods.

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

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3.1.1 Test medium

Liquid extraction (extraction liquid as a cleaning medium)

The majority of functionally-relevant automotive components come into contact with fluids during their manufacture or later operation. Capable of binding or detaching particles, examples of such fluids include:

- Cooling lubricants
- Preservatives
- Cleaning agents
- Joining aids
- Operating fluids.

For all components coming into contact with these fluids, an extraction procedure with a liquid is recommended. The primary task of the extraction liquid is to overcome the adhesive forces prevailing between the particles and the component. Tests have to be performed to determine which liquid is best suited for detaching the contaminants without attacking the component surface. Table 6-1 gives a general overview. It can be seen here that the majority of process fluids used in production can be removed with the aid of two groups of cleaning liquids: tensidic 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 protection of the environment (odorless isoparaffins, which are non-combustible at room temperature, are preferable).

Recommendations for selecting the extraction liquid:

a. Check whether aqueous neutral cleaning media containing tensides are suitable: they can generally be used to remove aqueous emulsions of cooling lubricants, animal and vegetable greases and oils and also amine-based anti-corrosives (ensure they do not foam).

b. If they cannot be used for any reason, check whether non-polar solvents such as those described above can be utilized. They are especially suited for removing mineral oil-based lubricants and anti-corrosives.

c. Should neither of the above be suitable, a special cleaning medium must be selected, e.g. ethanol (polar solvent) to clean brake components before their analysis.

The extraction liquid must be compatible with the component material (see Table 6-2).

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

Air 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). 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 influence cleanliness. If particles can be removed from such components without the need for a chemical solvent, an extraction procedure using air can be performed.

3.1.2 Temperature

Test media should be used at room temperature 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

Especially when removing particles, the use of mechanical forces to assist cleaning processes plays a major role. Cleaning mechanisms usually function in two ways:

- They detach firmly-adhering contaminants with the aid of strong mechanical forces, i.e. the actual cleaning task
- They remove the detached particles that may have started to resediment and are now adhering only slightly (to the surface of the component or extraction equipment) with the aid of relatively weak mechanical forces, i.e. a rinsing process.

This third step to be considered when selecting the extraction method is made up of two sub-points – “Selecting cleaning mechanisms”, i.e. the extraction method itself, and “Cleaning mechanism parameters”, i.e. deriving parameters (volume flow, ultrasound output, etc.) for the extraction.

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Selecting the cleaning mechanism

This is essentially determined by the size and geometry of the component as well as the location of the test surfaces (internal or external surfaces). For components with several functional surfaces that may have varying cleanliness specifications, different extraction methods may be used to inspect the respective areas of the same component (see also Annex 3).

Liquid extraction

Four different extraction methods can be utilized for liquid extraction – pressure-rinsing, ultrasonics, internal rinsing and agitation.

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 geometries that cannot be accessed directly with a spray jet, spray lances with a small diameter may be useful, e.g. inserted into blind holes.

Advantages:	Highly universal application, can be adapted to many extraction tasks.
Disadvantages:	Detached particles are distributed over a large area → costly final rinsing step required, the large wetted surface areas of the extraction equipment make it more difficult to attain low blank values, high operator influence due to largely manual procedure.
Note:	Spray nozzles can also be used for internal extraction by inserting them into the ends of tubing, borings 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.

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 in baths specially constructed for cleanliness analysis with an outlet to analysis filtration, or in beakers that are placed in standard laboratory ultrasound baths. To compensate for inhomogeneities in the ultrasound field, components should be moved gently in the bath. Movements should have an amplitude of at least half the wavelength of the ultrasound waves used.

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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: Easy to perform, good reproducibility, marginally influenced by inspection staff, cheap testing equipment for small parts, possible to achieve low blank values due to low wetted surface areas.

Disadvantages: If inappropriate parameters are set, cavitation effects may cause material to detach from the test component, which is then falsely recognized in the analysis as particulate contamination, difficult to validate cleaning parameters in the ultrasound bath (distribution of ultrasound waves, cavitation effect).

Internal rinsing: internal rinsing is suitable for extracting particles from the inner surfaces of a wide range of components, e.g.

- 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 complete inner geometry of the component to be cleaned is always wetted and the extraction liquid is fed into the component via adapters. 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: Easy to limit the method to the test surfaces concerned by adapting rinsing lines, low blank values attained due to low wetted surface areas, marginally influenced by inspection staff, for many fluid-conducting components this is the best extraction method for simulating real vehicle conditions.

Disadvantages: Test 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 test components, abrasion from joining processes (screwing, pushing, pressing, etc.) may occur, which could be falsely recognized as contamination originating from the component.

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Note: The term “internal rinsing” always refers to the rinsing of inner surfaces; consequently, there is no rinsing extraction procedure for external component surfaces. The term “final rinsing” refers to a pressure-rinsing step which removes particles that have re-sedimented (onto the test component or in the extraction apparatus) after detachment and forwards them for filtration.

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: Simple, very cheap, low blank values due to low wetted surface areas

Disadvantages: Only compatible for use on a very small spectrum of components. Cannot be performed manually on large test components (weight of test object + extraction liquid).

Note: 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 (risk of component abrasion).

Air extraction

Air extraction can be performed in two ways, either as air jet extraction, which corresponds with pressure-rinsing in liquid extraction, or as throughflow extraction where air flows through the test component, which is comparable with internal rinsing as a form of liquid extraction.

Air jet extraction: With this extraction method, particles are removed from the component 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: Closed chambers for liquid extraction procedures can be easily and cheaply converted to chambers for air jet extraction. The simple test method can also be applied to components that would be damaged if they came into contact with a liquid.

Disadvantages: The detached particles are spread over a large area → a thorough final rinse (with liquid) is required, low blank values are difficult to attain due to the large internal surfaces of the extraction apparatus, high operator influence because the procedure is generally carried out manually.

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Air throughflow extraction: with this type of extraction, air is usually guided through the test piece using specially-constructed test apparatus. The method is suitable for evaluating the cleanliness of inner surfaces of air conducting components, such as parts of engine air intake systems. With this procedure, large volumes of air are guided through component cross-sections several centimeters in diameter.

Advantages: Easy to separate the test area from non-relevant component surfaces by using adapters connected to piping systems. Low operator influence: for air intake components, the best extraction method for simulating real vehicle conditions. Air filters, which are not compatible with liquids, can be inspected using this method. The test medium leaves no residues in the component.

Disadvantages: Complex test apparatus, need for component-specific adapters, time-consuming execution due to the preparation of primary analysis filters for air which then have to be manually re-prepared as secondary analysis filters for liquid.

Cleaning mechanism parameters

The intensity of the extraction effect and even damage to the component surface is primarily dependent on the parameters of the extraction method responsible for the mechanical action on the component (impulses, forces, etc.). In order to select suitable parameters, sound knowledge of the test component, its manufacture and later usage may be necessary. However, if there are no requirements or experience known which justifies the implementation of specific extraction parameters, the start parameters recommended for the respective extraction method should be used.

3.1.4 Time

As opposed to other extraction parameters, extraction times are optimized for each component and not derived from features such as component geometry or type of contamination. The required time is determined by repeating cleanliness analyses with short exposure times and registering the decline in the particulate load extracted - so-called declining tests (see Chapter 5: Qualification tests and blank value). Even in cases where the volume of extraction liquid is used for validation purposes, the actual parameter that is qualified is the length of time the extraction method acts on the component surface.

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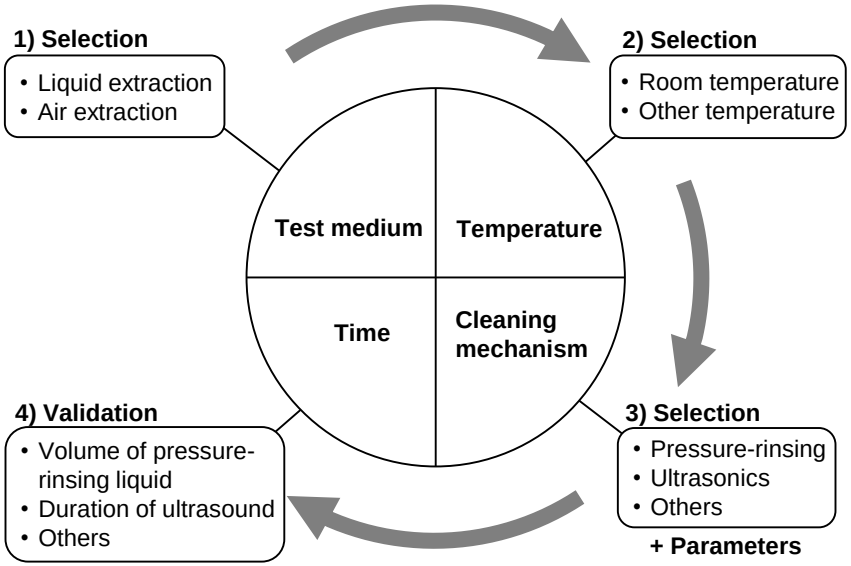


Fig. 3-2: Procedure for selecting the extraction method

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 utmost importance.

Note: If further analyses are required, it may be necessary to verify whether the analysis filter and analysis method are compatible with one another (e.g. if high radiation levels are used).

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3.3 Selecting the analysis method

The analysis method is selected according to the particle features stated in the cleanliness specification for the respective test component and also depends on the purpose of the analysis:

Standard analysis: this verifies the cleanliness limit values arranged between the customer and the supplier. In the standard analysis, the analysis method and the particle features requiring analysis are determined. Additionally, parameters for the analysis method are specified and particle features defined. Standard analysis can be implemented without further agreements having to be made between the customer and supplier.

Extended analyses: these supply information about the type and thus possible origin of particles. They are used:

- to optimize processes
- to research into causes (source of critical particles)
- to react to limit values being exceeded
- if the requirements made in a cleanliness specification go beyond the features covered by standard analysis.

Extended analyses are often associated with more effort and higher costs.

Shortened analyses: due to the rapid availability of results and therefore higher sampling quantities possible, this method is highly suitable for the purpose of process monitoring.

Note: Standard or extended analysis methods can also be used to monitor processes if they are performed at on a regular basis.

3.3.1 Standard analysis

Used to validate cleanliness limit values in the customer-supplier relationship. The two following analysis methods are used in a standard analysis procedure:

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Gravimetry:

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 or flatbed scanners are used to determine particle size classes and measure or characterize particles according to the following features.

Measurement of particles > 50 µm with regard to

- length and/or
- width

Characterization of particles with regard to

- fiber shape
- metallic shine (optional)

In order to implement light-optical analysis methods, skilled staff are required. They must be able to operate the equipment and also be prepared to scrupulously check measurement and characterization results.

In order to improve the comparability of results from different types of analysis systems as well as from identical systems handled by different operators, it is essential that the stated equipment, parameters, procedures and features are implemented and observed. If specified conventions are deviated from in a cleanliness analysis, the analysis is no longer considered to be standard and the respective points have to be agreed on and documented in the customer-supplier relationship.

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3.3.2 Extended analyses

Extended analyses are carried out if the following additional information on contaminant particles is required:

- Exact measurement of particles < 50 µm
- Geometric features of particles other than length and width, e.g. the third dimension
- Material identification or characteristics derived from this, such as the degree of particle hardness

The aim of the respective analysis, the method applied, the procedure implemented and the processing and interpretation of analysis results are all to be arranged and documented in the customer-supplier relationship.

3.3.3 Shortened analysis

The term “shortened analysis” refers to analysis techniques which, although needing an extraction step, do not require filtration for the actual analysis. This enables analysis results to be available much faster, i.e. larger quantities of components can be assessed within the same period of time. Results obtained from the two shortened analysis methods mentioned do not correspond exactly with those obtained from a standard analysis. Consequently, shortened analyses are not used to validate cleanliness limit values unless this has been explicitly arranged in the customer-supplier relationship.

The following tables list the analysis methods described in this chapter and their fields of application.

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Table 3-1: Analysis methods and possible applications

	Analysis method		Purpose of the analysis		
			Validate cleanliness specification	Cause research for process optimization	Process monitoring
Standard analysis	Gravimetry		++	--	+
	Scanner 2-D		++	+	+
	Light microscope	2-D ≥ 50 µm	++	+	+
Extended analysis		2-D < 50 µm	++ *)	+	+
		3-D	- *)	++	--
	Computer tomography		- *)	++	--
	SEM/EDX		0 *)	++	-
	LIBS		0 *)	++	-
	Raman		0 *)	++	-
	Infrared		-*)	++	--
Shortened analysis	Liquid particle counter		0 *)	-	++
	Filter-blocking (optical)		0 *)	0	++

*) Can be applied if arranged in the customer-supplier relationship provided analysis parameters are specified

++ highly suitable

+ suitable

0 suitable in principle

- less suitable, or not available for automated analysis, or too expensive for the intended purpose (if new equipment has to be purchased)

-- unsuitable, not available for automated analysis, too expensive for the intended purpose (if new equipment has to be purchased)

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Table 3-2: Analysis methods, information obtained and limits

Method	Information						Limitations
	Overall particle mass	Particle size			Other features		
		Length	Width	Height	Metallic shine	Material	
Gravimetry	x						Gives no information about single particles
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]		Not all features usable with one lens
Computer-tomography		x	x	x[5]			Prolonged analysis times
SEM/EDX		x	x			x	No differentiation between organic/inorganic particles
LIBS		x[3]	x[3]			x	No differentiation between organic/inorganic 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
Liquid particle counter		x[4]					Results may be inaccurate if air bubbles are present
Filter-blocking (optical)		x	x				Results may be inaccurate if residues are on the lens

() Depending on lenses and model

[1] Possible with material microscopes with small depth of field (focusing position between background of analysis filter and highest point of particle)

[2] Pre-requisite: manual double-check

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

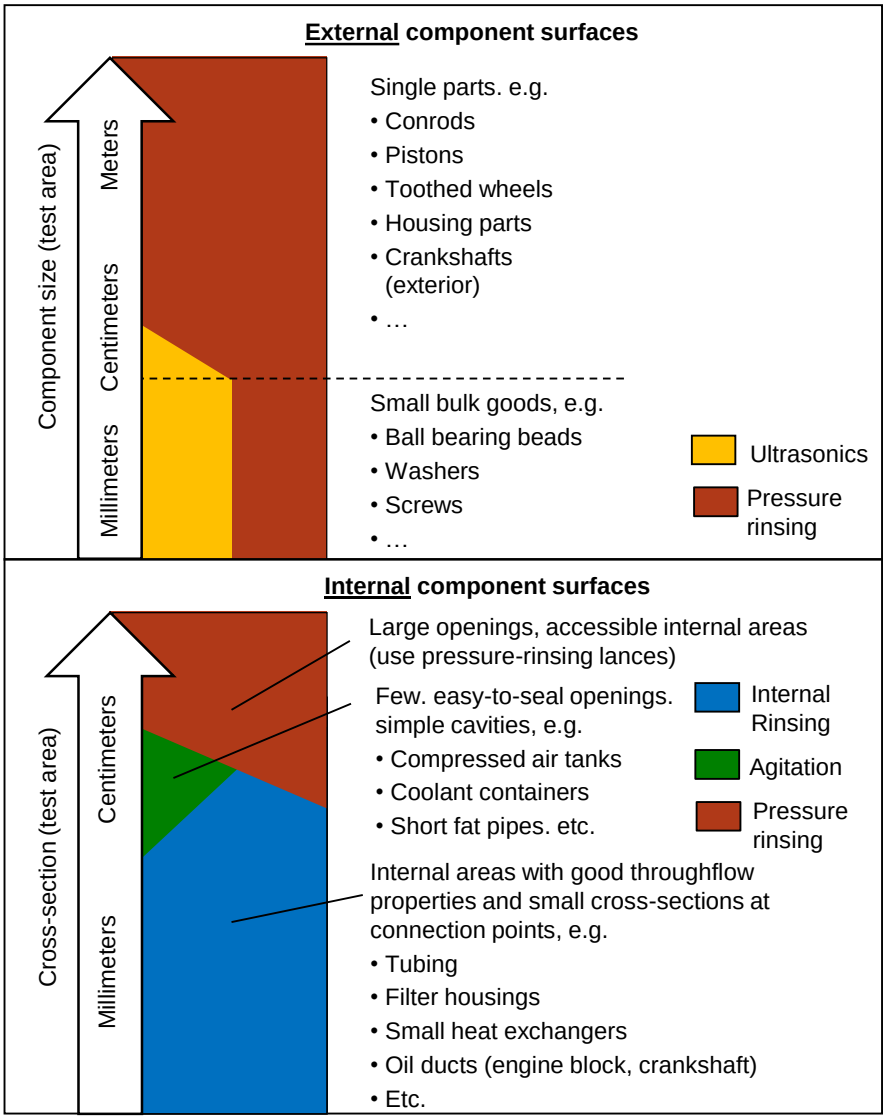
[4] Size often determined by the diameter of a circle with an equivalent surface area

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

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Annex 3 Selecting the inspection method

A 3.1 Liquid extraction: example illustrating the suitability of component groups for the various extraction methods



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A 3.2 Liquid extraction: examples of component features and suitable extraction methods

Extraction method	Component features	Examples
Pressure-rinsing or 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, toothed wheels, housing parts, crankshafts, 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, etc.
Internal rinsing or pressure-rinsing	**Inner component surfaces** with connector cross-sections and interior cross-sections in the centimeter range; accessible by internal rinsing and by pressure-rinsing jet	Hydraulic valve blocks, pipe or tube connections, turbocharger housing, rails, etc.
Internal rinsing and 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 or 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 or 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.

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