IEC TR 61191-7

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TECHNICAL REPORT

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Printed board assemblies –
Part 7: Technical cleanliness of components and printed board assemblies



IEC TR 61191-7:2020-03(en)

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Part 7: Technical cleanliness of components and printed board assemblies

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PRINTED BOARD ASSEMBLIES –

Part 7: Technical cleanliness of components and printed board assemblies

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IEC/TR 61191-7, which is a technical report, has been prepared by IEC technical committee 91: Electronics assembly technology.

The text of this Technical Report is based on the following documents –

Draft TR	Report on voting
91/1583/DTR	91/1595/RVDTR

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 61191 series, published under the general title *Printed board assemblies*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http//www.webstore.iec.ch" in the data related to the specific document. At this date, the document will be

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INTRODUCTION

The Technical Report applies to electric, electronic and electromechanical components, circuit boards and electronic assemblies and describes the resulting level of technical cleanliness that can be expected for products that are manufactured with state-of-the-art standard production methods and processes.

The Technical Report is an informative document which serves to illustrate the technically feasible options and provide a basis for customer and supplier agreements. It is not intended to be regarded as a specification or standard. It does not cover the production of electric motors, batteries, cable harnesses and relays.

Its primary focus is on loose or easily detachable particles (labile particles). Film residues, chemical and biological contamination are also briefly covered. It does not deal with the cleanliness of functional fluids and/or gases.

This Technical Report provides information, how the requirements put down in VDA 19.1 and VDA 19.2 could become reasonably applied in electronic industry. It provides information about particle generation considering processes and materials, illustrates their impact on performance and reliability and describes suitable countermeasures as well as procedures for risk assessments.

Related standards issued by the automotive industry and the electronic industry are gathered in the bibliography.

The Technical Report has been prepared based on material provided by the working group on component cleanliness of the ZVEI (Zentralverband Elektrotechnik- und Elektronikindustrie e.V., Germany).

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PRINTED BOARD ASSEMBLIES –

Part 7: Technical cleanliness of components and printed board assemblies

1 Scope

This part of IEC 61191 serves as a Technical Report and provides information, how technical cleanliness can be assessed within the electronics assembly industry. Technical cleanliness concerns sources, analysis, reduction and control as well as associated risks of particulate matter, so-called foreign-object debris, on components and electronic assemblies in the electronics industry.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

4 Technical cleanliness

4.1 What is technical cleanliness?

The term 'technical cleanliness' was coined by the automotive industry to address particle-related system interruptions in the automotive industry. In contrast to 'optical cleanliness', which relates to the cosmetic or visual appearance, e.g. vehicle coating, technical cleanliness always refers to the performance of components, assemblies and systems.

Particulate contamination in the automotive industry is often not limited to a certain area but may migrate from a previously non-critical to a sensitive location and hence impair performance. For instance, a particle on the lens of a traffic sign detection camera may cause it to malfunction. Similarly, a conductive particle from the aluminum cover of an electronic control unit may cause a short circuit on the circuit board and undermine its performance. This is why the cleanliness requirements of the automotive industry often apply to complete systems, whereby the most particle-sensitive component (weakest link in the chain) determines the cleanliness level and admissible limiting values for the entire system and all components within it. With regard to components, technical cleanliness refers to the specification, observance and verification of limiting values, e.g. according to weight of residual contamination, particle count, type and size. At the same time, the automotive industry tolerates failures only in the ppm range. New stipulations are continuously being added to the existing specifications. These are often tailored to suit the specific requirements of a company or component and its performance. Their scope of application is limited, i.e. they are valid in-house and/or for suppliers.

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Although the term 'technical cleanliness' was coined by the automotive industry, the procedures relating to cleanliness inspections in accordance with VDA 19 (liquid extraction, membrane filtration and subsequent analysis of the retained particles) have been increasingly adopted by other industries such as medical technology, the optical industry, hydraulic and mechanical engineering. Since there is no such thing as total cleanliness or purity, the focus should be on the most practically feasible and economically viable solution for the designated location and purpose.

4.2 History – standardisation of technical cleanliness

Contamination had been a growing problem for the automotive industry since the early 1990s as systems became increasingly complex and installation spaces ever smaller. The anti-lock braking systems in general or direct fuel injection systems for diesel engines were particularly prone.

In some cases, customers and suppliers concluded individual agreements about technical cleanliness to address the risk of potential damage.

As a result, the automotive industry called for the introduction of general standards regulating the technical cleanliness of components. In summer 2001, TecSa was founded, an industrial alliance for technical cleanliness. This panel published VDA 19 (*Inspection of Technical Cleanliness – Particulate Contamination of Functionally-Relevant Automotive Components*) in 2004, which was revised in 2015 and republished as VDA 19 Part 1. These guidelines make recommendations for inspecting the technical cleanliness of automotive products.

Its international counterpart is standard ISO 16232, which was published in 2007.

In 2010, VDA 19 Part 2 (*Technical Cleanliness in Assembly*) was published, detailing cleanliness-related design aspects for assembly areas.

4.3 Technical cleanliness in the electronics industry

The industry increasingly uses the generally valid VDA 19 guidelines in addition to company-specific standards.

This Technical Report outlines a system for designing and implementing component cleanliness analyses to enable quantifiable comparisons of component cleanliness levels. However, VDA 19 does not specify any limiting values for component cleanliness. These must be defined according to component function, producibility and verifiability.

This Technical Report supplements VDA 19 and ISO 16232 by addressing outstanding questions and providing practical solutions.

The producibility of a component as well as its performance must be considered in this context, as is the case when defining dimensional tolerances. Production processes, production environment and final packaging also influence component cleanliness. This often calls for agreements concerning compliance with limiting values between customer and supplier or product development and production. This is particularly relevant in instances where limiting values are exceeded without necessarily impairing performance. A careful review shall be carried out to ensure that efforts to comply with these values do not outweigh the potential risk, thereby avoiding excessive cleanliness requirements.

4.4 Potential particle-related malfunctions

Limiting values for component cleanliness ensure component performance and should be defined as early as possible during the component development stage. The following possible malfunctions should be considered:

- electrical short circuit;

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- shorter creepage and clearance distance;
- electrical insulation of contacts;
- impairment of optical systems such as cameras;
- reduced wettability/solderability;
- mechanical obstruction;
- increased or reduced friction;
- increased or reduced power;
- leaks.

If the remaining particulate contamination – also called residual contamination – is sufficiently low in a technical system to cause no short or long-term performance impairment or system damage, the system is considered adequately clean in the context of technical cleanliness.

5 Technical cleanliness as a challenge for the supply chain

5.1 General

In the past, drawings usually contained rather general information on component cleanliness, which was not systematically verified. Example:

Parts must be free from contamination e.g. swarf, release agents, grease, oil, dust, silicone…

With the publication of VDA 19 and ISO 16232, standardised cross-company procedures were defined to record, analyse and document component cleanliness information.

General attributive provisions that had previously been customary and checked via visual inspection were replaced, e.g. by specifying particle size classes with maximum particle count, which can be verified by means of laboratory analysis.

The procedures to determine component cleanliness according to VDA 19 are standardised, reproducible and also more objective than previously applied methods. However, the following points should be observed when applying these procedures:

- particle generation may vary significantly, even from the same production glass;
- particle detection depends on the method and quality of analysis;
- inspections are costly and require a laboratory;
- measurement system analyses (MSA) are not possible for the entire inspection process of technical cleanliness;
- in-process inspections with associated regulatory measures can be implemented only after lengthy delays.

In practice, cleanliness analyses according to VDA 19 are used for production releases or requalification, during production and when there are reasonable grounds for suspicion.

Limiting non-metallic particle contamination (e.g. dust, lint, abrasion) poses a further challenge to the supplier. If these particles are classified as functionally critical and hence limited, account shall also be taken of the manufacturing environment, suitability for subsequent cleaning, packaging (to maintain cleanliness) and logistical considerations when determining the limit. Detailed information is provided in VDA 19 Part 2. The controlled production conditions (clean zone grades) necessitated by this require more effort and expenditure. For this reason, it is advisable to determine limiting values only where functionally relevant.

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5.2 Contamination

5.2.1 Definition of particles

5.2.1.1 General

VDA 19 Part 1 defines a particle as a solid body composed of metal, plastic, minerals, rubber or a salt. Paste-like fractions are not considered to be particles.

The following terms and definitions for metallic and non-metallic particles apply to the terminology used in this document.

5.2.1.2 Metallic particles

Metallic particles are particles that are primarily characterised by a shiny metallic reflective surface. They can be detected through a combination of normal and polarised light imaging. An optical microscope with the relevant features normally suffices for identifying metallic particles.

However, using optical microscopy for metallic particle detection bears the following potential risks:

- extremely small metallic particles or sintered metals cannot be identified as metallic particles;
- strongly oxidised metallic particles cannot be identified as metallic particles;
- reflective non-metals, such as glass, may be wrongly classified as metallic particles owing to their reflective behaviour.

Since it would be too costly and time-consuming to differentiate between electrically conductive and non-conductive particles when assessing the technical cleanliness of the production process, or indeed impossible, the analysis concentrates on detecting metallic and shiny metallic particles.

Shiny metallic particles are generally assumed to be both metallic and conductive.

It must be stressed that differentiating between metallic and non-metallic particles by their metallic lustre does not permit a reliable distinction to be made regarding their electrical conductivity.

The following steps can be taken to avoid these pitfalls: manually re-examine the biggest metallic and biggest non-metallic particles detected using an optical microscope; subsequently reclassify these particles if necessary.

Other systems such as EDX, Raman or laser-induced breakdown spectroscopy provide more detailed and conclusive results. However, this entails greater expenditure.

5.2.1.3 Non-metallic particles

Non-metallic particles are particles that are not primarily characterised by a shiny metallic, reflective surface. They contain no fibres.

5.2.2 Definition of fibres

Component cleanliness analyses invariably detect textile fibres from clothing, which are ubiquitous in any production or laboratory environment where people are present. Fibres are non-metallic particles, which, although usually mentioned in the test reports, are not considered in the evaluation. To be classed as afibre, they must meet the following specific geometric boundary conditions in accordance with VDA 19 Part 1:

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- stretched length/maximum incircle > 20; and
- width measured across maximum incircle ≤ 50 µm.

In simple terms, this means that:

- the length-to-width ratio is between 1 and 20; and
- the width of a fibre is ≤ 50 µm.

Notes on the definition:

- implementing this theoretical approach with customary two-dimensional optical test systems often lacks a certain amount of precision;
- compared with previous definitions, a shift in the number of non-metallic particles and fibres must be envisaged with this approach;
- based on the current definition, a human hair with a thickness of approximately 60 µm to 80 µm would be classed as a non-metallic particle rather than a fibre;
- in contrast, a glass or carbon fibre with a thickness of 40 µm would be classed as a fibre rather than a particle, although it clearly has the potential to cause damage.

The following potential errors may occur when identifying fibres:

- fibres with a strong curl cannot be detected;
- particles may be wrongly identified as fibres if the width and height are very small in relation to the length (e.g. plastic burr);
- fibres positioned vertically to the membrane (in the z-axis) may be analysed incorrectly or not at all;
- fibres may be visually "chopped" and not detected as one fibre.

5.3 Test procedure to determine technical cleanliness

5.3.1 Fundamentals

The technical cleanliness of components refers to the level of particulate contamination on the relevant surfaces of test objects.

The aim of cleanliness inspections is to determine and measure the particle count as accurately as possible.

VDA 19 describes the application methods and conditions to determine and document particulate contamination. It also specifies the different extraction and analysis methods.

The following extraction methods are suggested for removing particles on electric, electronic and electromechanical components, circuit boards and electronic assemblies (hereafter referred to as 'components'):

- pressure rinsing,
- ultrasonic techniques,
- internal rinsing,
- agitation,
- air extraction.

According to the ZVEI working group on component cleanliness, 'pressure rinsing' as defined in VDA 19 has proved to be a reliable extraction method for a number of applications. Components are rinsed with liquid pressure jets during this process. The liquid is then filtered to separate the released particles for further analysis.

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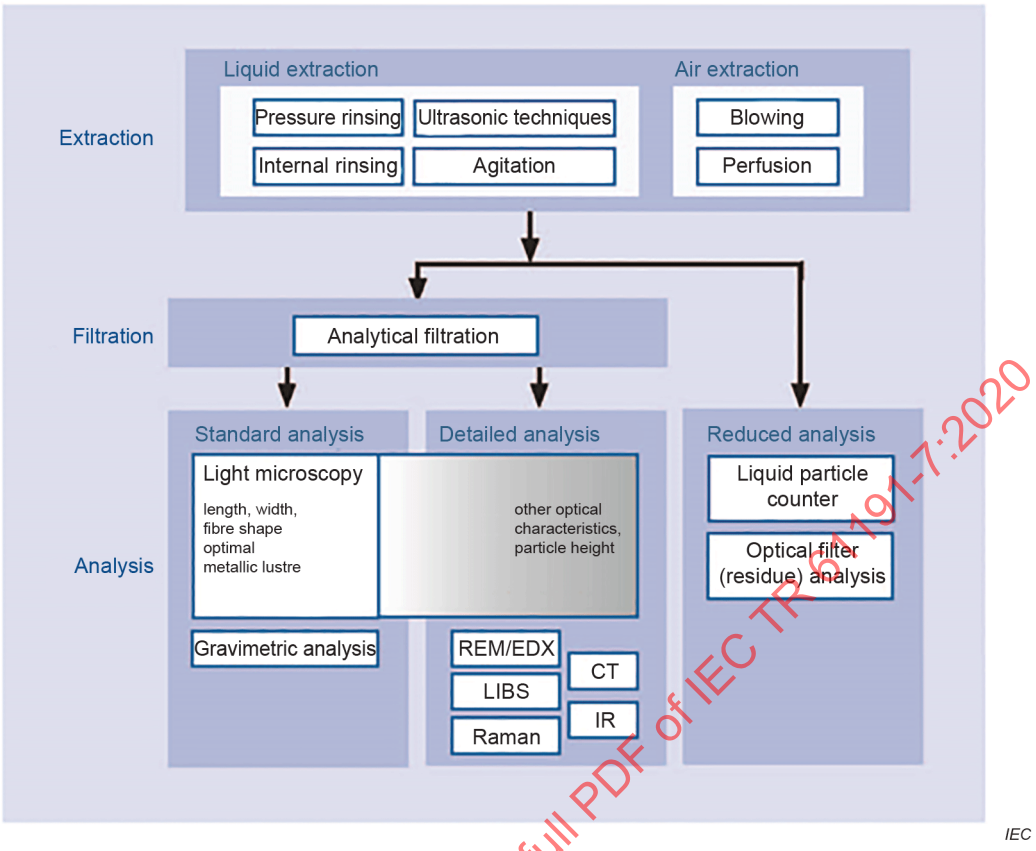


Figure 1 – Test method as per VDA 19 Part 1

To properly evaluate the cleanliness level of the component, the pressure rinsing extraction process shall be qualified. This is done by repeating the process several times and reevaluating the results each time. The count of extracted particles shall continuously decrease. By the sixth analysis at the latest, the particle count shall be ≤ 10 percent of the sum of all previous analyses (all relevant particles in total). This is referred to as an extraction curve. The extraction curve is a prerequisite for series analyses and shall be determined once for each component type.

The cleanliness of an extraction system and hence its suitability is determined without components. The same parameters are used for this component-free pressure rinsing process as for an analysis with components. The particle count obtained provides the basis for the release of the system for the next test and is referred to as the blank value.

The extraction method described in 5.3.4 is based on VDA 19 and details the use of pressure rinsing to separate particles from components and collect them on a filter membrane for subsequent measurement and analysis.

Particles that cannot be separated from the components by extraction are classified as "tightly adhering" and are not considered in the context of component cleanliness.

5.3.2 Clarification form

The clarification form defines all the specific test parameters required for an analysis. It is required not only for performing an analysis, e.g. in an analytical laboratory, but also for the internal review of different analyses and for submission to the customer for approval based on the test parameters from the requirements specification.

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How else can we ensure that comparable measurements have been analysed under the same conditions, e.g. with the same filter types and the same mesh width?

It is always advisable to design a clarification form that clearly defines those parameters which ensure comparability of analyses.

All options for performing an analysis shall be specified (see Figure 1 and Figure 2).

This Technical Report includes sample clarification form templates for 'environmental cleanliness' and 'component cleanliness' (see Annex B). Not everyone who requires an analysis has the specialist knowledge required to complete a clarification form in full.

For this reason, the clarification form is divided into two sections.

The first section covers the following points and must be completed by the requester:

- information about the test component,
- sampling conditions,
- cleanliness requirements,
- etc.

The second section should be completed by the specialist:

- details of particle count,
- type of filtration and filter,
- presentation of results,
- how packaging is dealt with,
- etc.

The use of a clarification form greatly simplifies the internal management of analyses which are intended to be compared with another. Furthermore, it also simplifies the commissioning process by reducing follow-up inquiries from the analytical laboratory regarding unclear or missing parameters.

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Figure 2 – Examples of extraction systems

5.3.3 System technology

The following criteria shall be considered when designing a pressure rinsing system:

Component holder

Containers or funnels that discharge directly to the filter membrane. If necessary, a suitable sieve can be placed in the container to hold the component. If particles are simultaneously extracted from several components, the components shall not be placed on top of each other but next to each other. It is important to avoid generating new particles during the extraction process.

Pressure rinsing equipment

An easily manoeuvrable pressure rinsing tool (lance) with a round nozzle of e.g. 4 mm in diameter is suitable for pressure rinsing components manually at stable flow rates.

Membrane holder

Membrane filters shall be easily removed from storage containers and loaded into the equipment, if necessary using tweezers. To ensure that no liquid remains between the container and the membrane filter, which would prevent the detection of particles, it is advisable to extract the test liquid from the container holding the components (if necessary by vacuum suction).

Number of components per test

The surface of the test components shall be sufficiently large to provide statistical data on component cleanliness. It is advisable to select the number of components per test that ensures the smallest possible extrapolation factor based on a 1 000 cm^2 reference surface area. However, no more than 50 components should be tested for practical reasons (see 5.5.2).

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5.3.4 Process parameters for pressure rinsing extraction

1) Extraction method: pressure rinsing in accordance with VDA 19
2) Test liquid [1] : solvent cleaners based on non-aromatic aliphatic of alicyclic hydrocarbons with a terpene content of < 30 percent, e.g. Haku 1025-921[2], DE-SOLV-IT 1000[3], Glogar G60 spezial[4]
3) Flow volume: 1 000 ml/min ± 200 ml/min
4) Nozzle: lance with 4 mm round nozzle
5) Filter type (membrane): 5 µm pore size, approx. 47 mm membrane diameter; material e.g. cellulose nitrate, PET mesh
6) Pressure rinse volume: result of extraction curve (approx. value of 2 l to 6 l)
7) Final rinse volume[5]: approx. value ≥ 2 000 ml
8) Number of components: 1 to 50 units or ideally ≥ 200 cm^2 surface area

5.3.5 Pressure rinsing process

Care shall be taken to ensure that the spray reaches the target surface of all components during the pressure rinsing process. To achieve this, the pressure rinsing device (lance) is directed along the entire surface of all components at a distance of approximately 1 cm to 10 cm until the rinse volume has been reached (see Figure 3). The test components shall be handled in a manner which ensures that no further particles are generated during the extraction process (e.g. owing to abrasion).

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1 The compatibility of solvent, components and assemblies should be verified at least once during testing.

2 Haku 1025-921 is the trade name of a product supplied by Chemische Werke Kluthe GmbH. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.

3 DE-SOLV-IT 1000 is the trade name of a product supplied by Mykal Industries Ltd or A. + E. FISCHER-CHEMIE. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.

4 Glogar G60 spezial is the trade name of a product supplied by Fa Glogar Umweltechnik GmbH. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.

5 The final rinse volume is **not** determined by the decay test, but by the extraction chamber used.



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Figure 3 – Component holder during manual pressure rinsing

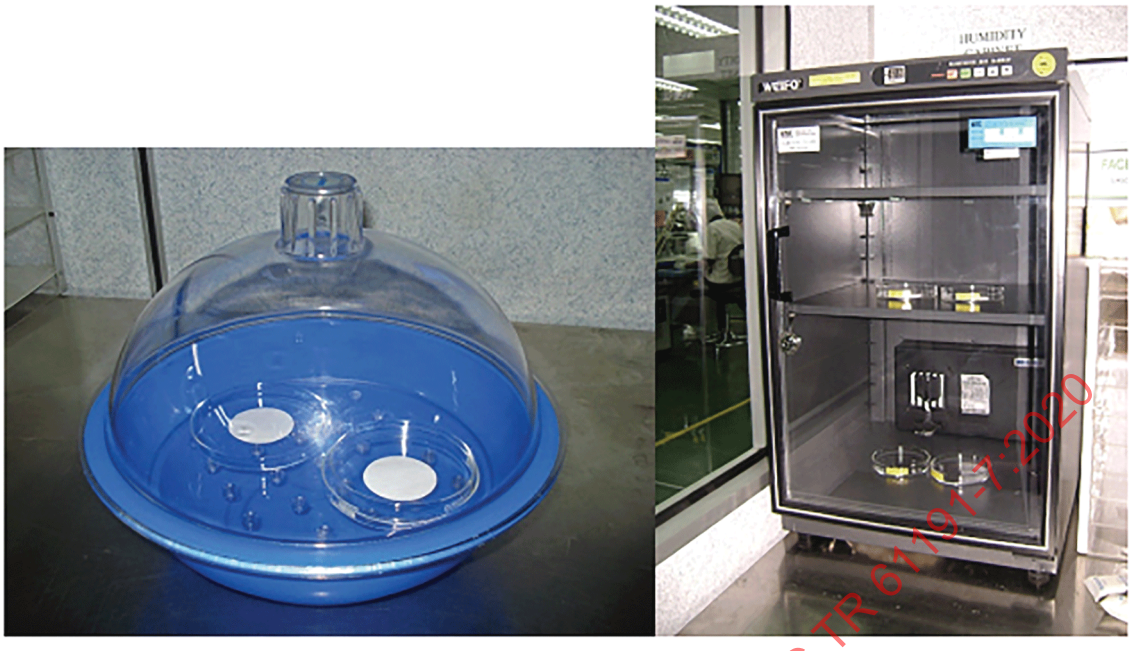
The components are then removed and the empty component holder with container is rinsed as part of the extraction process.

5.3.6 Preparing membrane filters for measurement analysis

On completion of the extraction process, the membrane filters shall be dried at room temperature or using a drying oven. To prevent additional contamination or loss of particles on membranes, the oven should be operated without air recirculation. A desiccator may also be used for drying the membrane filters at room temperature (approximately 12 h to 24 h) to protect them from contamination. Petri dishes can be used to facilitate the handling of moist membrane filters (see Figure 4).

This process shall take place in a clean environment which will not adversely affect the results.

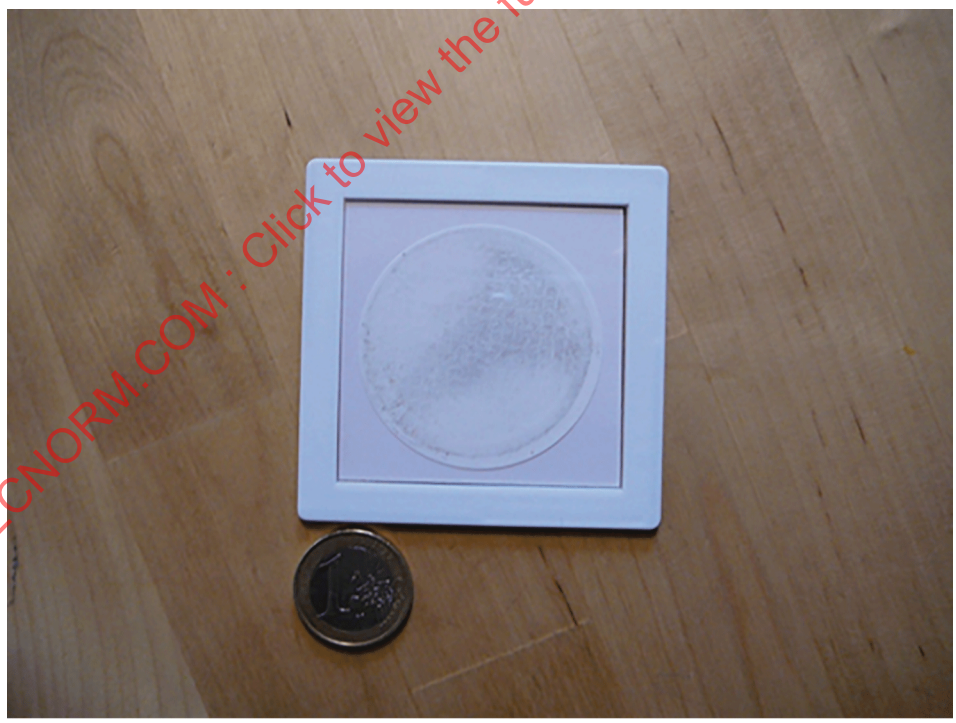
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Figure 4 – Examples of different options for drying membrane filters

The dried membranes can be mounted in standard slide frames (60 mm × 60 mm) for the measurement analysis (see Figure 5).



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Figure 5 – Slide frame with membrane filter

The qualification test (extraction curve) and blank value determination shall be performed in line with VDA 19 Part 1.

For the first decay test to determine the extraction curve, 1 litre of pressure rinsing liquid per extraction process may be used for reference.

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In the event that no decay takes place and the decay criterion is not reached, the process shall be repeated with a higher volume of liquid and new components.

Once dried, the components used for analysis purposes may be re-fed to the production process.

5.4 Measurement analysis

Light microscopy is normally used to evaluate the particles on the membrane filters. The microscope and camera automatically scan the membrane filters and determine the shape and dimensions of the individual particles. Software then classifies the particles according to the size classes defined in VDA 19, differentiating between metallic and non-metallic particles according to 5.2.1. Fibres (see 5.2.2) are not usually considered in the evaluation.

Heavily contaminated membrane filters can result in analytical errors owing to overlapping particles. In this case, the number of test components per analysis should be reduced to minimise the risk. Alternatively, cascade filters can be used.

In addition to extremely contaminated membrane filters, other parameters such as:

- filters (pore size, material, mesh structure),
- filter handling (positioning in measurement system, transport),
- microscopes ,
- image processing (software),
- analysis methods (cross-polarisation, EDX, Raman spectroscopy),
- illumination systems (incidental light, light/dark field, transmission light),

can skew the results of the particle count.

5.5 Evaluating the results of cleanliness analyses

5.5.1 Overview

Particles on components are not generated deliberately using defined methods, but arise as incidental waste products. For this reason, the particle generation process is neither stable nor actionable, and therefore particles have a wider spread compared with characteristics that have been specifically produced. Although component cleaning effectively reduces the number of particles, it does not significantly alter their spread.

VDA 19 Part 1 Ch. 2.1, defines cleanliness limits as action control limits rather than tolerance limits. When a limit is exceeded, it does not necessarily mean that an error has occurred; it increases its likelihood of occurrence. An error occurs only when a critical particle is found at the right time in the right location on a sensitive position within the system.

The aim of the cleanliness analysis is not to find random errors arising from the large spread of cleanliness values, but to find systematic errors such as worn tools, errors in the cleaning process, incorrect storage conditions and incorrect process parameters.

Particle numbers and dimensions are difficult, if not impossible, to predict during the planning phase. They are influenced by numerous process and environmental parameters which are difficult to control. Measuring particles on existing components (samples if necessary) or using comparable components for reference (creating groups) is the most reliable method of obtaining information on particulate contamination for (future) series production.

Of the different procedures available to measure particles, the two variants below are the most common:

a) determining particle count per particle class; and

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b) determining maximum particle length.

The appropriate variant is selected on the basis of the parameters, specifications or requirements.

5.5.2 Particle count relative to component surface

The option mentioned in VDA 19 Part 1 is most widely chosen in practice, in which the number of particles detected is expressed relative to a 1 000 cm^2 component surface area. This is useful when comparing the contamination level of different sized components. If during the extraction process, fewer components are rinsed than would be necessary to achieve 1 000 cm^2, the number of particles detected per class shall be extrapolated to 1 000 cm^2.

Determining the component surface area is difficult and time-consuming owing to the complex surface structure of assembled circuit boards. The working committee has therefore specified a standard method to determine the surface area, which provides largely accurate and comparable results while minimizing time and effort (see Annex A).

When measuring technical cleanliness, it is important to aim for the largest possible component surface area (at least 200 cm^2, ideally 1 000 cm^2). However, a tiny chip component, e.g. EIA0603, would have to be extrapolated by a factor of 300 or more to avoid having to use several thousand parts for a cleanliness analysis. Clearly, it would not make economic sense to use such a large number of components.

This extrapolation process may result in a very high particle count for a specific particle class, when in reality only a single particle may have been found in this class on one occasion. In such cases, it is not normally possible to comply with the permitted blank value (10 % rule as per VDA 19 Part 1) because small components carry too few particles. The smaller the total surface area of the components being analysed, the greater the disproportionate rise in the ratio of particles originating from the analytical equipment with no products.

A method is proposed below to reduce the influence of the blank value on the measurement results during the extrapolation process. After the measurement, the (theoretical) blank value is initially deducted, the measurement result is extrapolated to 1 000 cm^2, and then the blank value is added to the extrapolated result. In this case, the blank value is estimated to be x percent of the total contamination (see also Table 1).

This procedure is expressed in the following extrapolation formula:

$$N = n \times (1\,000 + B) / (A + B)$$

where:

N = number of particles extrapolated to 1 000 cm^2 component surface;

n = number of particles on all components measured;

A = surface area of components, measured in cm^2;

B = blank value equivalent in cm^2, corresponds to x % of 1 000 cm^2).

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Table 1 – Influence of the blank value on the measurement results for different material surfaces (examples for a blank value fraction of 2,2 % and above)

Surface of components measured in cm^2	1000	500	200	29	10	1
Blank value equivalent in cm^2 (corresponds to 2.2% of 1000 cm^2)	22	22	22	22	22	22
Blank value fraction in %	2.2%	4.2%	10%	43.1%	68.8%	95.7%
Pie chart showing blank value fraction (light blue)						
Example (see blue column in the table): One Class H metallic particle (200–400 µm) was found during a cleanliness inspection of 50 components with a total surface area of 29 cm^2. A 'normal' extrapolation to 100 cm^2 (multiply 1000/29) gives a value of 35 Class I particles on 1000 cm^2. Extrapolation using the abovementioned formula gives a value of 20 metallic particles on 1000 cm^2.						

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5.5.3 Procedure for violation of action control limits

Owing to the large spread of particle occurrence, a single analysis has only limited meaningful value. In order to distinguish between systematic and random discrepancies, several cleanliness analyses shall be performed.

The following course of action is recommended (see Figure 6).

If a particle count is exceeded in one class, a further analysis shall be performed.

If only one part of a component surface was analysed owing to its very large size, when the test is repeated, at least three parts per analysis shall be tested to increase the reliability of the information obtained from the new analyses.

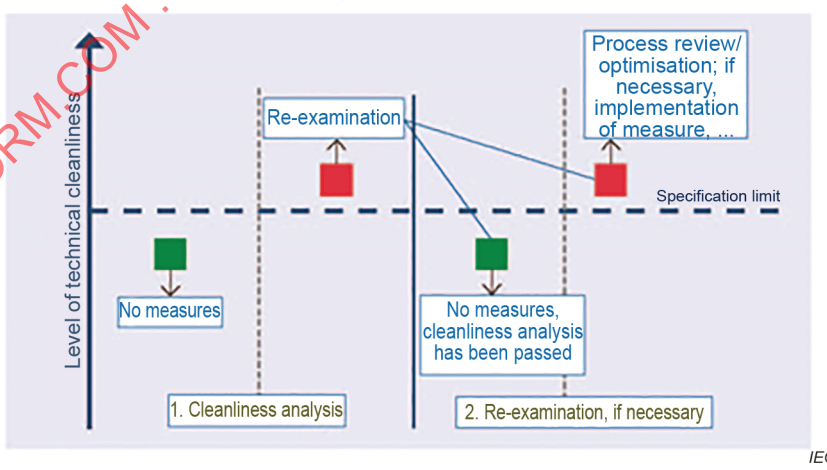


Figure 6 – Example procedure if specifications are exceeded

If the cleanliness values obtained from these additional analyses lie within the agreed limits, it is fair to assume that the discrepancy was a random event and the entire cleanliness test is deemed to have been passed successfully.

However, if one value from these additional analyses again lies outside the agreed values, it can be a systematic discrepancy. Different follow-up measures can then be taken:

- review and optimise the manufacturing process and perform further follow-up tests; it is useful at this point to perform materials tests on the particles found to help pinpoint their source;
- re-clean;
- exceptional release in individual cases following an appropriate risk assessment;
- increase the confidence interval by testing further components from the same production batch.

5.6 Extended risk assessment

5.6.1 General

The cleanliness risk can be estimated more accurately by applying the following approaches; the likelihood of occurrence of particles above a certain size can be inferred from the data obtained from a single cleanliness analysis.

1) Use one or several analyses to determine raw data by particle measurements according to VDA 19 Part 1 or 5.3. The greater the number of analyses, the more accurate the estimation. The data should contain the true sizes of the relevant particles. The number of relevant particles should be sufficient to enable statistical evaluation.
2) Experience shows that particle size and count create a function similar to exponential distribution. The data shall be transformed into a natural distribution using a suitable program to allow statistical evaluation.
3) It is also possible to obtain information on the likelihood of occurrence of particles above a certain size even if these were not found in the analysis by taking into account the test samples used for the analysis.

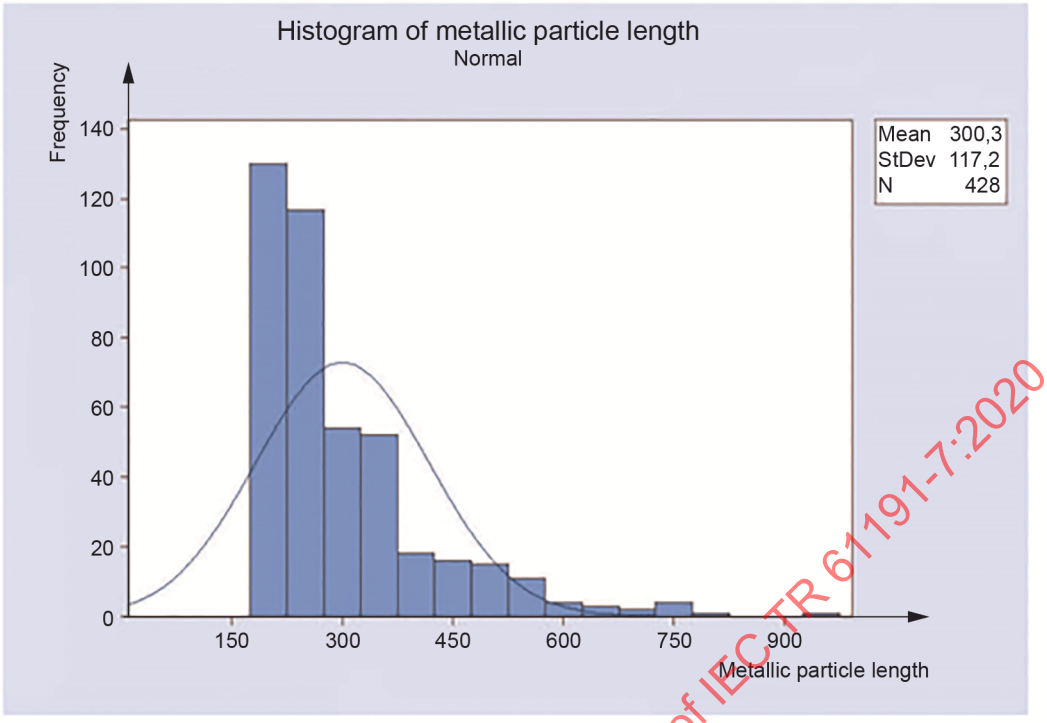
5.6.2 Example

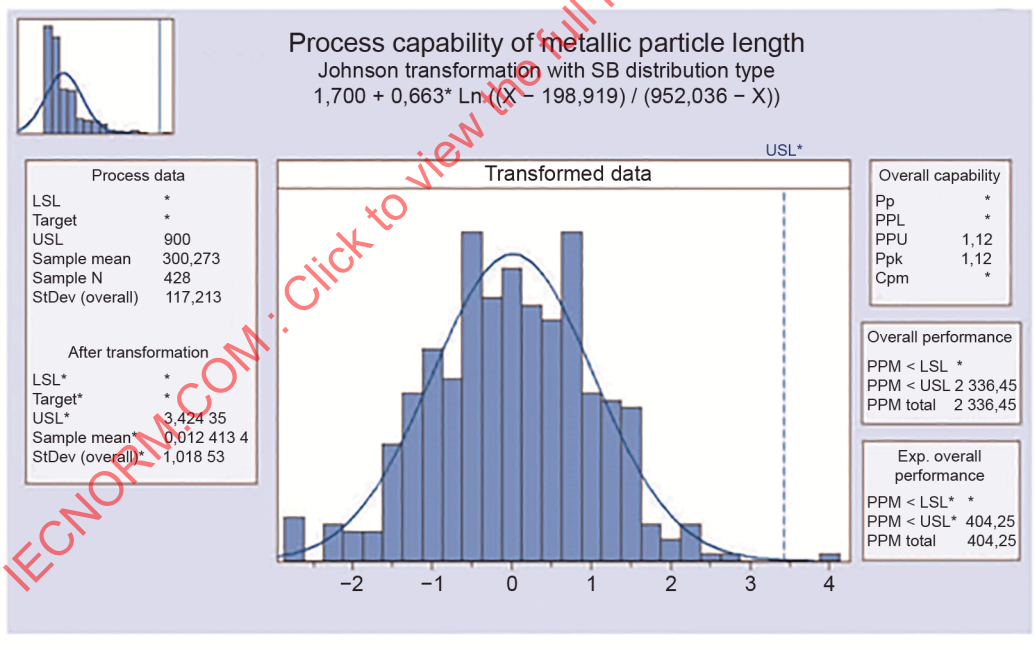
A total of 428 particles (≥ 200 µm) has been extracted from 1 510 contacts and analysed in terms of size in this example (see Figure 7).

- When extrapolated, this corresponds to 283 443 particles (≥ 200 µm) out of one million contacts.
- Statistically, 404,25 ppm or 114 particles of these are ≥ 900 µm.

Assuming an even particle distribution, i.e. a maximum of 1 particle per contact, one metallic particle ≥ 900 µm can be found on 114 out of 1 million contacts, which corresponds to a failure rate of 114 ppm.

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Figure 7 – Particle size distribution and corresponding process capability

5.7 Component cleanliness – Data management and visualization

5.7.1 Component cleanliness analysis – flow diagram

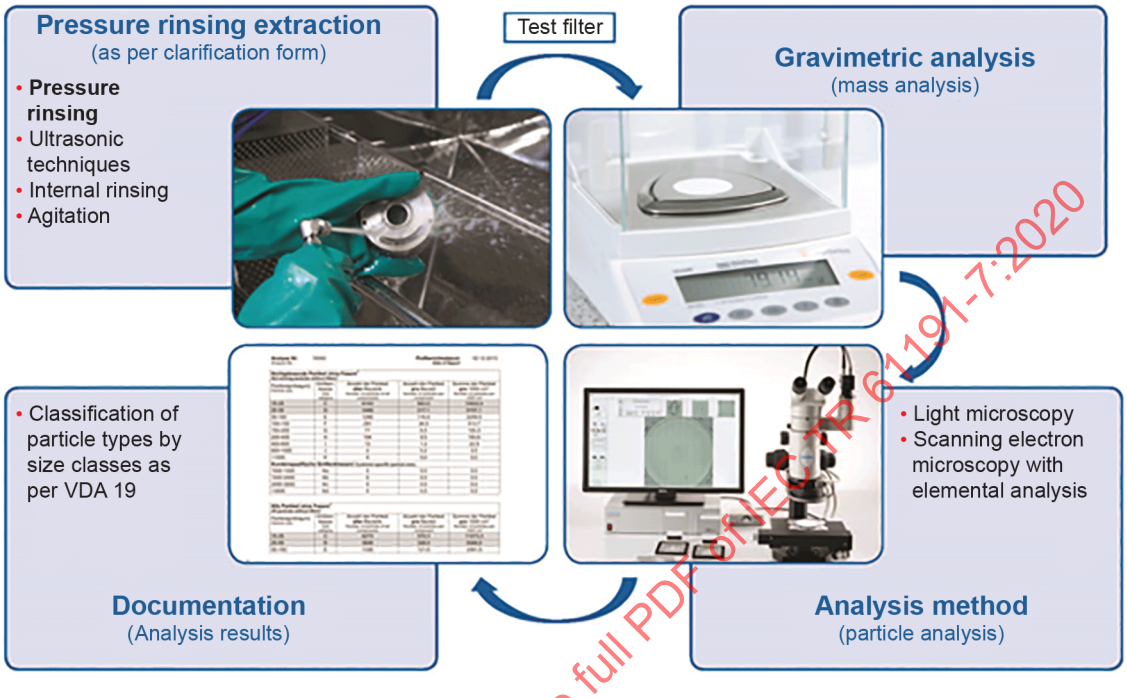


Figure 8 – Flow diagram for component cleanliness analysis

Figure 8 shows the flow diagram for component cleanliness analysis. All test and analysis parameters shall be defined before conducting component cleanliness analyses. The clarification form or a company specification sets out the conditions under which the laboratory is to perform the analysis in question (regulation of analytical values/parameters), see Annex B.

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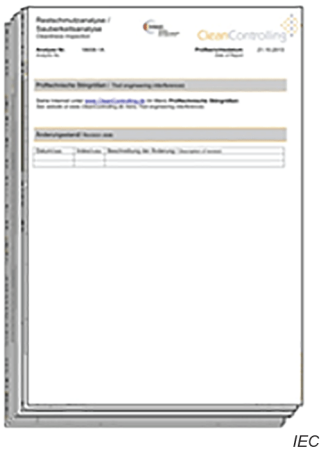


Figure 9 – Scope of analytical report

Clearly defined performance standards, i.e. the same framework conditions, are the only way to ensure comparability with other analyses (see 5.3.2).

The analytical laboratory shall provide the following information (see Figure 9):

- analysis report in compliance with e.g. VDA 19 Part 1, including indication of blank value;
- test specification including decay test.

Optional:

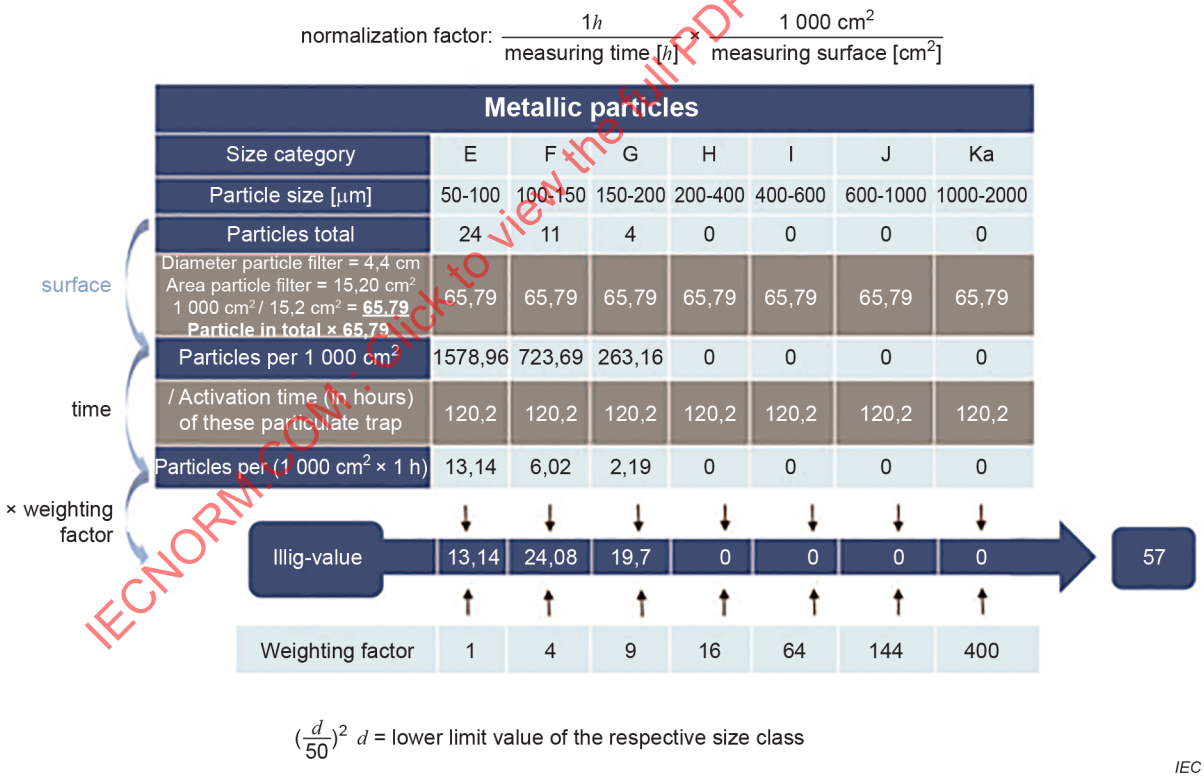
- video showing the performance of the decay measurement filter.

5.7.2 Explanation of SCI (Surface Cleanliness Index)

The derivation of the Illig value is shown in Figure 10. The Illig value can be used to compare the environmental cleanliness of production areas and assess measures that have been introduced. For example, does a new ventilation system achieve the desired effect?

This need to provide evidence applies not only to environmental cleanliness, but also in particular to the products. For example, does an additional cleaning process achieve the desired effect?

This can be verified using the SCI (surface cleanliness index), which is a variation of the Illig value. The derivation of the SCI is shown in Figure 11. It indicates the significant sum of particles. Like the Illig value, the SCI is a single numerical value which reflects the results of analysis for the relevant particle type.



Scaling factor: see VDA 19 Part 2.

Figure 10 – Derivation of Illig value

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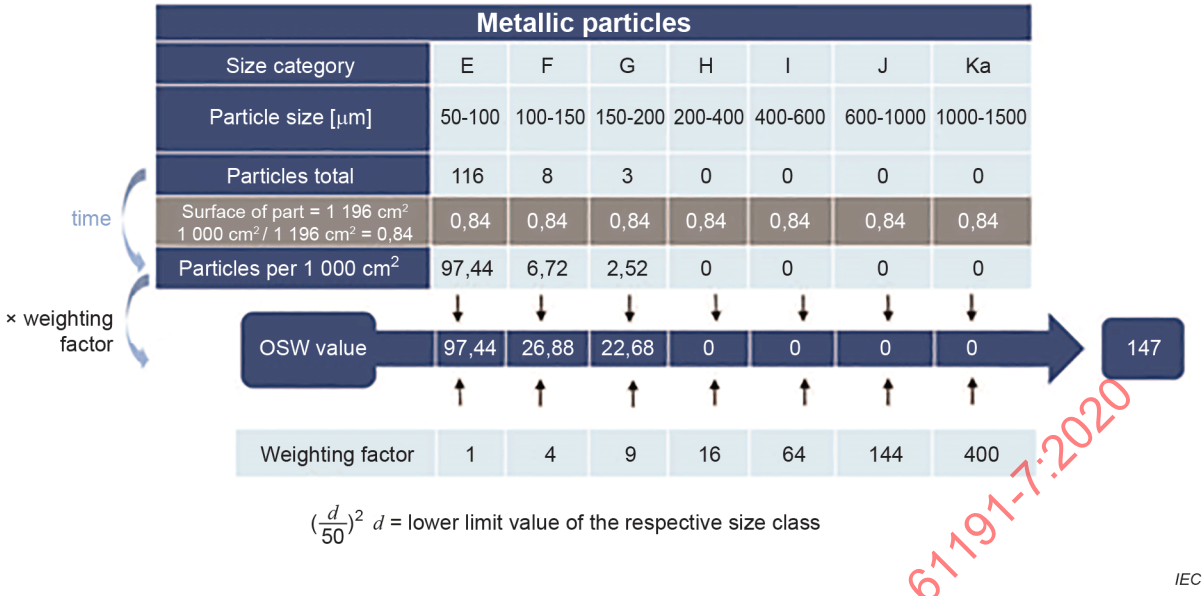


Figure 11 – Derivation of SCI

The SCI differs from the Illig value only in the absence of scaling over time.

It is obtained by calculating the combined surface area of all test components in an analysis and then scaling up the number of particles per size class and type to 1 000 cm^2. Like the Illig value, the SCI uses the same weighting factors for each size class. These are derived from the lower limit d of the size class divided by 50 and squared. The number of particles in each size class per 1 000 cm^2 is multiplied by this weighting factor to obtain the SCI per size class. The SCIs for each class are then added up to give the SCI for the complete analysis.

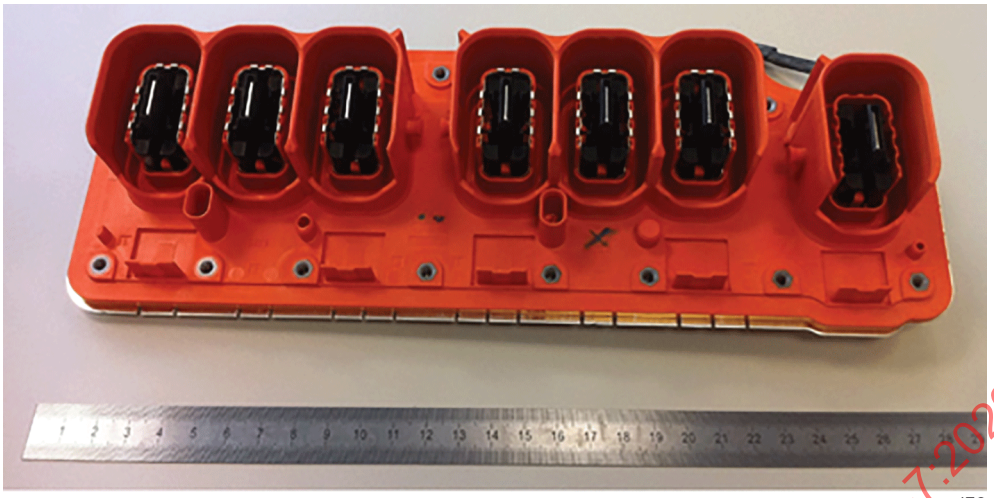
Note that in graphic representations, the SCI, like the Illig value, should always be shown in relation to the largest particles so that a comprehensive statement can be made about the effect of the measure (see Figure 12, Figure 13 and Figure 14 for an example). Individual "outliers" in particular tend to get lost with a high SCI.

The SCI is suitable for comparing measures such as cleaned/not cleaned. The maximum particle lengths, which are normally defined in the specifications, give an indication of the extent to which the outlier rules and escalation strategy should be characterised.

It is advisable to use diagrams or a database as a visualisation tool to provide a quick overview of the results of a measure.

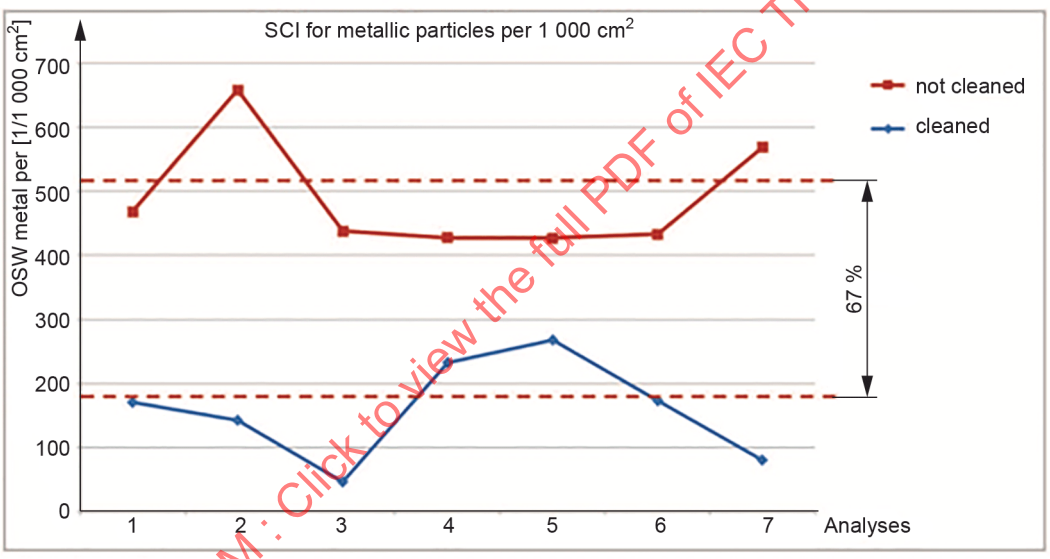
The informative value of a review of measures is directly related to the number of representative analyses. If one analytical value is worse after a measure (e.g. cleaning) than before, this is most likely due to the large standard deviation (see VDA 19 Part 1 Ch. 10.1).

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Figure 12 – Evaluation of 7-pin HV strip connector



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Figure 13 – Graph showing cleaning effect based on SCIs

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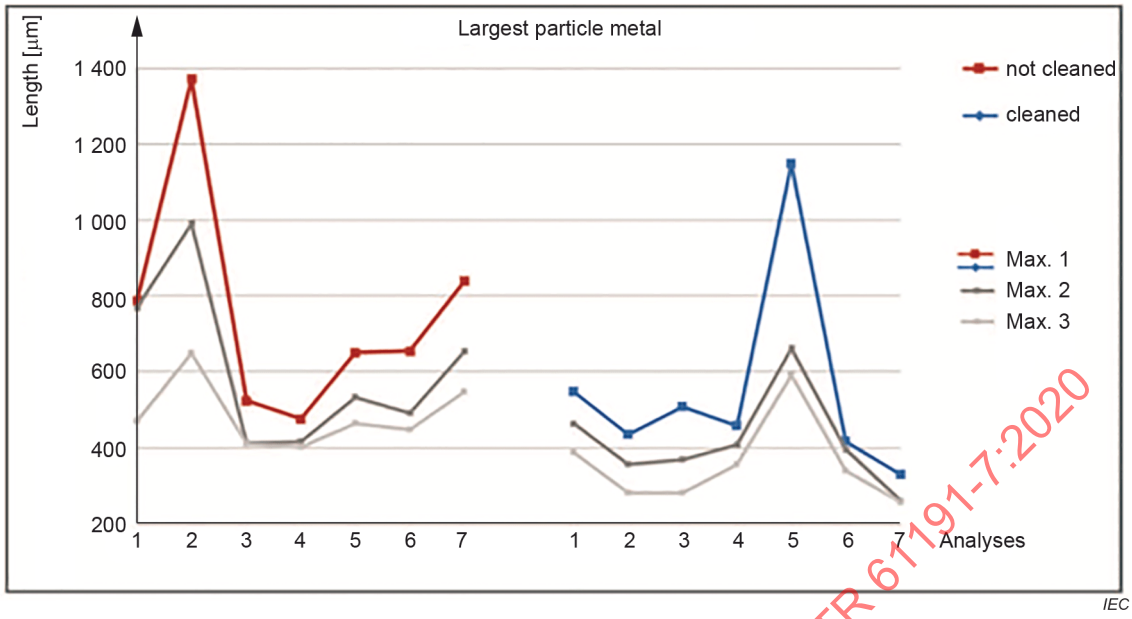


Figure 14 – Comparison of the three largest particles

5.7.3 Creating a database

Analytical reports can be transferred to a database manually or automatically.

Before a database can be set up, its scope must be defined. Experience shows that the spectrum of information increases over time; however, if every value from an analysis were to be transferred, the size of the database would increase very substantially.

Analyses are performed on the basis of individual cleanliness specifications. In most cases, analyses provide information specific to the given application only. For this reason, it is advisable to clarify (e.g. clarification form) which parameters should generally be stored.

If these parameters from the analyses are stored digitally in a database, they can be used for other purposes in the future.

Certain parameters from the analyses must be present in the database, depending on the requirements for the database. Ideally, a software program capable of performing evaluations of technical cleanliness is required.

Alternatively, an Excel[6] database can be used. This can be compiled at low cost and with little programming expertise.

Different options for structural levels of a database are illustrated in Figure 15 to Figure 19.

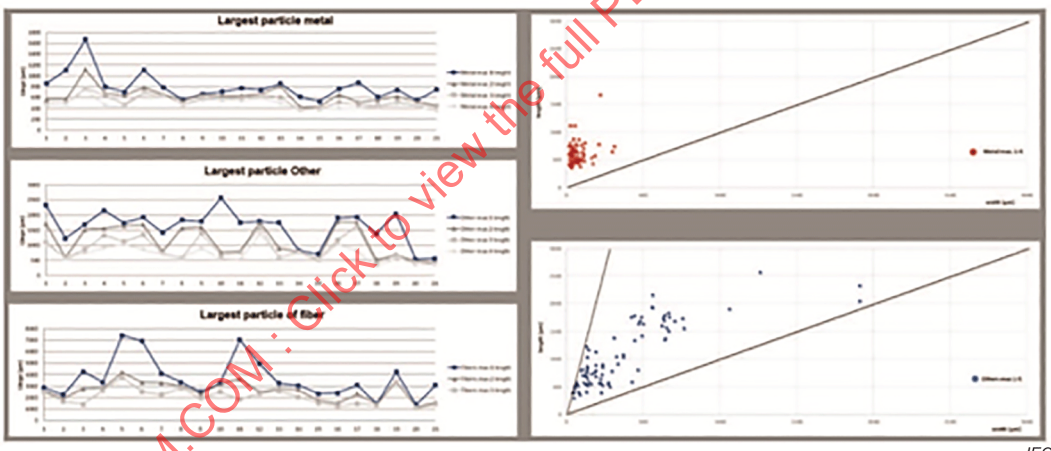
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6 Excel is the trade name of a product supplied by Microsoft®. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.

	Option A	Option B	Option C	Option D
	In order to perform simple evaluations of the largest particles in length and width, the following data from the analyses are required:	In order to compare the degree of contamination of different analyses using OSW (MCV, TCV and FCV) and, if necessary, to specify the residual dirt mass, the following data must also be integrated into the database:	Extension by a separate data sheet "direct comparison of test series":	Extension of the database by "comparison to customer standards":
Product-No.	X			
Designation	X			
Remark	X			
Reference for carrying out the analyses	X			
At least the three largest particles (per particle type) in length and width	X			
Number of particles in the respective size class and particle type of the inspection lot		X		
Residual dirt mass of the inspection lot		X		
Number of parts required per analyses		X		
Component surface per part		X		
Calculation operation that calculates an OSW value from the number of particles per class and, if applicable, the residual dirt mass (per analysis, per 1 000 cm^2 or per component)		X		
Description of measures, e.g. type of cleaning, as well as process and material assignements			X	
Selection fields for selecting analyses for comparisons			X	
Additional data sheet to compare the selection			X	
Establishment of TecSA customer/supplier standards in the database				X

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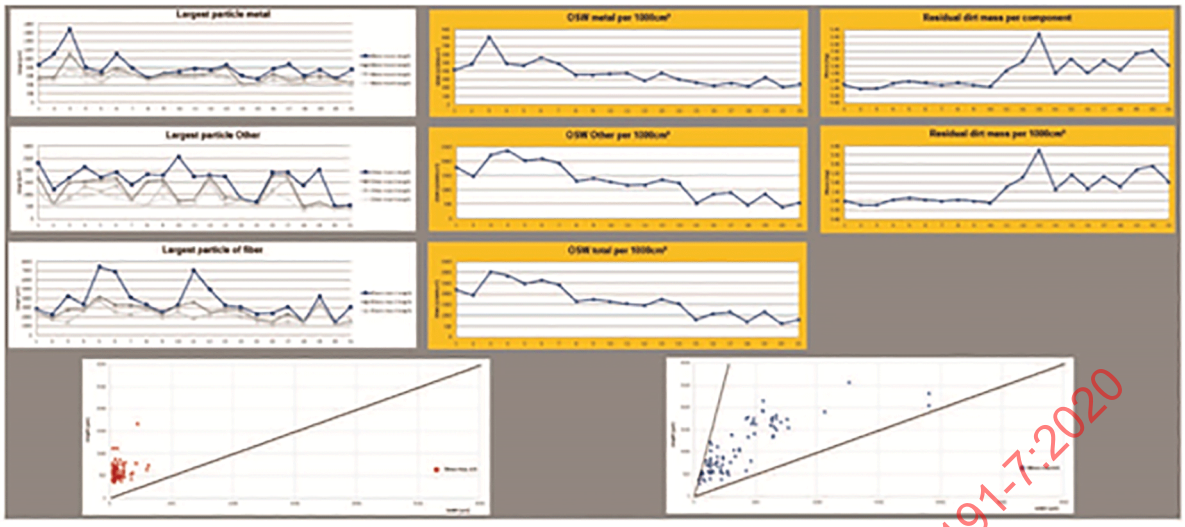
Figure 15 – Structural levels of a database



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Figure 16 – Option A – Evaluation of the largest particles by length and width

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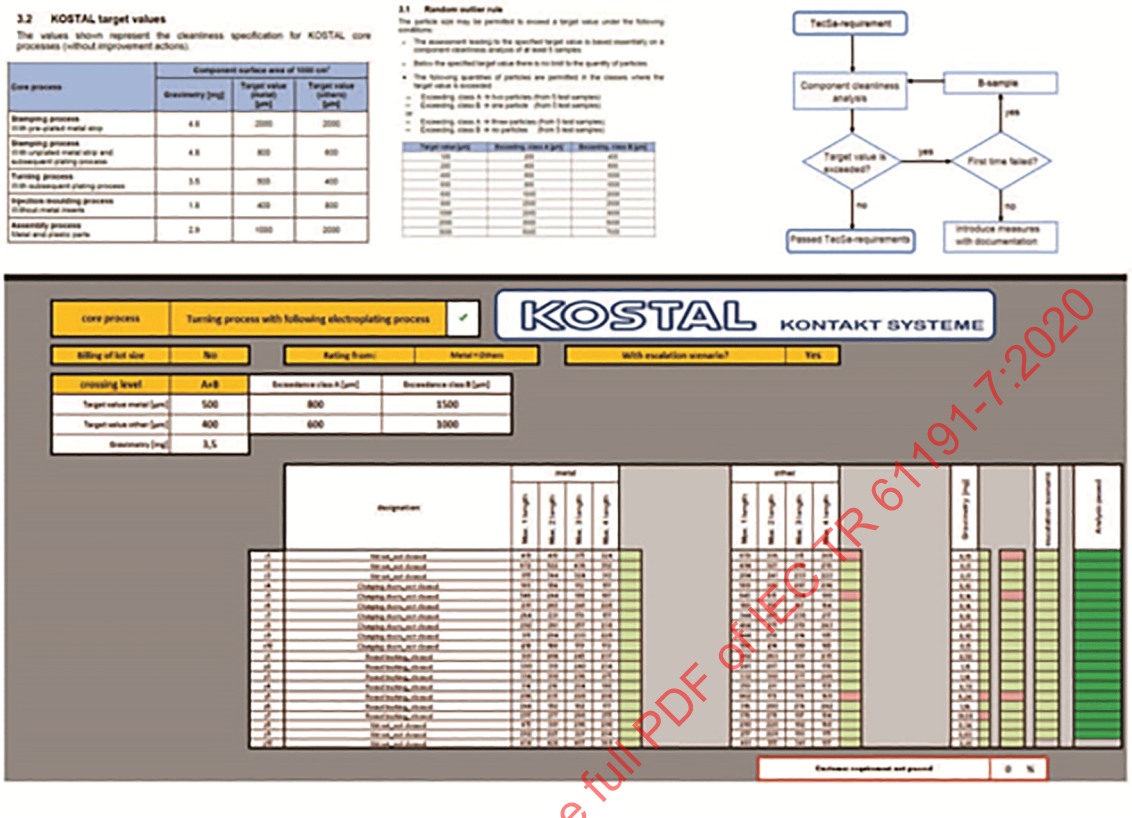
Figure 17 – Option B – Extension to include the degree of contamination – SCI



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Figure 18 – Option C – Extension to include a separate data sheet "direct comparison of test series"

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Example – LK3223 (Kostal Kontakt Systeme GmbH, Kostal Kontakt Systeme is a supplier of contact systems. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of the supplier named).

Figure 19 – Option D – Extension of the database "to include 'comparison with customer standards'"

Factory standards on technical cleanliness are based on mathematical operations, so it is possible to integrate these into the database. Analyses can be automatically compared with standard specifications – e.g. particle type/s that is/are part of the specification, number of, the number of particles per size class, outlier rule, escalation strategy, etc.

5.7.4 Summary

The integration of an SCI enables statements to be made about the degree of contamination on the products themselves and comparisons with other test series if necessary. It is advisable to view this in the context of the "largest particles".

When the particle type/s of interest has/have been defined, a database is indispensable for providing retrospective/prospective statements. The greater the number of representative analyses available, the more accurate and informative the statements. Each analysis yields a substantial volume of data, but with the aid of a database, an overview can easily be obtained by selecting the three "largest particles"/analysing them (per particle type) and calculating the corresponding SCI. This is all the more important when comparing the status quo with two different cleaning methods, for example. In this case, it is advisable to use at least five analyses per test series.

Then at the "press of a button" measures or cleanliness levels can be evaluated and compared with customer standards as required.

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6 State of the art – Technical cleanliness in the electronics industry

6.1 Process flow (per cluster)

6.1.1 General

The following Subclauses 6.1.2 to 6.1.5 summarize the process flow within different clusters in the supply chain of the electronics industry.

6.1.2 Electronics manufacturing cluster

Table 2 summarizes the process flow for the electronics manufacturing cluster.

Table 2 – Electronics manufacturing cluster process flow

Process flow					Process steps
SMT single-sided	SMT+THT single-sided	SMT double-sided	SMT double-sided +THT (automatic)	SMT double-sided +THT (manual)	
X	X	X	X	X	Goods receipt
X	X	X	X	X	PCB marking
X	X	X	X	X	Paste application (stencil printing, dispensing, jetting)[1]
(X)	(X)	(X)	(X)	(X)	SPI
	[X]	[X]	[X]	[X]	Dispensing (SMT glue)
X	X	X	X	X	SMD assembly
X	X	X	X	X	Soldering (reflow/vapour phase)[1]
(X)	(X)	(X)	(X)	(X)	Inspection (MOI/AOI/AXI)[2]
[X]	[X]	[X]	[X]	[X]	Rework
			X		THT assembly (automatic)
		X		X	Paste application (stencil printing, dispensing, jetting)[1]
		(X)		(X)	SPI
		[X]	[X]	[X]	Dispensing (SMT glue)
		X	X	X	SMD assembly
			[X]		Curing glue
		X		X	Soldering (reflow/vapour phase)[1]
		(X)	(X)	(X)	Inspection (MOI/AOI/AXI)[2]
		[X]		[X]	Rework
	X			X	THT assembly (manual)
	X		X	X	THT soldering (wave/selective/stamp soldering)
	(X)		(X)	(X)	Inspection (MOI/AOI)[2]
	[X]		[X]	[X]	Rework
[X]	[X]	[X]	[X]	[X]	Press-fit process
(X)	(X)	(X)	(X)	(X)	ICT
[X]	[X]	[X]	[X]	[X]	Depaneling (hand break, circular cutter, punching, routing, laser cutting)[1]
[X]	[X]	[X]	[X]	[X]	Cleaning
[X]	[X]	[X]	[X]	[X]	Coating (dip, spray, tumbling)
(X)	(X)	(X)	(X)	(X)	Final inspection
[X]	[X]	[X]	[X]	[X]	Final assembly
X	X	X	X	X	Packaging

The table shows an example of five typical process flows in PCB assembly.

( ) requirement-specific measurement and test steps

[ ] product-specific process steps

[1] only one procedure possible in each process step

[2] several procedures possible in each process step

Process reduces particle count

Process is the main source of non-metallic particles

Process is the main source of metallic particles

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6.1.3 Passive components cluster (e.g. for inductors and aluminium electrolytic capacitors)

Table 3 summarizes the process flow for inductors.

Table 3 – Process flow for inductors

1	Provide material
2	Attach contacts to core
3	Wind core
	Wind bobbin
	Wind air coil
	Selectively remove core coating
4	Strip wire ends
5	Tin wire ends
6	Bend wire ends
7	Mount coil in housing
	Mount air-core coil on core
	Mount bobbin on core
8	Connect (twisting) wire ends and contacts
	Clip wire ends into taps
9	Connect wire ends and contacts (solder, weld)
10	Clean component
11	Bond, pot or impregnate coil
	Embed component by injection or press-moulding
	Coat component
12	Assemble and glue second core
13	Cut wire ends to final length
14	Final inspection
15	Marking
16	Packaging

Process reduces particle count
Process is the main source of non-metallic particles
Process is the main source of metallic particles

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Table 4 summarizes the process flow for aluminium electrolytic capacitors.

Table 4 – Aluminium electrolytic capacitors

1.	Goods receipt
2.	Production preparation
	Slit foil
	Cut paper
3.	Provide material
4.	Tack and wind
	Connect lead wires to foil (tacking)
	Wind foil and paper into a cylinder and secure with adhesive tape (winding)
5.	Assembly
	Impregnate element with electrolyte
	Push end seal on lead wires
	Assemble capacitor element with end seal in case and close
	Push printed sleeving over case and shrink-wrap
6.	Reform and measure
	Repair damage to the oxide layer of the anode foil caused by preceding processes (ageing)
	Determine (measure) electrical capacity of capacitor
	Printing (for capacitors without sleeving)
7.	Prepare capacitors according to specification
	Taping
	Lead cutting
	Forming
	Reverse polarity protection
	SMD
8.	Final inspection
9.	Packaging

Process is the main source of metallic particles

Process is the main source of non-metallic particles

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6.1.4 Electromechanical components cluster

Electromechanical engineering comprises many technological areas. As representative electromechanical components, electrical connectors should be analysed for the electronics industry and in particular for PCB assemblies in this context.

Table 5 summarizes the process flow for stamped contact production and plastic production (housing) and Table 6 summarizes the process flow for finished parts.

Table 5 – Stamped contact production/plastic production (housing) process flow

Component part process flow	
Sequence	**Stamped contact production**
1	Goods receipt
2	Supply raw material as coiled strips or wires to stamping press
3	Stamp contacts and wind as strips interleaved with paper on reels or pallets
4	Electroplate blank contacts and wind interleaved with paper on reels or pallets. This step can be omitted for contacts made of pre-plated material.
5	Package in different types of outer packaging (e.g. wire mesh containers, boxes, PE bags)
6	Storage

Component part process flow	
Sequence	**Plastic production (e.g. housing)**
1	Goods receipt
2	Supply raw material as plastic granules to injection moulding machine
3	Inject molten plastic into mould tool and allow to cool
4	Eject/remove plastic housing from mould tool
5	Package as bulk goods or in layers in different types of outer packaging (e.g. with PE bags, lined)
6	Storage

Table 6 – Housing assembly process flow

Finished part process flow	
Sequence	**Housing assembly**
1	Supply contacts on reel and housings in outer packaging to assembly line
2	Feed aligned housings into system
3	Feed contacts on reel to cutting station for separation
4	Insert individual contact element in plastic housing with positioning finger
5	Bend contact elements (if necessary)
6	Package finished connectors in layers interleaved with paper into cardboard/ plastic boxes with trays and PE bags
7	Shipping

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6.1.5 PCB cluster

Table 7 summarizes the process flow for the PCB cluster.

Table 7 – PCB cluster process flow

Process low			
Sequence	Rigid circuit board	Flexible circuit board	Sequence
1	Goods receipt	Goods receipt	1
2	Inner layer production for multi-laver boards		
3	Drilling	Drilling/punching	2
4	Through-hole plating	[Trough-hole plating]	3
5	Photo imaging	Photo imaging	4
6	Electroplating		
7	Pickling	Pickling	5
8	AOI	Visual inspection	6
9	Solder mask	Cover layer tacking/lamination	7
		Bake process	8
		Cleaning	9
10	Surface finish	Surface finish	10
11	[V-scoring]	Depaneling	11
12	Milling	Punching/separating	12
13	Internal rinsing		
14	E-test	E-test	13
		Stiffener tacking/laminating	14
		Bake process	15
15	Final inspection	Final inspection	16
		[Cleaning]	17
16	Packaging/shipping (parts trays)	Packaging/shipping (blister, parts trays)	18

[ ] product-specific process step

Process reduces particle count

Process is the main source of metallic and non-metallic particles

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6.2 Technical cleanliness in the electronics industry – current situation

6.2.1 General

Different electronic and electromechanical components, circuit boards and assemblies have been grouped in families based on similar designs and comparable manufacturing processes. To illustrate the particle count per size class, several analyses have been conducted for each component type.

The values in Tables Table 8 to Table 27 indicate the level of cleanliness that can be achieved without special cleaning processes (unless otherwise stated). Most values are determined from several cleanliness analyses – in some cases 20 or more.

The values have to be assessed as empirical values (best practice for the companies involved).

In Tables Table 8 to Table 27, the particle count is indicated in relation to a surface area of 1 000 cm^2. The metallic particle count and the sum of all particles (without fibres) are indicated.

The empirical values in the tables are neither limit values nor typical values. Fixed limit values cannot be practically applied to component cleanliness; instead the values should be regarded as active control limits, with typical values often significantly lower than the tabular values. These values are exceeded only in rare cases or for specific components; generally they are undercut.

Note –

- The previous Class K (> 1 000 µm) has only been partially expanded to include the revised classes defined in VDA 19 Part 1, Version 2015 K (1 000 µm to 1 500 µm), L (1 500 µm to 2 000 µm), M (2 000 µm to 3 000 µm) and N (> 3 000 µm) because some of the data available has been analysed using the old VDA 19 system.
- The particle count normally falls as the particle size increases. Sporadic exceptions to this rule can be found in the tables, which are based on real measurements. This could be related to the fact that certain processes favour the production of a particular particle size.

The tables represent empirical values. They do not constitute limit values; owing to the very wide variation in component complexity, limit values shall be determined and agreed individually for each component/assembly.

6.2.2 Electronics manufacturing

Table 8 – Empirical data from electronics manufacturing cluster

Empirical particle data from **assembled PCBs**[2] per 1000 cm^2 surface, based on particle class			
Particle size [µm]	**Size classes**	**All particles**	**Metallic particles**[1]
50 ≤ x < 100	E	14500	1000
100 ≤ x < 150	F	2500	250
150 ≤ x < 200	G	800	90
200 ≤ x < 400	H	600	110
400 ≤ x < 600	I	70	17
600 ≤ x < 1000	J	20	13
1000 ≤ x	K	6	2

[1] The count of metallic particles can be significantly higher on connectors with metal housings or heat sinks.

[2] Without any cleaning process

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6.2.3 Electronic components

6.2.3.1 Inductors

Table 9 – Empirical data from inductors

Empirical particle data from **inductors** per 1000 cm² surface, based on particle class			
Particle size [µm]	**Size classes**	**All particles**	**Metallic particles[1)]**
50 ≤ x < 100	E	3500[3)]	450[1)2)]
100 ≤ x < 150	F	700[3)]	150[1)2)]
150 ≤ x < 200	G	250[3)]	60[1)2)]
200 ≤ x < 400	H	160[3)]	30[1)]
400 ≤ x < 600	I	20[3)]	10[1)]
600 ≤ x < 1000	J	8[3)]	0.00[1)]
1000 ≤ x	K	3[3)]	0.00

[1)] The count of metallic particles on components with lead frame or metal housings is likely to be higher than indicated in the table
[2)] The count of metallic particles on components with more than 10 open end pins is likely to be higher than indicated in the table
[3)] The count of non-metallic particles on molded components is likely to be higher than indicated in the table

6.2.3.2 Capacitors

Table 10 – Empirical data from aluminium electrolytic capacitors

Empirical particle data from **aluminium electrolytic capacitors** per 1000 cm² surface, based on particle class			
Particle size [µm]	**Size classes**	**All particles**	**Metallic particles[1)]**
50 ≤ x < 100	E	7500	2500
100 ≤ x < 150	F	1500	550
150 ≤ x < 200	G	360	200
200 ≤ x < 400	H	240	150
400 ≤ x < 600	I	45	30
600 ≤ x < 1000	J	6	5
1000 ≤ x	K	0.00	0.00

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Table 11 – Empirical data from tantalum capacitors

Empirical particle data from **tantalum capacitors** per 1000 cm² surface, based on particle class			
Particle size [µm]	Size classes	All particles	Metallic particles[1)]
50 ≤ x < 100	E	1600	150
100 ≤ x < 150	F	500	60
150 ≤ x < 200	G	30	60
200 ≤ x < 400	H	80	20
400 ≤ x < 600	I	0.00	0.00
600 ≤ x < 1000	J	0.00	0.00
1000 ≤ x < 1500	K	0.00	0.00
1500 ≤ x < 2000	L	0.00	0.00
2000 ≤ x < 3000	M	0.00	0.00
3000 ≤ x	N	0.00	0.00

6.2.3.3 Chip components

Table 12 – Empirical data from chip components

Empirical particle data from **resistors, MLCCs, varistors, NTCs, PTCs** per 1000 cm² surface, based on particle class			
Particle size [µm]	Size classes	All particles	Metallic particles[1)]
50 ≤ x < 100	E	3000	400
100 ≤ x < 150	F	1200	140
150 ≤ x < 200	G	300	30
200 ≤ x < 400	H	120	5
400 ≤ x < 600	I	30	0.00
600 ≤ x < 1000	J	5	0.00
1000 ≤ x < 1500	K	0.00	0.00
1500 ≤ x < 2000	L	0.00	0.00
2000 ≤ x < 3000	M	0.00	0.00
3000 ≤ x	N	0.00	0.00

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6.2.3.4 Shunt-resistors

Table 13 – Empirical data from shunts

Empirical particle data from **shunts** per 1000 cm² surface, based on particle class			
Particle size [µm]	Size classes	All particles	Metallic particles[1)]
50 ≤ x < 100	E	1300	600
100 ≤ x < 150	F	200	150
150 ≤ x < 200	G	60	50
200 ≤ x < 400	H	60	30
400 ≤ x < 600	I	20	10
600 ≤ x < 1000	J	30	0.00
1000 ≤ x < 1500	K	10	0.00
1500 ≤ x < 2000	L	0.00	0.00
2000 ≤ x < 3000	M	0.00	0.00
3000 ≤ x	N	0.00	0.00

6.2.3.5 Quartz

Table 14 – Empirical data from quartz

Empirical particle data from **quartz** per 1000 cm² surface, based on particle class			
Particle size [µm]	Size classes	All particles	Metallic particles[1)]
50 ≤ x < 100	E	2800	400
100 ≤ x < 150	F	600	90
150 ≤ x < 200	G	250	20
200 ≤ x < 400	H	230	5
400 ≤ x < 600	I	10	0.00
600 ≤ x < 1000	J	5	0.00
1000 ≤ x < 1500	K	5	0.00
1500 ≤ x < 2000	L	0.00	0.00
2000 ≤ x < 3000	M	0.00	0.00
3000 ≤ x	N	0.00	0.00

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6.2.3.6 Semiconductors

Table 15 – Empirical data from semiconductors

Empirical particle data from **semiconductors** per 1000 cm² surface, based on particle class			
Particle size [µm]	Size classes	All particles	Metallic particles[1)]
50 ≤ x < 100	E	8000	100
100 ≤ x < 150	F	1600	20
150 ≤ x < 200	G	600	0.00
200 ≤ x < 400	H	320	0.00
400 ≤ x < 600	I	0.00	0.00
600 ≤ x < 1000	J	0.00	0.00
1000 ≤ x < 1500	K	0.00	0.00
1500 ≤ x < 2000	L	0.00	0.00
2000 ≤ x < 3000	M	0.00	0.00
3000 ≤ x	N	0.00	0.00

6.2.4 Electromechanical components

6.2.4.1 Metallic components – stamping from pre-treated strip stock

Table 16 – Empirical data from metallic components – stamping from pre-treated strip stock

Empirical particle data from **metallic components – stamping from pre-treated strip stock** per 1000 cm² surface, based on particle class			
Particle size [µm]	Size classes	All particles	Metallic particles[1)]
100 ≤ x < 150	F	3000	2000
150 ≤ x < 200	G	1200	900
200 ≤ x < 400	H	1000	850
400 ≤ x < 600	I	160	150
600 ≤ x < 1000	J	80	75
1000 ≤ x < 1500	K	20	13
1500 ≤ x < 2000	L	3	3
2000 ≤ x < 3000	M	1	1
3000 ≤ x	N	0.02	0.00

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6.2.4.2 Metallic components – stamping of contacts from un-treated strip stock

Table 17 – Empirical data from metallic components – stamping of contact from untreated strip stock and subsequent electroplating process

Empirical particle data from **metallic components – stamping of contacts from untreated strip stock** per 1000 cm² surface, based on particle class			
Particle size [µm]	Size classes	All particles	Metallic particles[1)]
100 ≤ x < 150	F	9000	3000
150 ≤ x < 200	G	3000	1000
200 ≤ x < 400	H	1500	500
400 ≤ x < 600	I	160	12
600 ≤ x < 1000	J	20	4
1000 ≤ x < 1500	K	30	0.04
1500 ≤ x < 2000	L	0.52	0.20
2000 ≤ x < 3000	M	0.76	0.00
3000 ≤ x	N	0.03	0.00

6.2.4.3 Metallic components – turning of pins

Table 18 – Empirical data from metallic components – turning of pins and subsequent electroplating process

Empirical particle data from **metallic components – turning of pins** and subsequent electroplating process per 1000 cm² surface, based on particle class			
Particle size [µm]	Size classes	All particles	Metallic particles[1)]
50 ≤ x < 100	E	3900	3300
100 ≤ x < 150	F	360	310
150 ≤ x < 200	G	45	37
200 ≤ x < 400	H	43	31
400 ≤ x < 600	I	7	7
600 ≤ x < 1000	J	0.00	0.00
1000 ≤ x	K	0.00	0.00

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6.2.4.4 Pure plastic parts

Table 19 – Empirical data from pure plastic parts

Empirical particle data from **pure plastic parts** per 1000 cm² surface, based on particle class			
Particle size [µm]	Size classes	All particles	Metallic particles[1)]
100 ≤ x < 150	F	900	120
150 ≤ x < 200	G	300	20
200 ≤ x < 400	H	200	10
400 ≤ x < 600	I	20	0.78
600 ≤ x < 1000	J	10	0.00
1000 ≤ x < 1500	K	2	0.00
1500 ≤ x < 2000	L	2	0.00
2000 ≤ x < 3000	M	2	0.00
3000 ≤ x	N	0.06	0.00

6.2.4.5 Joined strip connectors

Table 20 – Empirical data from joined strip connectors

Empirical particle data from the **assembly of metal and plastic parts – joined strip connectors** per 1000 cm² surface, based on particle class			
Particle size [µm]	Size classes	All particles	Metallic particles[1)]
100 ≤ x < 150	F	650	300
150 ≤ x < 200	G	200	80
200 ≤ x < 400	H	190	40
400 ≤ x < 600	I	30	4
600 ≤ x < 1000	J	12	1
1000 ≤ x < 1500	K	4	0.35
1500 ≤ x < 2000	L	1	0.05
2000 ≤ x < 3000	M	1	0.03
3000 ≤ x	N	0.02	0.00

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6.2.4.6 High-voltage connectors

Table 21 – Empirical data from high-voltage connectors (typically shielded)

Empirical particle data from the **assembly of metal and plastic parts – high-voltage connectors (typically shielded)** per 1000 cm² surface, based on particle class			
Particle size [µm]	**Size classes**	**All particles**	**Metallic particles[1)]**
100 ≤ x < 150	F	4000	2000
150 ≤ x < 200	G	1500	700
200 ≤ x < 400	H	1200	500
400 ≤ x < 600	I	150	100
600 ≤ x < 1000	J	70	40
1000 ≤ x < 1500	K	20	8
1500 ≤ x < 2000	L	7	2
2000 ≤ x < 3000	M	4	1
3000 ≤ x	N	3	0.00

6.2.4.7 Non-metallic components

Table 22 – Empirical data from the assembly process of non-metallic components

Empirical particle data from the **assembly of non-metallic components** per 1000 cm² surface, based on particle class			
Particle size [µm]	**Size classes**	**All particles**	**Metallic particles[1)]**
100 ≤ x < 150	F	2800	30
150 ≤ x < 200	G	1000	0.10
200 ≤ x < 400	H	900	0.06
400 ≤ x < 600	I	80	0.06
600 ≤ x < 1000	J	30	0.00
1000 ≤ x < 1500	K	15	0.00
1500 ≤ x < 2000	L	0.00	0.00
2000 ≤ x < 3000	M	7	0.00
3000 ≤ x	N	0.00	0.00

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6.2.5 Metal housings

6.2.5.1 Die-cast aluminum housing

Table 23 – Empirical data from die-cast aluminium housing

Empirical particle data from **die-cast aluminium housing** per 1000 cm² surface, based on particle class			
Particle size [µm]	Size classes	All particles	Metallic particles[1)]
100 ≤ x < 150	F	1100	700
150 ≤ x < 200	G	310	230
200 ≤ x < 400	H	230	200
400 ≤ x < 600	I	50	47
600 ≤ x < 1000	J	30	28
1000 ≤ x < 1500	K	10	10
1500 ≤ x < 2000	L	4	4
2000 ≤ x < 3000	M	3	3
3000 ≤ x	N	1	1

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6.2.6 Packaging

6.2.6.1 Deep-drawn trays (new)

Table 24 – Empirical data from deep-drawn trays (new)

Empirical particle data from **deep-drawn trays (new)** per 1000 cm² surface, based on particle class			
Particle size [µm]	Size classes	All particles	Metallic particles[1)]
100 ≤ x < 150	F	600	20
150 ≤ x < 200	G	200	3
200 ≤ x < 400	H	150	2
400 ≤ x < 600	I	20	0.15
600 ≤ x < 1000	J	10	0.00
1000 ≤ x < 1500	K	6	0.00
1500 ≤ x < 2000	L	2	0.00
2000 ≤ x < 3000	M	0.00	0.00
3000 ≤ x	N	0.00	0.00

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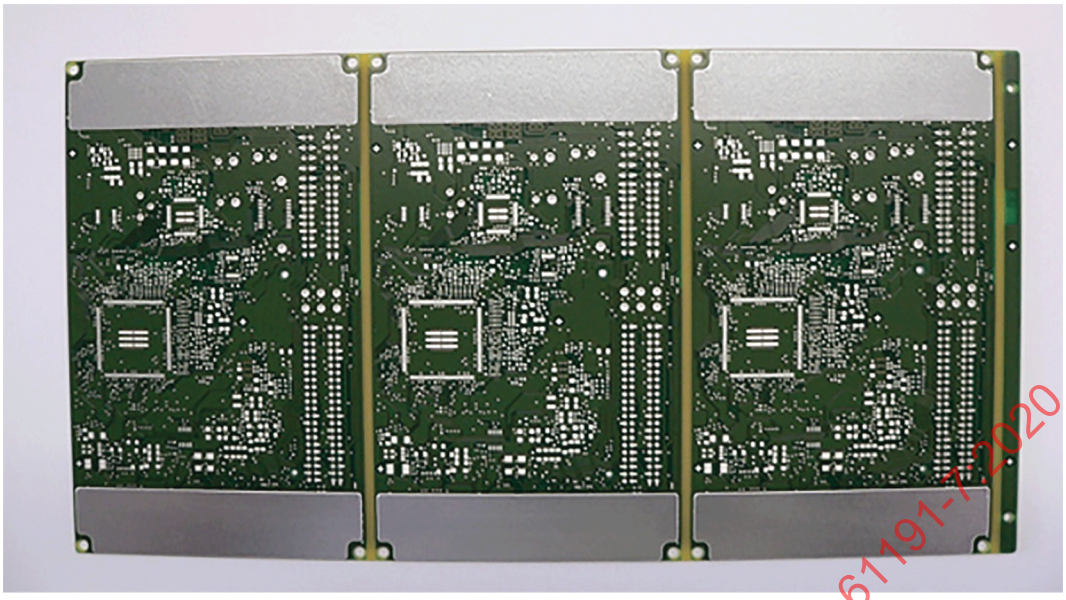
6.2.7 Printed circuit boards (PCBs)

In a PCB cluster (unassembled), a distinction is made between rigid (double-sided and multilayer boards, see Figure 21) and flexible circuit boards (see Figure 20).



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Figure 20 – Flexible circuit board



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Figure 21 – Rigid circuit board

Flexible circuit boards can be partially reinforced using punched metal and/or plastic stiffeners. This may increase the theoretical number of metal and plastic particles. The theoretical number of metallic and plastic particles may also increase on rigid circuit boards with special features such as copper or aluminium heat sinks, depth milling, cavities, etc.

Flexible and rigid circuit boards are usually subjected to rigorous electrical testing, which minimizes the risk of electrical functional failures owing to conducting particles.

Table 25 – Empirical data from flexible PCBs without cleaning step

Empirical particle data[1] from **flexible PCBs without cleaning step** per 1000 cm² surface, based on particle class			
Particle size [µm]	**Size classes**	**All particles**	**Metallic particles[1]**
50 ≤ x < 100	E	3000[2]	400[3]
100 ≤ x < 150	F	400[2]	40[3]
150 ≤ x < 200	G	50[2]	10[3]
200 ≤ x < 400	H	40[2]	10[3]
400 ≤ x < 600	I	4[2]	4[3]
600 ≤ x < 1000	J	0.00[2]	0.00[3]
1000 ≤ x	K	0.00[2]	0.00[3]

[1] The indicated values are mean values of different circuit board designs with different metallic and non-metallic stiffeners

[2] The count of non-metallic particles on PCBs with plastic stiffeners is likely to be higher than indicated in the table

[3] The count of metallic particles on PCBs with punched metal stiffeners is likely to be higher than indicated in the table

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Table 26 – Empirical data from bare, flexible PCBs with cleaning step

Empirical particle data[1] from **bare, flexible PCBs with cleaning step** per 1000 cm² surface, based on particle class			
Particle size [µm]	**Size classes**	**All particles**	**Metallic particles[1]**
50 ≤ x < 100	E	700[2]	300[3]
100 ≤ x < 150	F	200[2]	50[3]
150 ≤ x < 200	G	40[2]	10[3]
200 ≤ x < 400	H	20[2]	10[3]
400 ≤ x < 600	I	0.00[2]	0.00[3]
600 ≤ x < 1000	J	0.00[2]	0.00[3]
1000 ≤ x	K	0.00[2]	0.00[3]

[1] The indicated values are mean values of different circuit board designs with different metallic and non-metallic stiffeners

[2] The count of non-metallic particles on PCBs with plastic stiffeners is likely to be higher than indicated in the table

[3] The count of metallic particles on PCBs with punched metal stiffeners is likely to be higher than indicated in the table

Table 27 – Empirical data from bare, rigid PCBs

Empirical particle data from **bare, rigid PCBs** per 1000 cm² surface, based on particle size			
Particle size [µm]	**Size classes**	**All particles**	**Metallic particles[1]**
100 ≤ x < 150	F	140	30
150 ≤ x < 200	G	50	15
200 ≤ x < 400	H	20	5
400 ≤ x < 600	I	6	3
600 ≤ x < 1000	J	2	0.00
1000 ≤ x < 1500	K	0.00	0.00
1500 ≤ x < 2000	L	0.00	0.00
2000 ≤ x < 3000	M	0.00	0.00
3000 ≤ x	N	0.00	0.00

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6.3 Determining potential particle sources in production areas

6.3.1 General

Analysis of a part's component cleanliness provides information on the number and size distribution of extracted particles, and often the number and size distribution of metallic shiny particles as well. The particle source, however, is not immediately identifiable.

Nevertheless, it is essential to know the particle sources and relevant influencing factors to minimise particulate contamination. VDA 19 Part 2 deals with this subject.

6.3.2 Particle generation

Particles are distinguished according to their source:

- non-specific particles present in manufacturing areas (dirt, dust, skin cells, minerals/salts, soot...);
- particles originating from product elements:
  - from the product itself;
  - from adjacent products.

Particles originating from a product have either been introduced by externally supplied parts or produced during the process steps.

Dust is always present in any manufacturing facility. Typically, 6 mg of dust is produced per square metre per day; humans, for instance, shed 1 g to 2 g of skin cells per day on average.

Other possible sources of dust are:

- fibres, lint (from clothing, textiles, paper, cardboard...);
- plant parts such as pollen and flower particles;
- live and dead bacteria;
- mold;
- remains (dead bodies, shed skin, excrement) from other microorganisms;
- rock particles (road debris, sand drift...);
- particulate matter (soot from internal combustion engines, heating systems, industrial fumes and fires).

Although the percentage of mites and similar organisms is much lower in industrial dust, additional wear debris is created in production facilities by rotating equipment such as motors (carbon), belts (rubber), brakes (asbestos) as well as fumes (hot oil) and dust (grinding).

The production of metallic particles is a process that can rarely be controlled and hence regulated. In most cases, particles are generated randomly and governed by few principles or laws. The prevention of particles should always take priority over their subsequent removal.

But first, they have to be identified, e.g. by REM/EDX. Light microscopy is also an established method of identifying particles by shape and colour.

6.3.3 Electronics manufacturing cluster

Electrically conductive particles are considered to be particularly critical due to their ability to impair the performance of electronic components. However, non-metallic particles may also result in failures (e.g. leaking housings, contact problems) since components are increasingly integrated into complete systems.

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Potential metallic particle sources:

- carry-over from upstream processes (PCB, components, housings);
- carry-over of solder paste during application process (contaminated solder mask bottom, splatters during solder jetting process), loose solder balls;
- solder splatter during the melting process → loose solder balls;
- flux residue during THT soldering;
- residue during repair soldering → loose solder balls;
- chip formation during press-fit process (contacts, connectors, screening shields, etc.);
- chip formation during test system connection (bed-of-nails tester, flying probe, plug-in connections, etc.);
- chip formation during system assembly (burrs on injection-moulded parts, bolted connections);
- etc.

Potential non-metallic particle sources:

- contaminated manufacturing systems;
- PCB material residue during depaneling (glass fibre fragments, milling dust);
- smoke residue during laser depaneling;
- chip formation during system assembly (plastic chips, etc.);
- packaging material (boxes, polystyrene);
- etc.

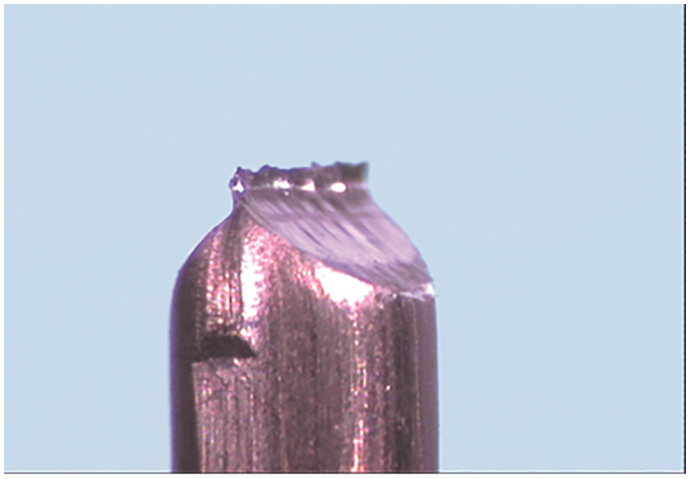
6.3.4 Passive components cluster

Metallic particles

The majority of components use conductors or connecting elements that are typically made of copper or copper alloys. Coatings consisting of tin or tin alloys with partial pre-nickel plating are often used to ensure solderability.

A higher copper particle count occurs when wires are used, e.g. for wound elements (inductive components). When a wire is cut, a flush-cut area and a fracture area are created at the cut face. Burrs frequently form in the fracture area. These may, or may not, adhere tightly to the wire ends.

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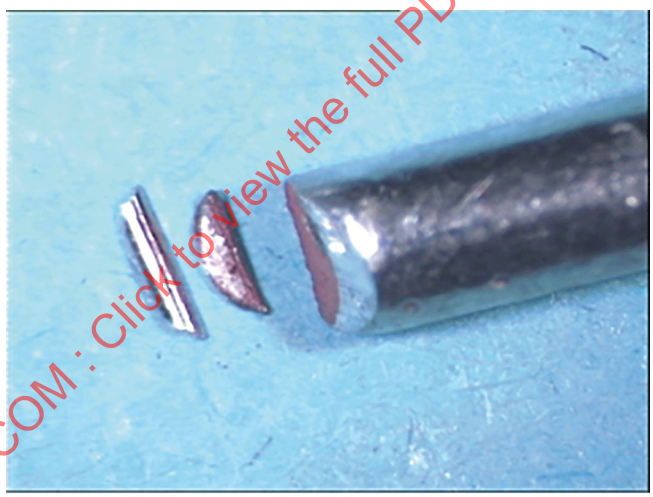


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Figure 22 – Burr formation on copper wire (D = 2,25 mm) after use of wire-cutter

The condition and wear of the cutting tool greatly influence the formation of burrs.

Figures Figure 22 and Figure 23 clearly show that, in this case, the maximum length of possible particles corresponds to the length of the cut edge. Another example of a particle generated by wire cutting is shown in Figure 24.



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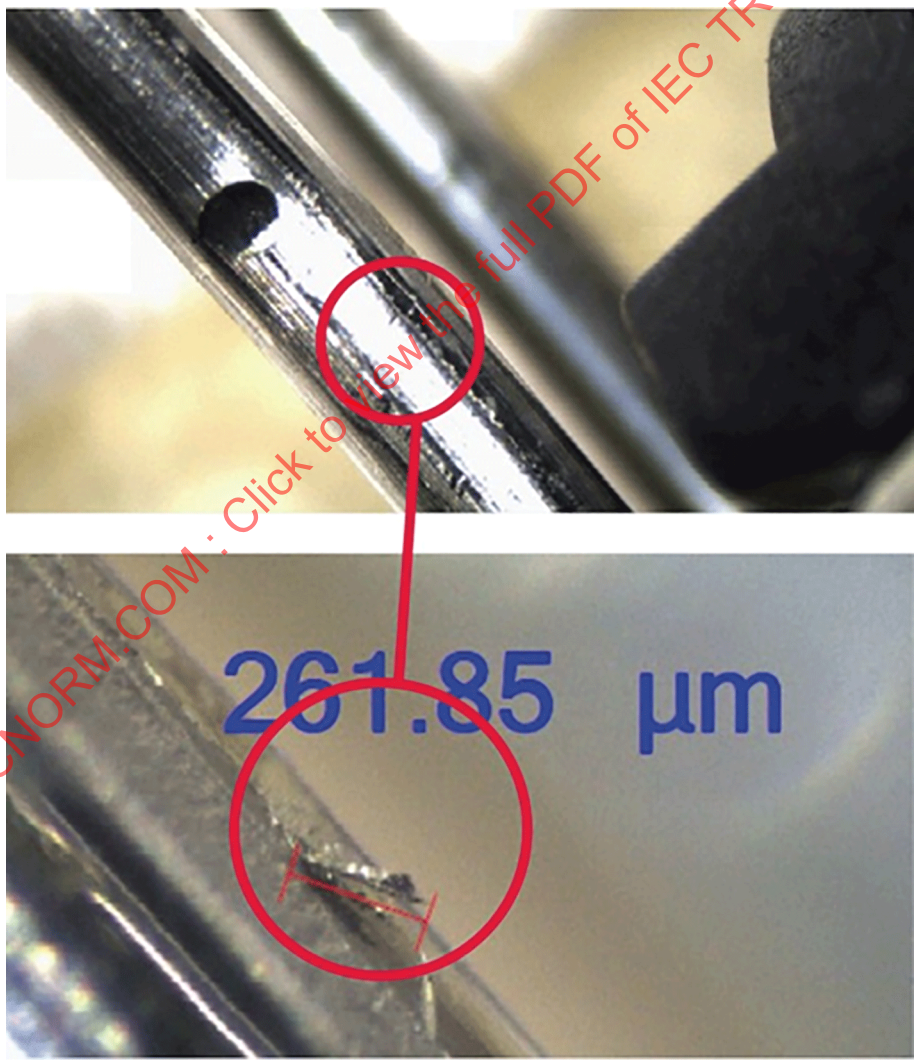
Figure 23 – Particles generated by wire cutting D = 1,8 mm (tinned copper)

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Figure 24 – Particles generated by wire cutting D = 1,8 mm (tinned copper)



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Figure 25 – Particle (tin) adhering to a tinned copper wire D = 2,25 mm

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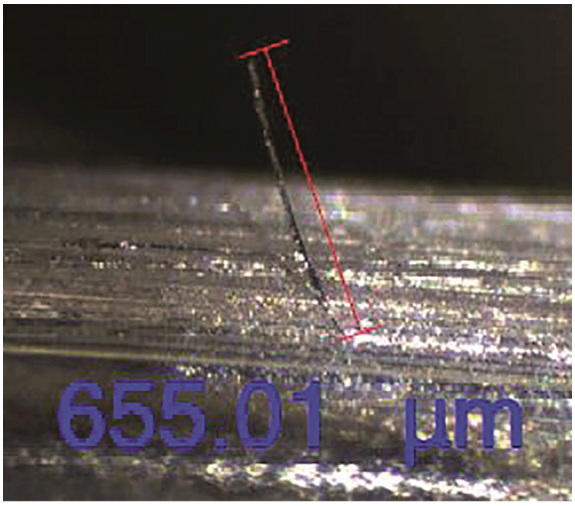


Figure 26 – Hair-like particle (tin whiskers) chipped off a tinned wire (655 µm long)

If tinned wires are used, lots of swarf and metal dust can be found on the wire material supplied (see Figure 25 and Figure 26). Chips may form during winding and re-routing processes and are sometimes pressed back onto the wire.

Chips automatically form during the mechanical stripping (rotational milling) of round enamel wires (see Figure 27). They stick to the base material owing to the softness of copper.

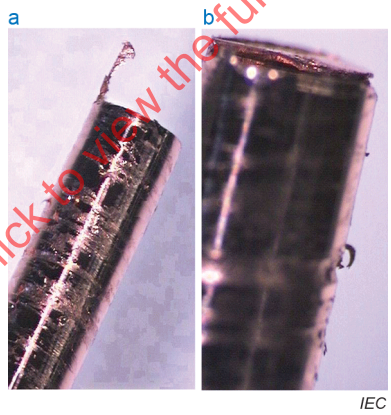


Figure 27 – Milled enamel wires

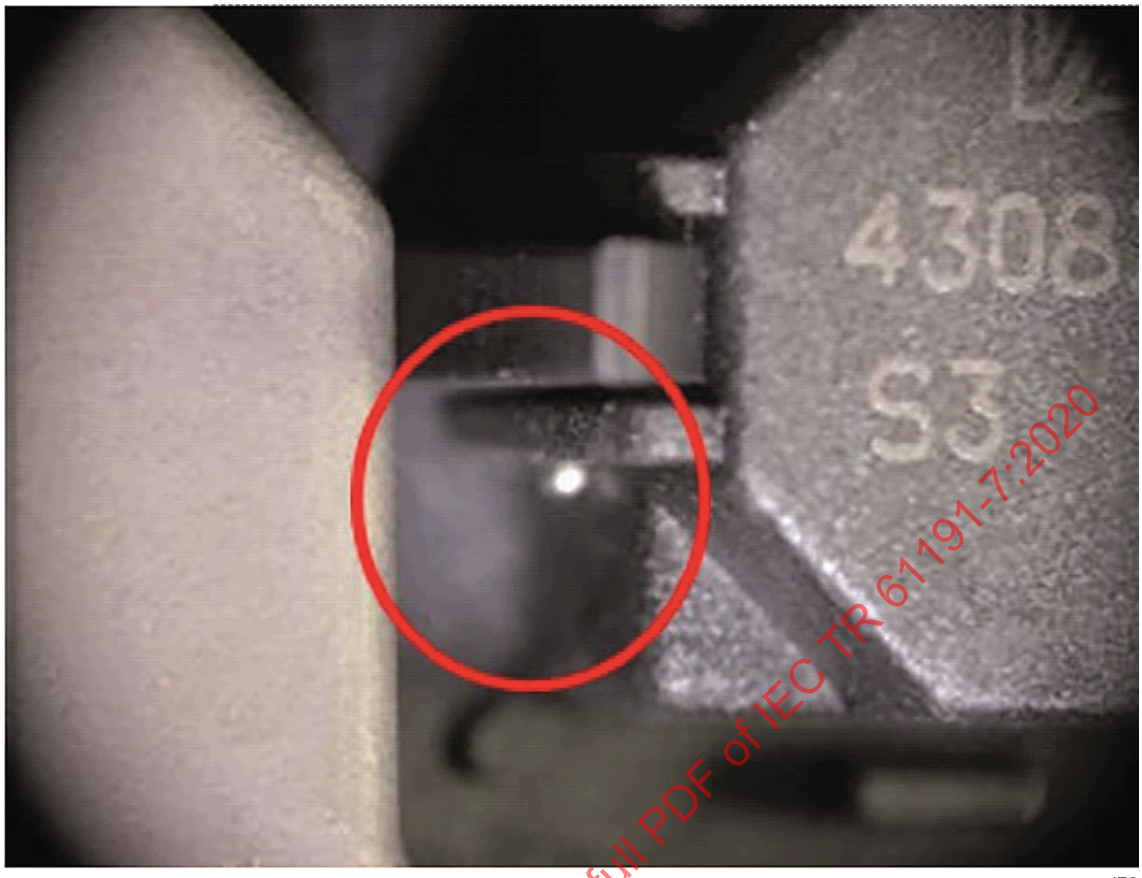
Many components use solder or tin to attach the leads to the pin, which requires hot tin dipping with molten solder. To ensure good wetting, they shall be moistened with flux in advance.

The flux uses a carrier material (water, solvent) that evaporates immediately on immersion in the solder. This creates gas bubbles, causing solder balls to "fly off".

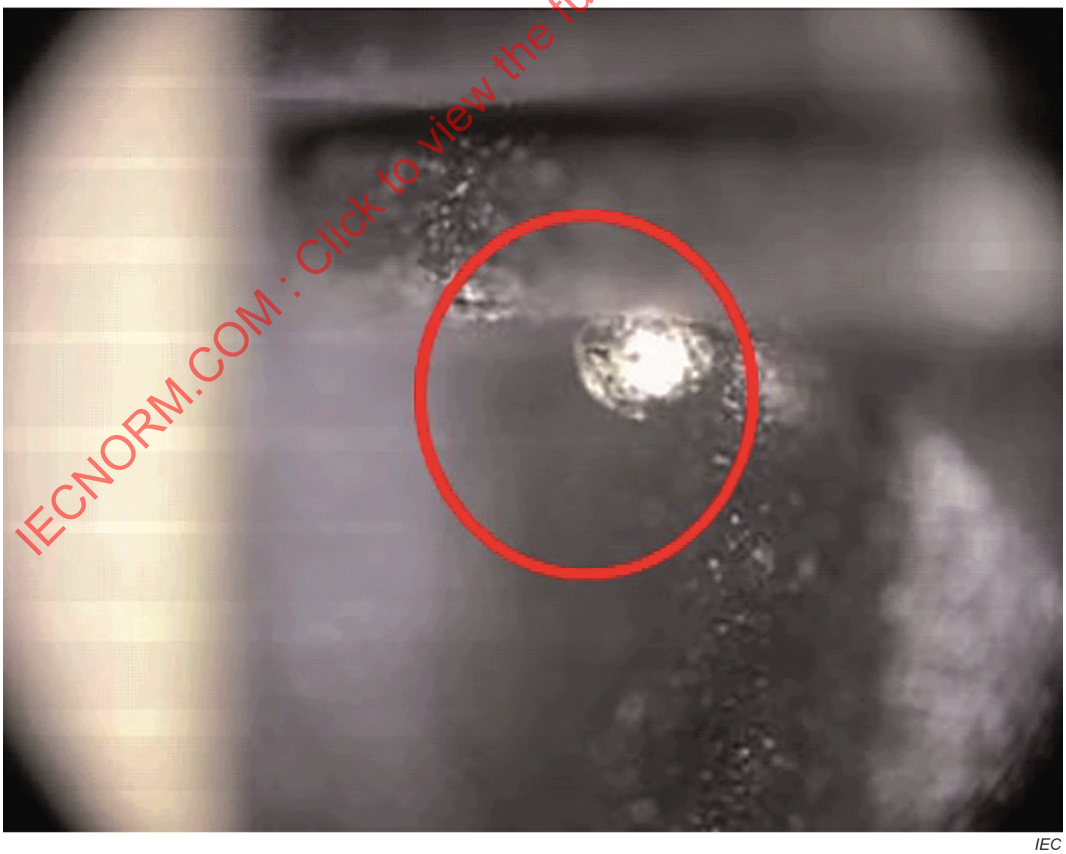
This effect is known to occur during PCB soldering using wave-soldering systems. The solder splatters or balls are usually catapulted several centimetres away and often stick to adjacent surfaces.

Sometimes, these splatters or balls even melt into plastic material (see Figure 28).

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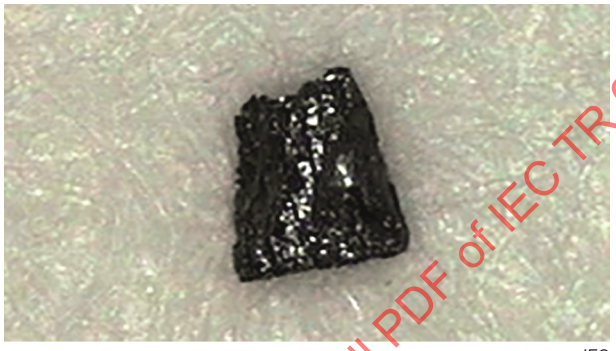
Figure 28 – Molten solder balls fused to plastic housings

These solder balls can also be found squeezed flat on housings as carry-over particles. Since tin is soft, small balls on tabletops or between tools are pressed flat and easily adhere to rough surfaces.

The number of tin balls can be reduced by shielding adjacent areas with a splash guard during the tin plating process.

Inductive components normally have a magnetic core, which means that particles can accumulate there. Ferrites (iron-oxide based ceramics), for example, are breakable and have sharp edges and burrs, which chip off easily on contact (see Figure 29). Lots of ferrite dust as well as particles of several millimetres can be found at core assembly stations.

Ferrites are typically semiconductors, allowing electrical currents to flow and thus also causing short-circuits.



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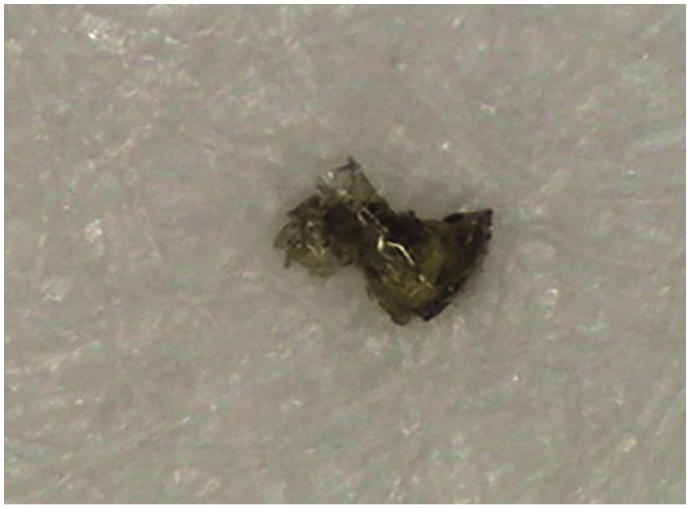
Figure 29 – Ferrite particle, identified as metallic (419 µm)



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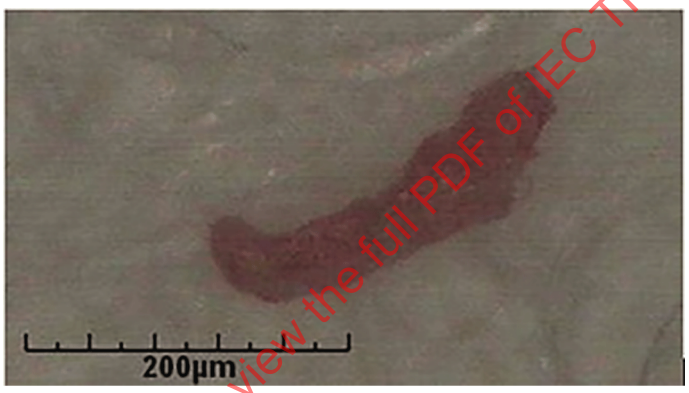
Figure 30 – Ferrite particle, identified as non-metallic (558 µm)

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Figure 31 – Non-metallic particle, probably burr or plastic residue (217 µm)



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Figure 32 – Non-metallic particle, probably pink polystyrene packaging material

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The ferrite particle in Figure 30 is a good example of the difficulties in detecting metal with optical analysis methods. Owing to the difference in lustre (compared to Figure 31), it is incorrectly classified during the automatic metal/non-metal selection.

Soft magnetic cores of amorphous and nanocrystalline materials consist of strip stock, which tends to chip easily. Since the cores are often encapsulated in plastic, direct chipping is no longer possible. However, the casings shall be cleaned on the outside since the processing area is prone to contamination introduced by transportation or employees.

6.3.5 Electromechanical components cluster

6.3.5.1 General

Electrically conductive particles are classified as primarily critical to the performance of electrical connectors.

Potential sources of metallic particles:

- carry-over from previous processes;
- stamping process (cutting/ripping, bending, re-routing, further transport, burr formation);
- transport, routing during/after winding;
- separation of metallic components on the belt;

- shear stress during joining processes;
- peeling during bending processes;
- abrasion during or caused by the handling of metallic components;
- vibrations during transportation;
- etc.

6.3.5.2 Metallic components stamped from pre-treated strip stock

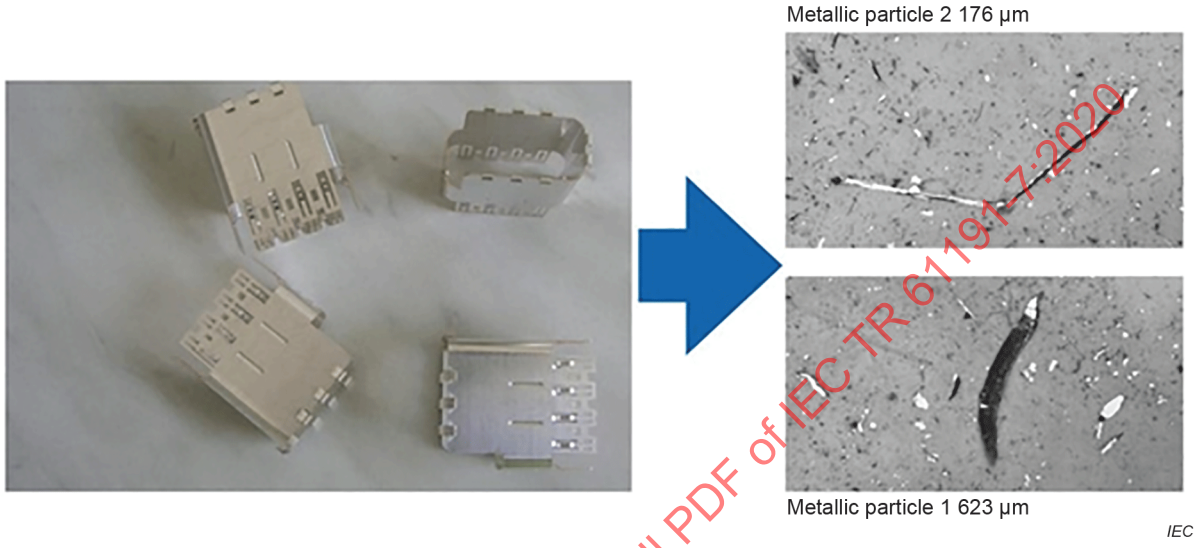


Figure 33 – Shielding plate

The example of a metallic shielding plate metallic stamped from pre-treated strip-stock is shown in Figure 33.

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6.3.5.3 Metallic components – stamping of contacts from pretreated strip stock and subsequent electroplating process

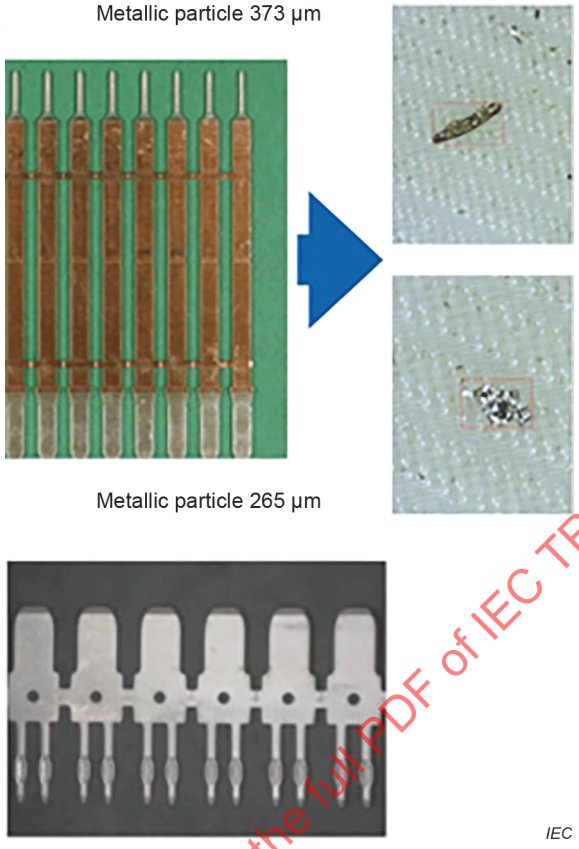


Figure 34 – Stamped contacts

The example of contacts stamped from pretreated strip stock and subjected to subsequent electroplating is shown in Figure 34. The parts undergo a cleaning stage during electroplating, which has a positive effect on component cleanliness.

6.3.5.4 Metallic components – turning of pins and subsequent electroplating process

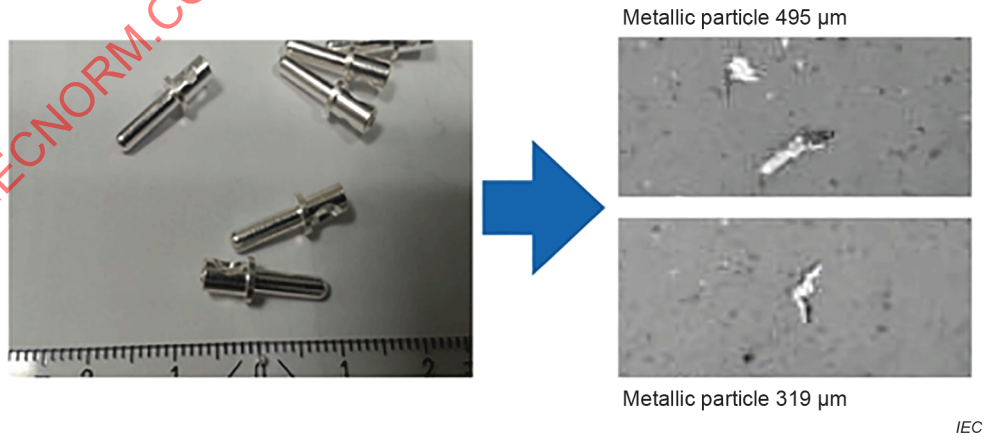


Figure 35 – Connector pin

The example of connector pins is shown in Figure 35.

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6.3.5.5 Injection molding process (without metal inserts)

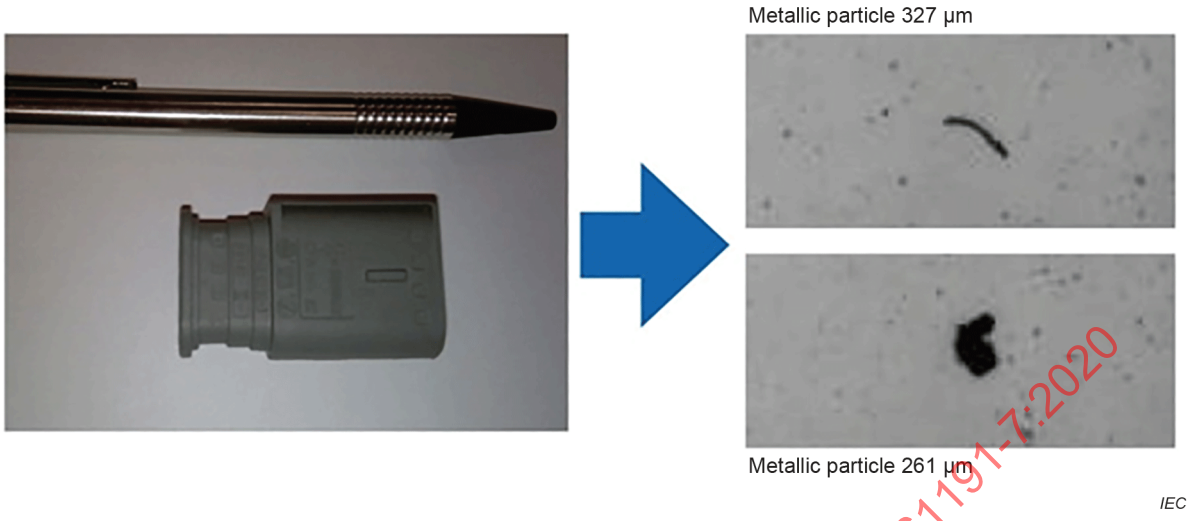


Figure 36 – Connector housing

The example of a connector housing produced by injection molding is shown in Figure 36. Tool wear is normally low during injection moulding and has no significant impact on component cleanliness.

6.3.5.6 Assembly process of metal and plastic parts

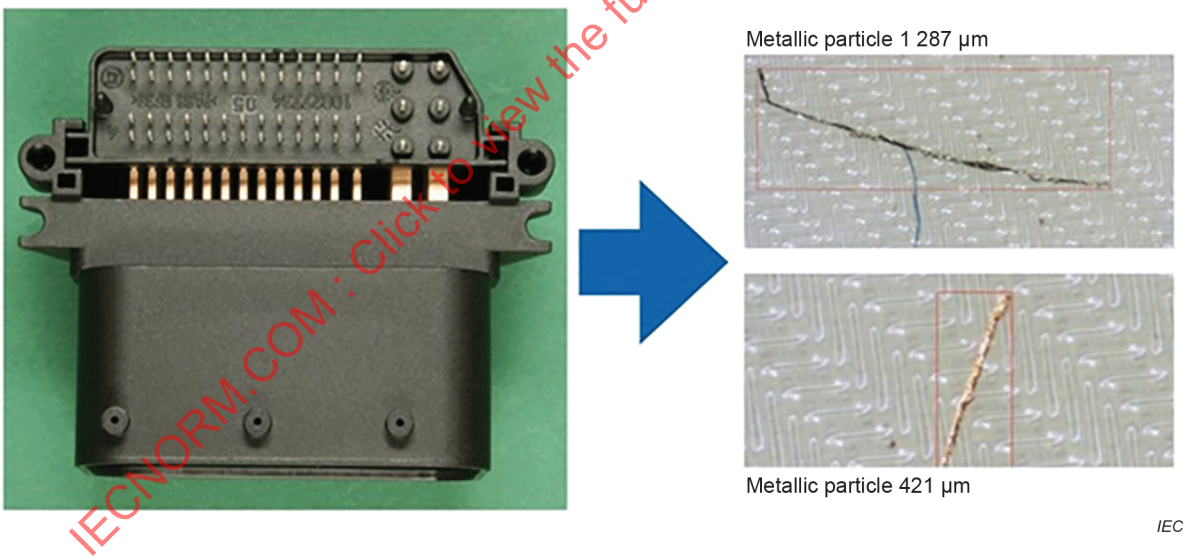
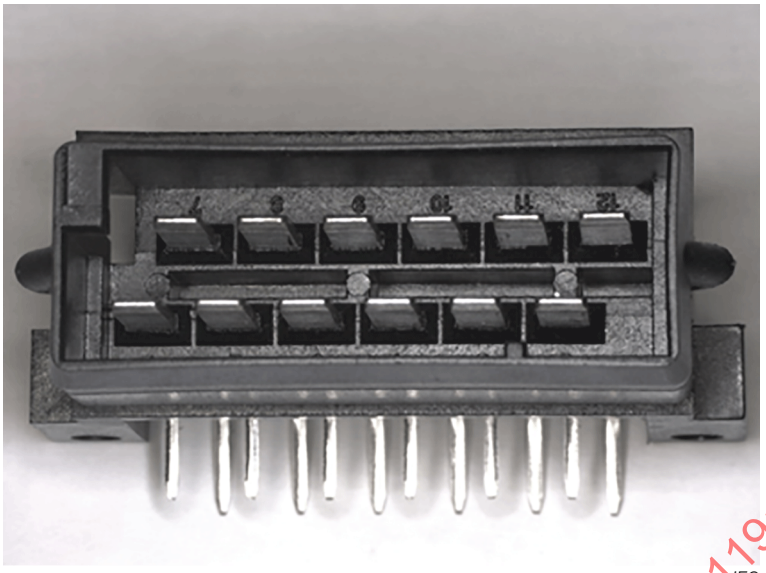
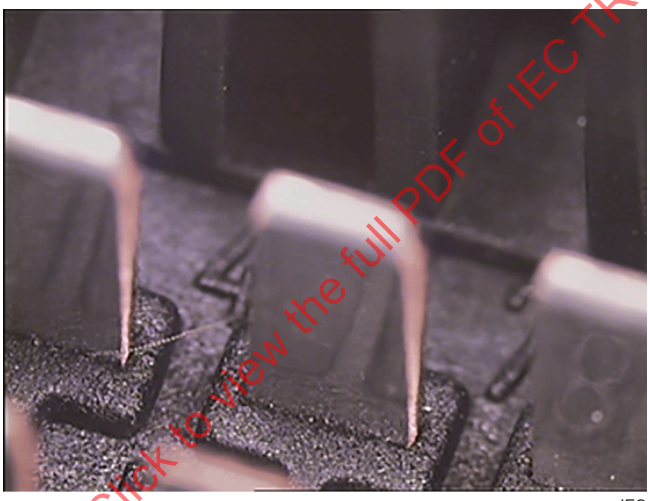


Figure 37 – 58-pin connector housing

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Figure 38 – 12-pin connector with bridged contacts

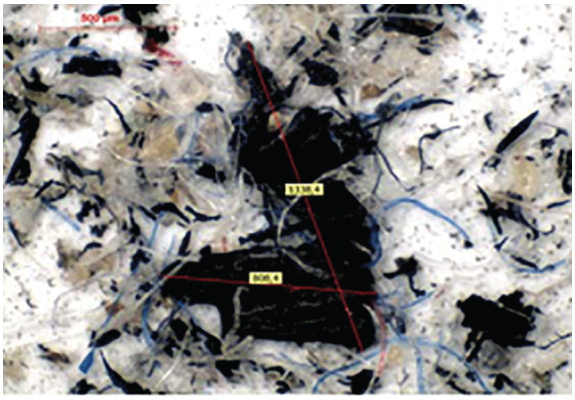
Examples of connectors are shown in Figure 37 and Figure 38. The retrofitting of cleaning stations (mechanical and/or fluid) calls for substantial effort and expenditure and significantly increases manufacturing costs, but is sometimes needed to improve or achieve the required level of component cleanliness.

6.3.6 PCB cluster

6.3.6.1 General

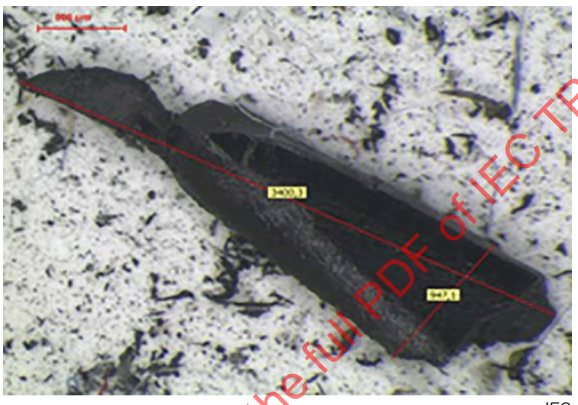
Particle generation cannot be avoided during circuit board manufacturing, and especially when defining contours and processing punched metallic and non-metallic stiffeners.

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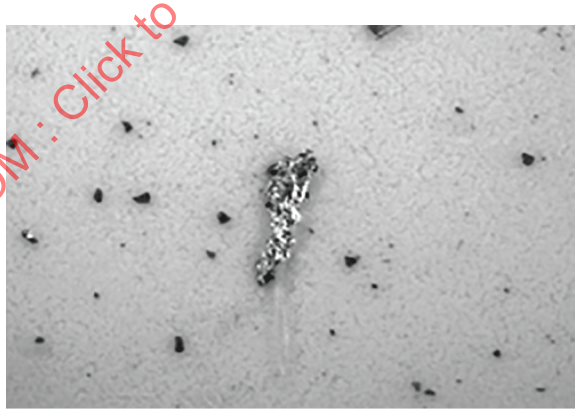
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Figure 39 – Plastic particles + fibres



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Figure 40 – Plastic particles



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Figure 41 – Metallic particle

Potential sources of metallic particles:

- cross-contamination due to uncleaned systems/processes;
- punching process (re-routing, further transport, burr formation);
- shear stress during joining processes;
- abrasion during or caused by the handling of metallic components;
- transportation in contaminated packaging, etc.

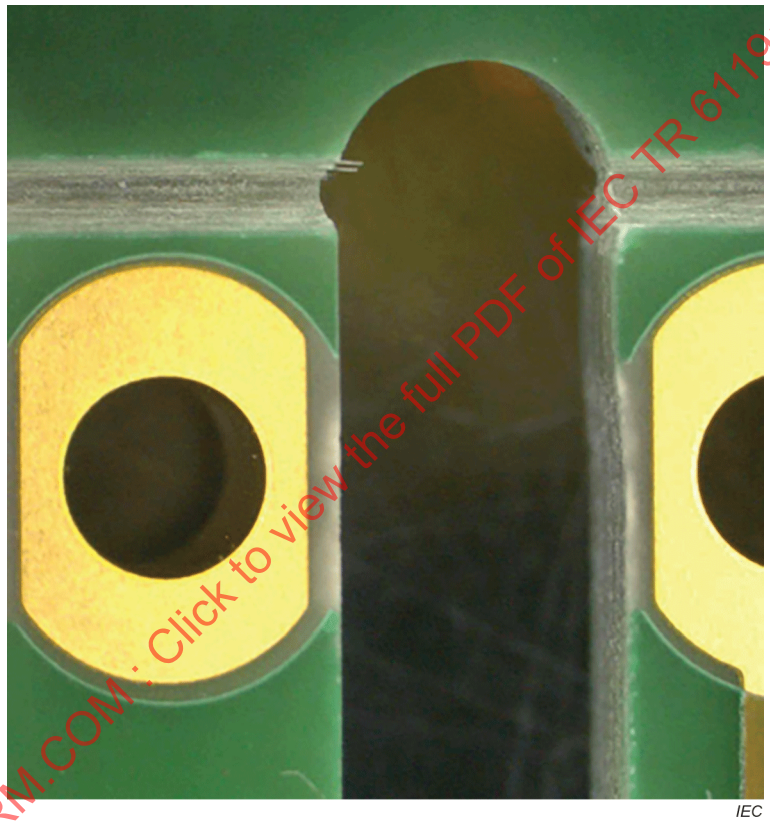
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The smaller the metallic particles, the better they adhere to the circuit board owing to electrostatic forces. Metallic and non-metallic particles can – if necessary – be largely, but not entirely, removed with additional cleaning steps (see Figure 39, Figure 40, Figure 41). The cleaning processes require more effort and significantly increase manufacturing costs.

Particle generation may also be influenced by the design and construction of a PCB. The production and deposition of metallic and non-metallic particles can thus be reduced in advance.

6.3.6.2 Design guidelines for reducing particles

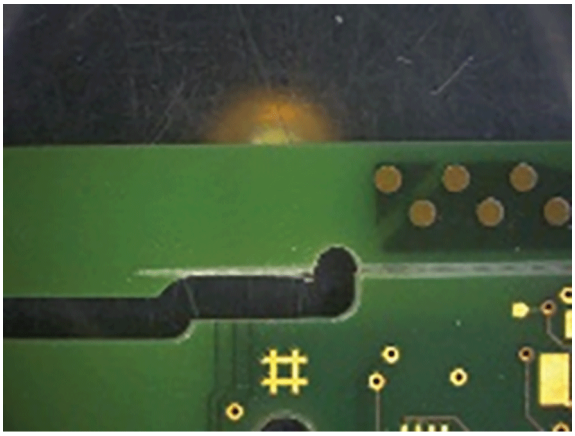
- V-scoring of circuit board panels:
  - Milling lines should not cross V-scoring lines (see Figure 42);
  - V-scoring lines should not overlap milled areas (see Figure 43).



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Figure 42 – Milling crosses V-scoring line

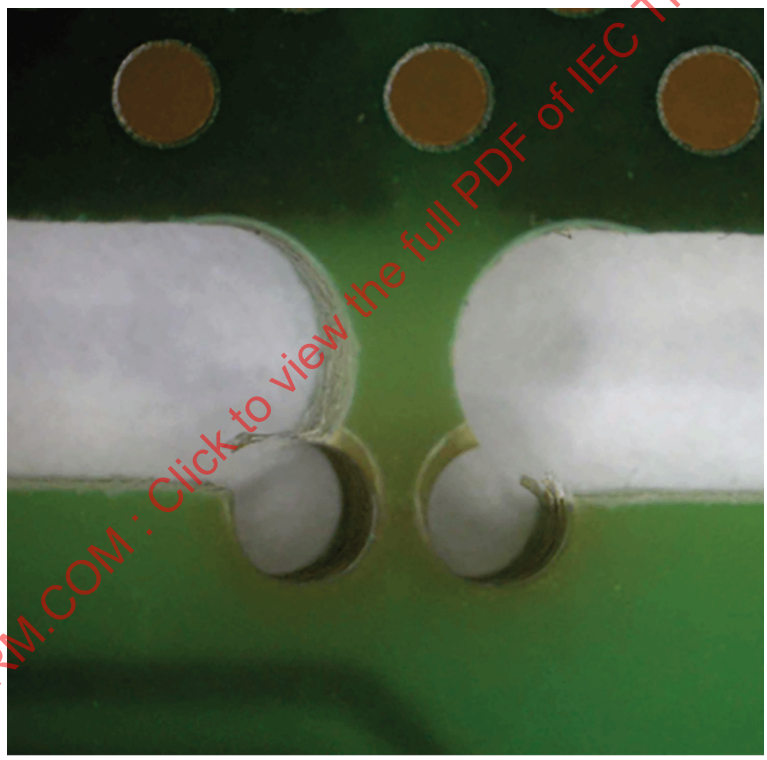
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Figure 43 – V-scoring line on milling edge

- Milling of holes for predetermined breaking points produces non-metallic particles (ses Figure 44)



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Figure 44 – Chip formation in milled hole

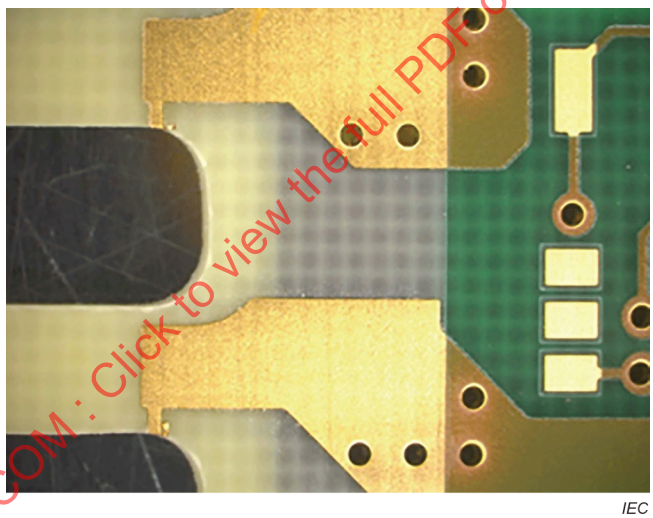
- Copper areas on the circuit board contour generate metallic particles, e.g. during edge plating (see Figure 45) or when cutting the connection for electroplated gold pins (see Figure 46).

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Figure 45 – Edge plating

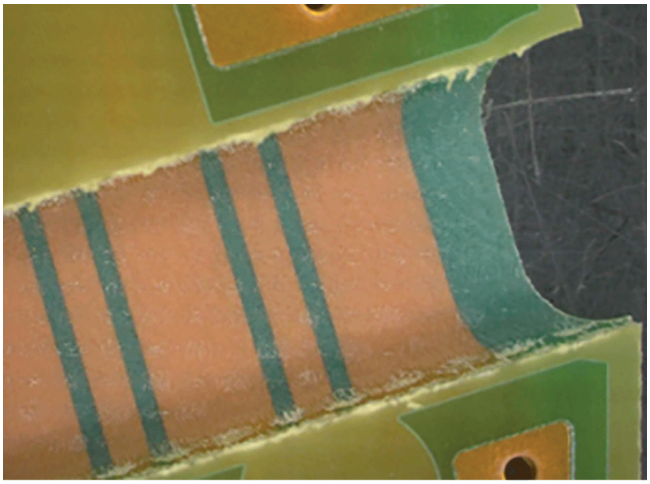


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Figure 46 – Connections for electroplated gold areas

- Cavities, recesses and deep millings produce non-metallic particles (see Figure 47).

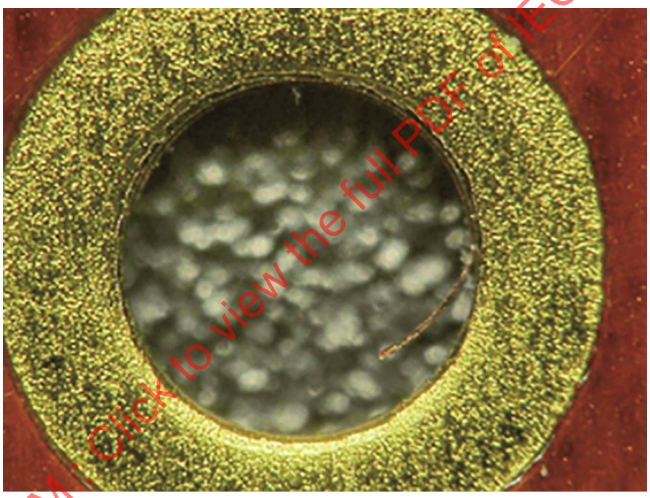
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Figure 47 – Deep milling

- Avoid stamping metallic areas (e.g. nickel, gold, tin) to reduce chip formation (see Figure 48)

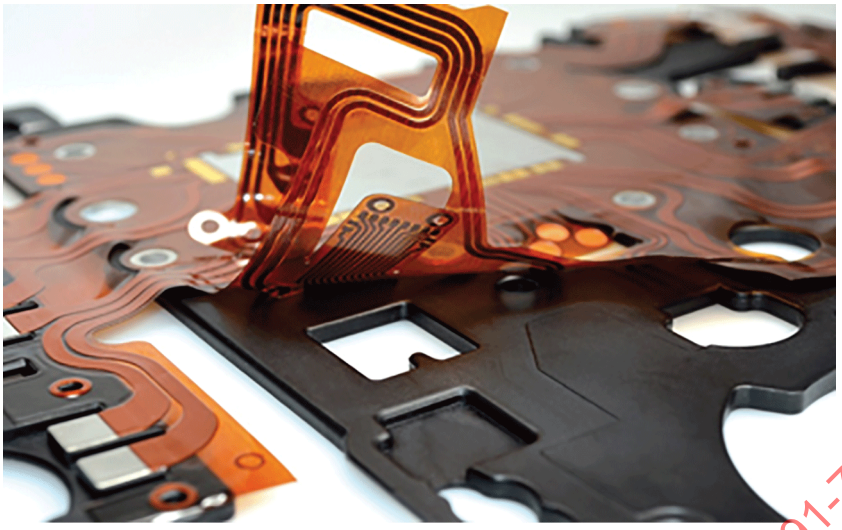


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Figure 48 – Chip formation caused by stamping

- Avoid undercuts – Particles accumulate in undercuts and are difficult to remove even with an additional cleaning step (see Figure 49) .

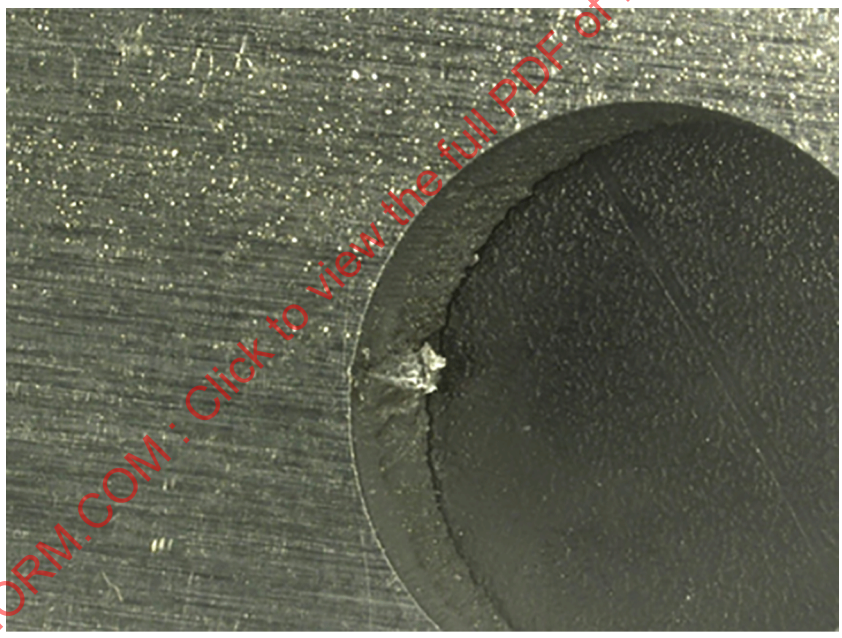
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Figure 49 – Flexible circuit board with undercut

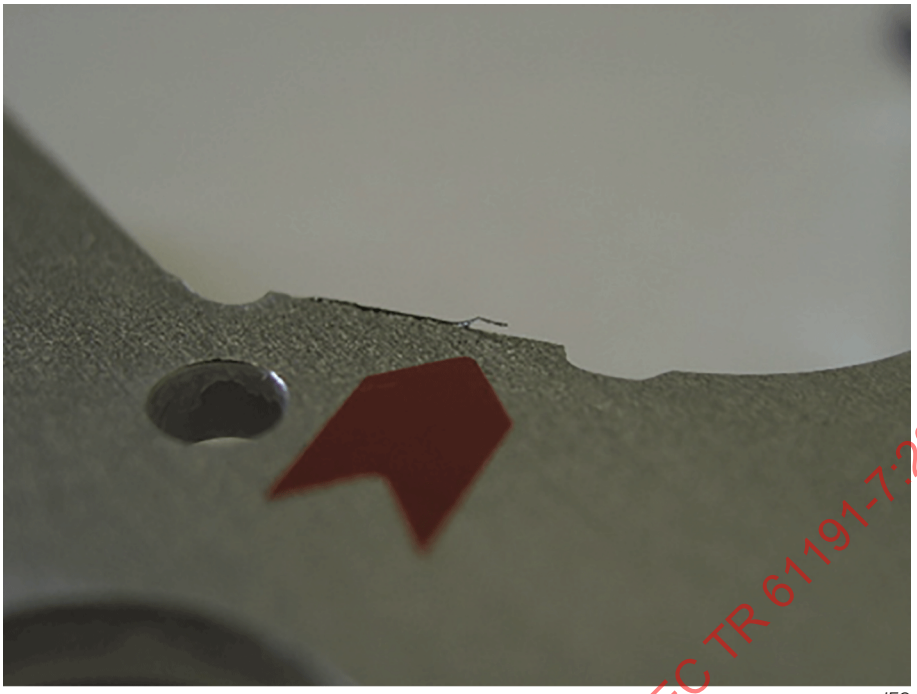
- Ensure burr and damage-free processing of punched metallic elements to reduce particulate contamination (see Figure 50, Figure 51, Figure 52 and Figure 53).



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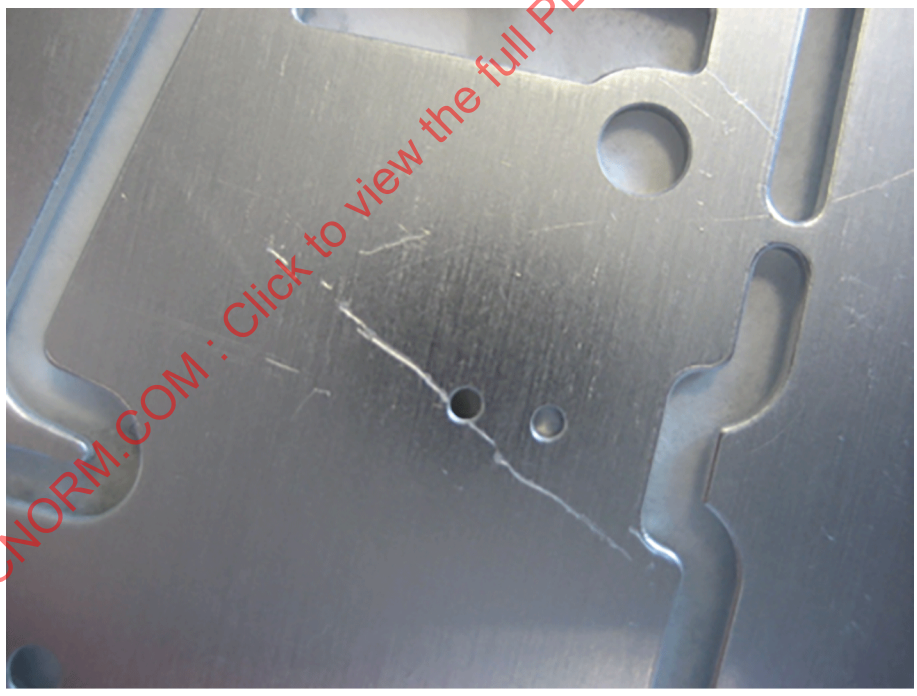
Figure 50 – Punching burr in hole

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Figure 51 – Punching burr

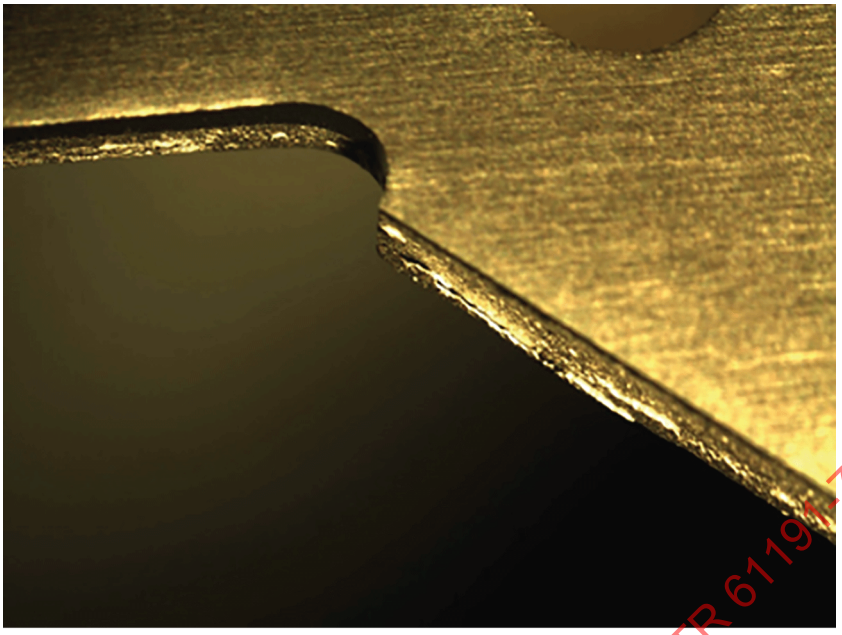


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Figure 52 – Damaged metallic stiffener

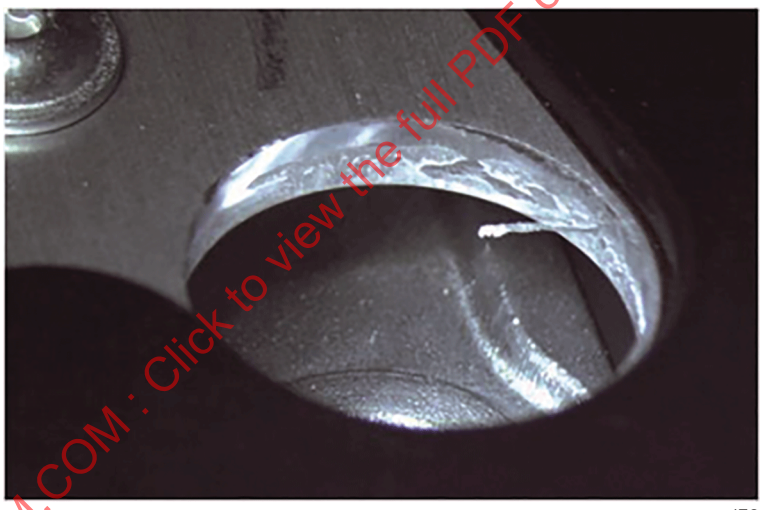
- The pickling process loosens stamping residue along the metal edges and so redefines the details of the stamped edge (see Figure 54).

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Figure 53 – Stamping residue along stamped edge

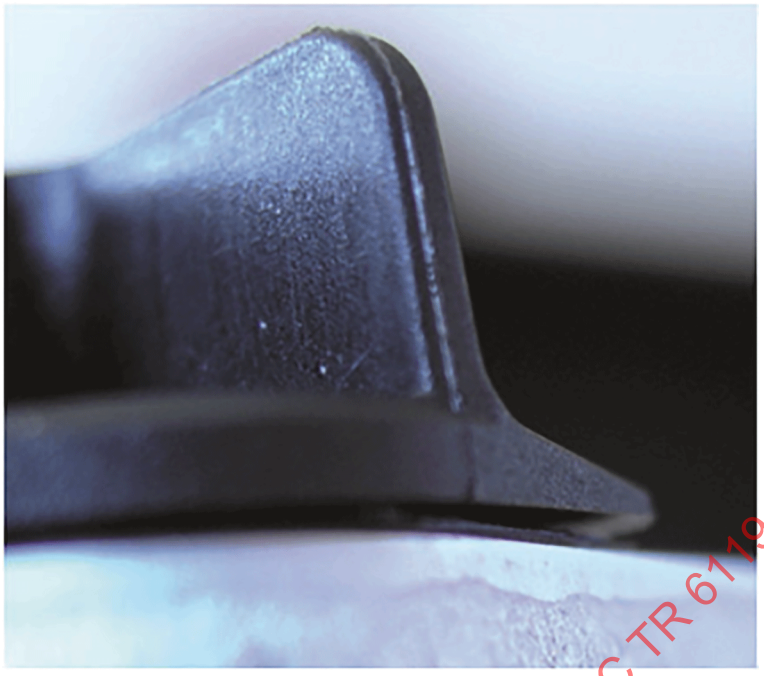


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Figure 54 – Stamping residue loosened by pickling bath

- Ensure burr and damage-free processing of plastic elements to reduce particle contamination (see Figure 55 and Figure 56).

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Figure 55 – Plastic element with burr



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Figure 56 – Particles on externally supplied plastic elements

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6.4 Cleanliness-controlled design and process selection

6.4.1 Aspects of cleanliness-controlled design/production with regard to metallic particles

According to our present understanding, most particles are generated during the processing of components and assemblies (approximately 80 %) and only a fraction (approximately 20 %) are due to environmental influences.

Since it is not possible to address every possible malfunction and manufacturing process due to the sheer complexity of the subject (see 4.3 and 6.1), the aim here is to focus on metallic particles.

To produce a product with the minimum particle contamination possible, the manufacturing processes best suited to achieving this shall be defined preemptively in the product and process analysis. In other words, how and with what can the product be configured to achieve the lowest possible potential particle contamination?

1) Product

- The component design should be sufficiently robust to ensure that the component is able to tolerate a certain level of contamination without impairing performance. For example, the clearance between electrical potentials and air gaps and creepage distances should be as generous as possible and electrical potentials should be physically separated from one another, not placed side-by-side. If this is not possible, areas at risk shall be protected (protective coating, partitions, housing...).
- It should be possible to remove particles easily. The component should undergo an effective final cleaning stage before commissioning. Concealed and contorted structures impede or prevent this process.
- Stamped products have a high particle load, which is reduced to a minimum during electroplating processes. Stamped products that do not undergo a subsequent galvanic cleaning process should be re-cleaned if necessary.
- Joining processes can generate particles; for example, contact holders with a high glass fibre content can produce chips when the contacts are mounted to the relatively soft tin surfaces. Contact surfaces should be as small as possible, and provision made from re-cleaning.
- Loose particle reduction. A vertically mounted flat assembly encourages self-cleaning since the particles slide off. If these loose particles are removed completely or at least captured in bags, they are rendered harmless to the system.
- Ideally, replace bare die chips with housed chips.
- Use BGAs with underfill.
- Restrict or completely eliminate the use of components typically associated with a high particle load or pack them in housing (e.g. ferrites, cable harnesses with crimped contacts, electromechanical assemblies, large reels...)
- Screw holes in housings should either be left open and re-cleaned or ideally sealed immediately by inserting self-tapping screws in the blind hole (caution: in this case, reworking should be restricted or prohibited).

2) Production processes

Optimisation strategies aimed at controlling particle sources should start from inside (processes, assemblies) and work outwards (immediate and general environment). In other words, look at events directly affecting the component first.

Prioritise processes according to the criterion which shall be checked first and optimised if necessary. This gives the following sequence:

Priority 1:

- punching/bending processes;
- joining processes;
- screwing processes;
- soldering/welding processes;
- alignment;
- pincers;
- workpiece holders;
- packaging type (bulk goods);
- …

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These processes and tools should be designed for wear resistance and ease of cleaning. Unavoidable particles shall be removed from the product by passive means (particles fall off) or active means (e.g. blowing and suction).

Particles shall not be allowed to accumulate in the production area. These areas shall be kept clean and inspected at regular intervals.

Priority 2:

- particles generated by system and tool wear;
- particle carry-over by personnel;
- particles from packaging;
- …

The active dispersal/discharge of particles by external operations such as maintenance work, open compressed air cleaning, angle grinding, etc. should be avoided during production.

Draw up a code of conduct that defines the requirements (see clean zone definition in VDA 19 Part 2).

Priority 3:

- particles from the production environment (airborne particles that can travel large distances);
- particles from the external environment (open windows, doors…);
- particles thrown up by forklift trucks;
- …

6.4.2 Environmental cleanliness and internal production processes

Accurate answers and solutions can be found only by taking a product-related approach. This requires a specific analysis of internal production processes.

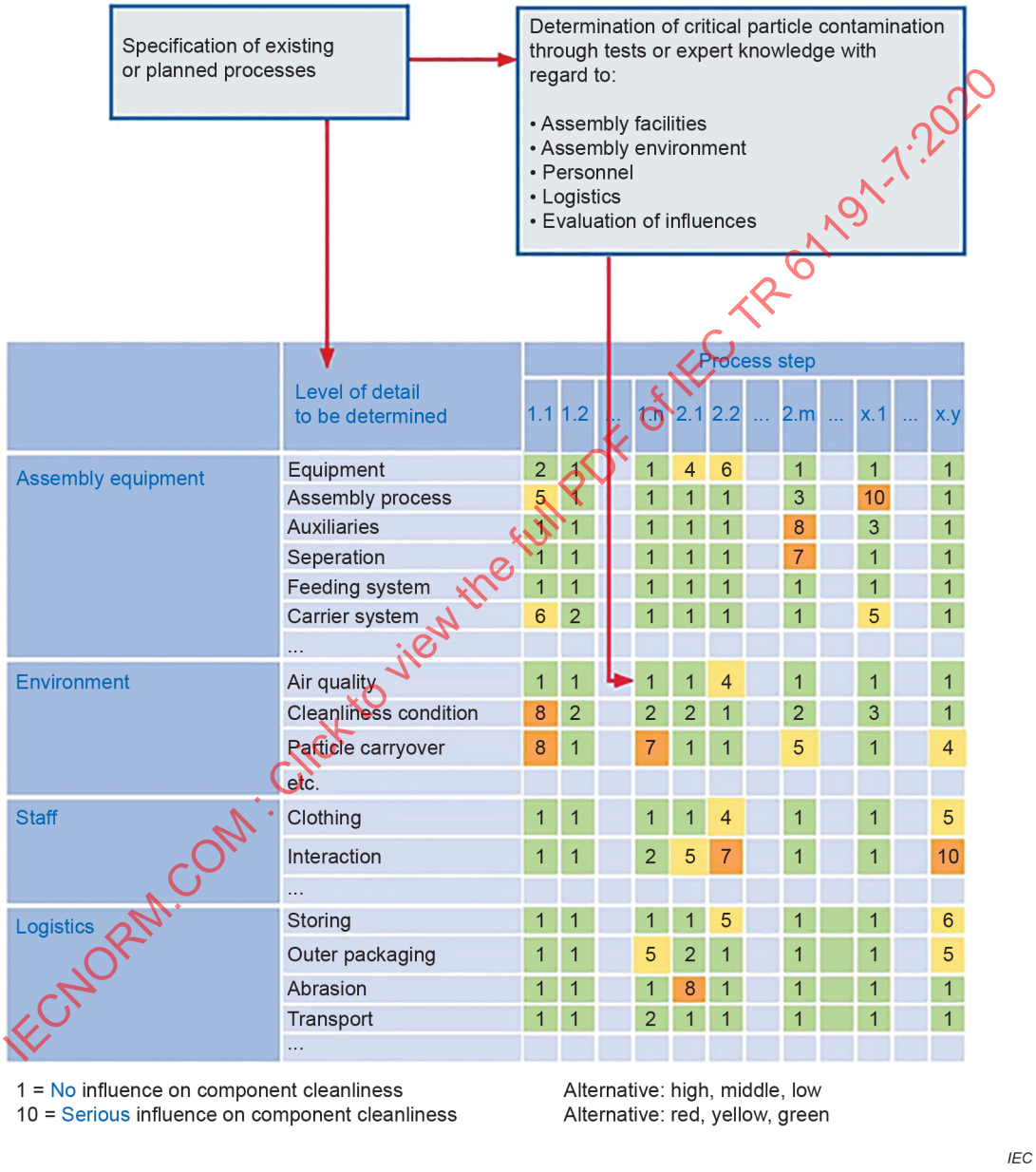
When preparing a tender specification (assembly machine), technical cleanliness shall be dealt with as a special point. It is also advisable to draw up design rules specific to the product (error list with corrective measures) which define the following points, for example, in concrete terms:

- processes should generate as few particles as possible or better still, reduce the number of particles present;
- process environments should be easy to clean;
- processes should remove particles from the component and from the operational environment;
- particles shall not be allowed to accumulate;
- sensitive processes shall be separated/partitioned to isolate them from processes that generate particles;
- workpiece holders shall be designed to avoid generating particles;
- minimum point supports;
- deburred and polished:
  - contact points/surfaces;
  - 'soft' contact points/surfaces.
- workpiece holders shall be designed to avoid particle accumulation:
  - easy to clean;

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  - reduced surface area and open.
- gravity:
  - preferred processing area 'underneath' – particles drop down below the part;
  - particle generation and reduction in the vibrator feeder/oscillating conveyor.

A process chain analysis as proposed in VDA 19 Part 2 gives structure to the process and provides an overview of the relevant particle sources.



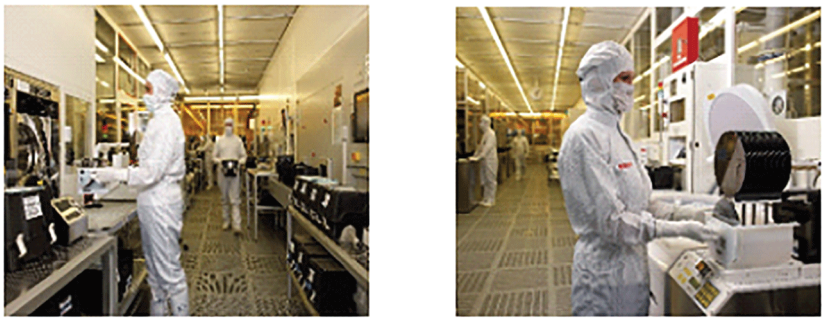
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Figure 57 – Process chain analysis as per VDA 19 Part 2

VDA 19-2 dedicates a whole chapter to 'assembly equipment', describing in detail the criteria and measures for different processes. It also includes an assessment of joining processes with examples (see Figure 57).

6.5 Environmental cleanliness analysis and visualisation

6.5.1 General



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Figure 58 – Cleanroom production

Cleanrooms (see Figure 58) are only rarely used in the electronics industry. The following subclauses provide guidance for environmental analysis and the visualization of the results.

6.5.2 Procedure for environmental analysis

6.5.2.1 Setting up and labelling particle traps

- If particle traps are to be used for comparisons, make sure they are installed at the same height.
- Label particle traps individually and systematically so that they can be assigned to the analysis reports (see Figure 59) .
- A photo illustrating the location of particle traps helps ensure reproducibility during reruns (see Figure 60).
- Place a brief notice for employees with instructions such as "do not touch the adhesive pad" beside each trap.
- After removing the cover and protective film, mark the time of activation on the trap.
- After activation, make sure the cover of the particle trap is kept clean to avoid cross-contamination when it is replaced.

6.5.2.2 Exposure time

- Inspect the adhesive pads regularly during the exposure period to check that they are not overloaded (see VDA 19 Part 2 Ch. 7.6).
- The usual exposure time is seven days. Cleaning operations undertaken in this period shall be taken into account.

6.5.2.3 Deactivating particle traps

- Replace the cover on the particle trap and ideally, secure it with adhesive tape.

6.5.2.4 Analysis

- Analysis reports contain detailed information, such as the level of contamination on the particle traps.
- We strongly recommend the use of a clarification form with clear instructions on how to perform and record a particle trap analysis (see Annex B).

6.5.2.5 Documentation

- A database can be used to automatically calculate the Illig values (see VDA 19 Part 2). The Illig value expresses the results of the analysis in a single numerical value.

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Figure 59 – Example particle trap



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Figure 60 – Position of particle trap

6.5.2.6 Creating a database

- Comprehensive data acquisition facilitates a systematic analysis of information. For this reason, it is worthwhile understanding the scope and scalability of the database. The aim is to capture data in as much detail as possible.

Examples:

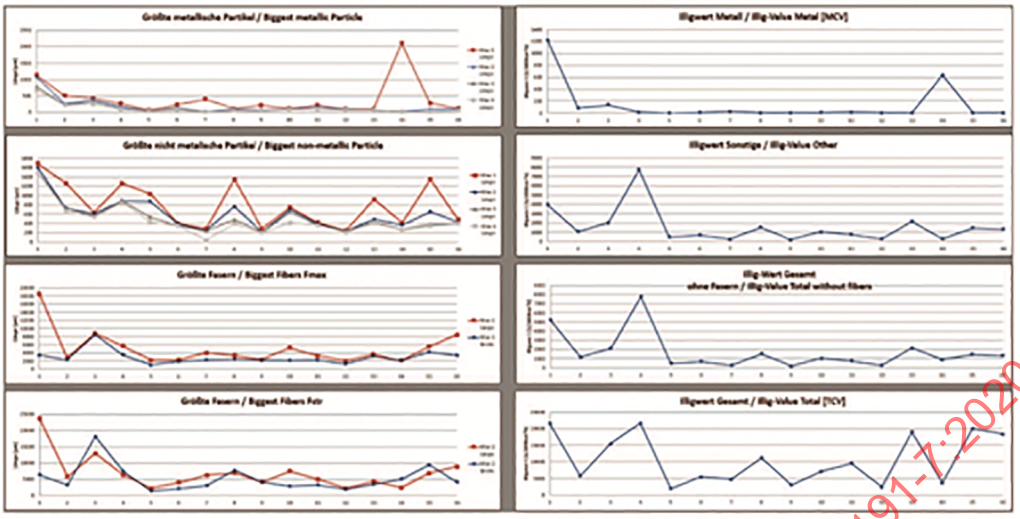
- particle trap number, date and place of installation;
- the three largest particles in each group (shiny metallic particles, other particles and fibres), length, and width if possible;
- number of particles in each size class and particle type;
- exposure time and installation height;
- links to: analyses, photo of location and position in the production layout;
- important information such as 'insect in the trap', 'fingerprint' or 'significantly different height'.

Diagrams generated automatically from selected values provide a visual snapshot of the degree of contamination of each production area (see Figure 61).

Important information:

Since individual outliers tend to get lost if the Illig value is high, it is advisable to compare the length, and possibly width, of the three largest particles with the Illig value.

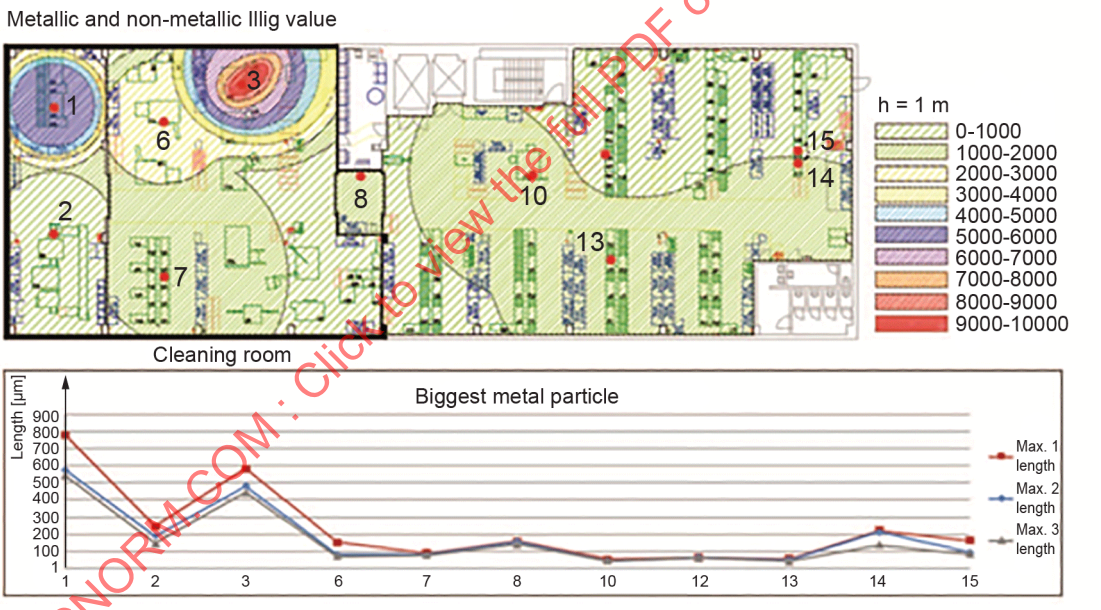
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Figure 61 – Database – Visualisation

6.5.2.7 Visualisation the Illig value in the production area



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Figure 62 – Illustration of the Illig value with max. three particles

It is important to:

- indicate the Illig value on the production layout (see Figure 62), for example "metal Illig value", "metal + other Illig value", etc.;
- include a key.

If changes are made in the production areas, for example the installation of a new ventilation system, evidence can be provided to show how the level of environmental contamination has changed.

6.5.2.8 Interpreting the results

- Do ambient air particles cause critical contamination?

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- In theory, the diagram showing the airborne dispersion of particles serves as the starting point.

The airborne dispersion diagram (see Figure 63) shows that metallic particles (worst-case scenario – fibre-shaped aluminium particle) of 50 µm or below can float in the air. This means that a clean room cannot effectively reduce the number of larger metallic particles.

Codes of conduct shall be drawn up for the implementation of cleanliness-controlled areas (see Figure 64 and Figure 65). VDA 19 Part 2 makes a wide range of suggestions which can be applied to individual configurations.

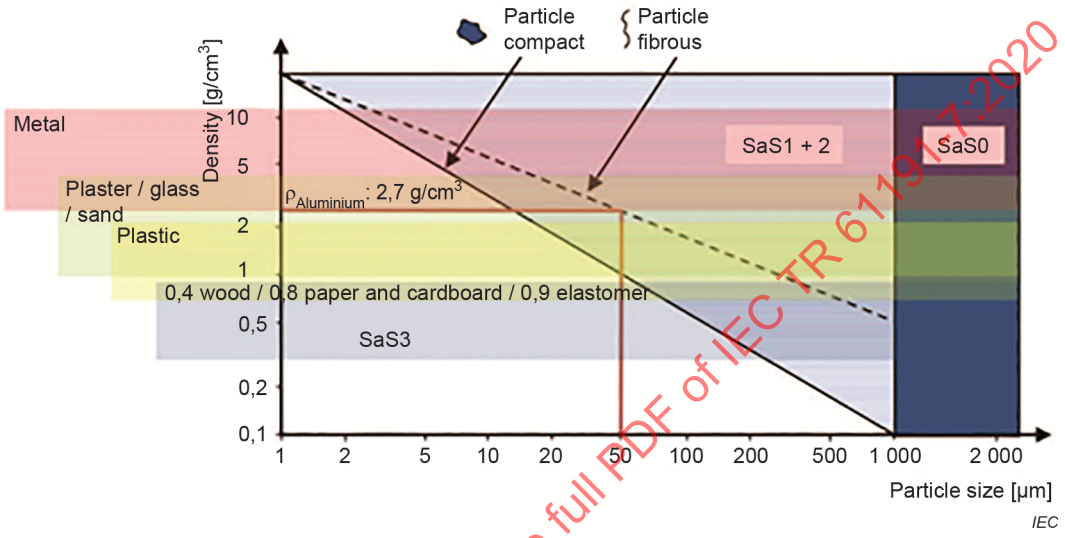
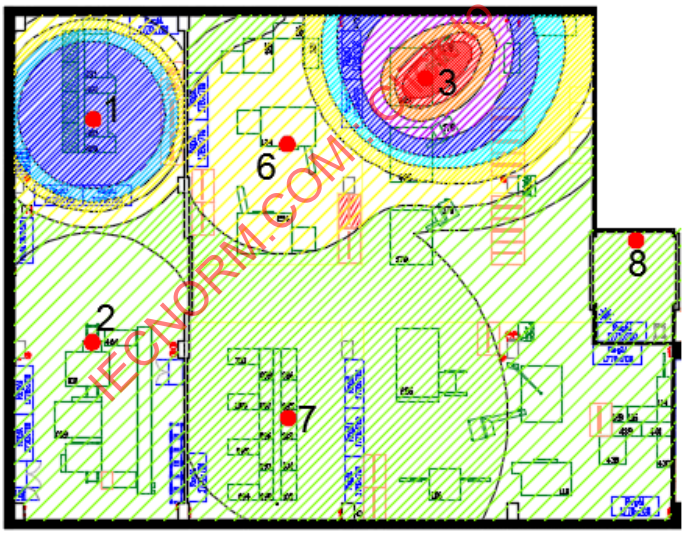


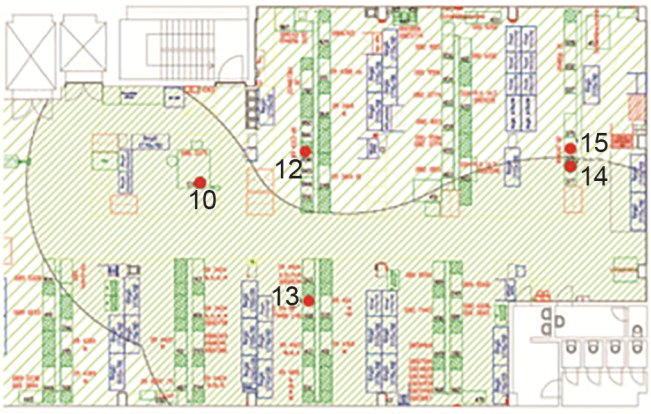
Figure 63 – Airborne dispersion diagram



The analysis results show that some particle traps (shown in red) in the cleanroom are significantly more contaminated than others. These are also significantly worse than the results from the area not governed by VDA 19.

Figure 64 – Analysis results in the cleanroom

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This is due to the chosen locations of the particle traps. Particle traps 2, 6, 7, 10, 12, 13, 14 and 15 were placed away from the manufacturing processes to collect particles from the ambient air environment.

Particle traps 1 and 3 were placed within the processing area and have recorded the process environment in addition to the ambient air environment.

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Figure 65 – Analysis results in the area not governed by VDA 19

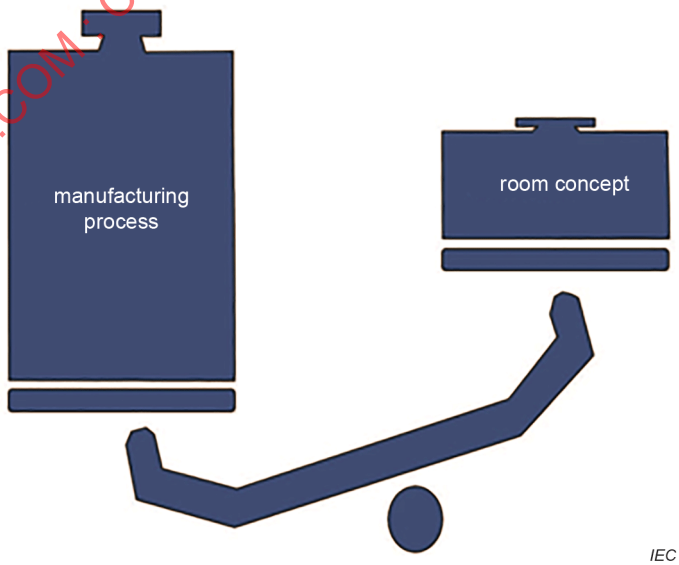
6.5.3 Conclusions:

Environmental cleanliness generally has a limited influence on component cleanliness. Production processes (internal/external) usually have a significant influence on component cleanliness (see Figure 66).

The use of particle traps is an appropriate means of monitoring cleanliness. This method provides an opportunity to focus monitoring efforts on the ambient air environment or the process environment. This should be specified in advance.

When choosing suitable locations for particle traps in the process environment, consideration should be given to the particle trajectory.

Unlike the 5S method, in this case the main concern is to obtain information about product contamination.



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Figure 66 – Weighting of factors influencing technical cleanliness

Manufacturing processes (internal/external) shall be compatible with cleanliness control!

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6.6 Cleaning tips

6.6.1 General

A clean workstation is essential to ensure technical cleanliness standards are met. Any particles produced at a workstation should ideally be removed immediately. Screen-type (fly screen) work surfaces, for example, facilitate separation at no additional costs. Use suction-cleaning to promptly remove large quantities. Particle contamination caused by hands or work clothes is particularly problematic when employees frequently change activities. In this case, measures such as airlocks, handwashing and gown-changing are advisable.

6.6.2 Washing

Parts washers are cleaning systems for components; however, they have not been introduced as a standardised industry-wide procedure. Owing to costs, technical compatibility (e.g. corrosion, deformation) and in some cases, poor efficiency, washing processes are primarily used for critical applications (aerospace industry) or in the event of special contamination. For instance, they are widely used for removing oil, grease or flux residue (ionic contamination) rather than particulate contamination.

The electronics and metal sector account for the majority of applications.

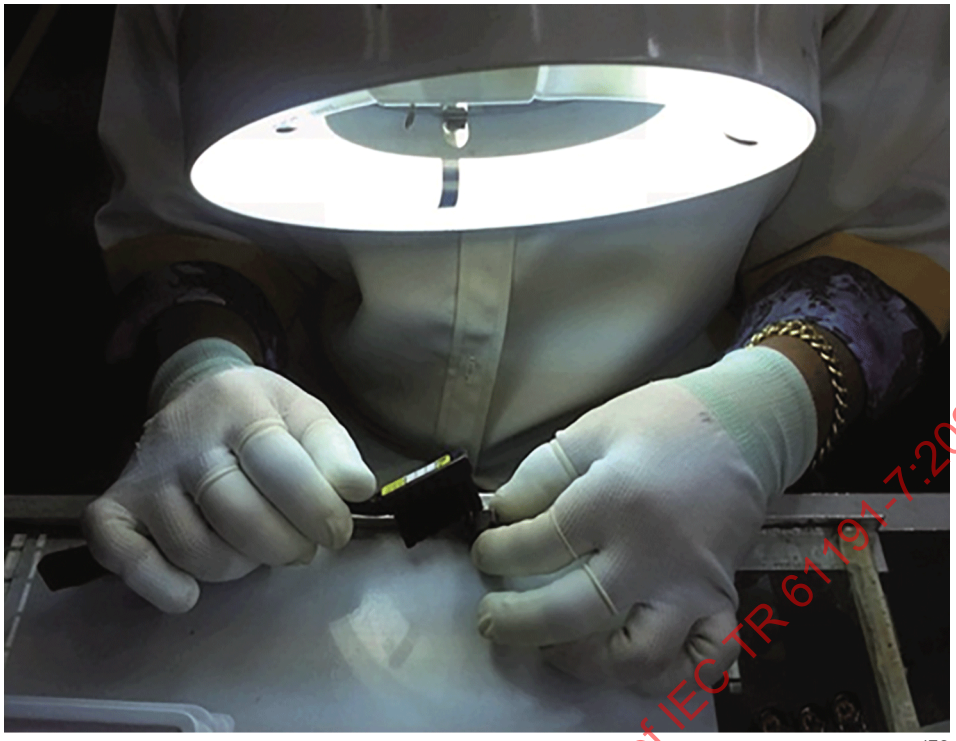
Efficient filtering is required to extract the particles from the cleaning liquid. With wet cleaning, for instance, there is a risk that dirt particles will be washed up into 'dead zones' and cavities or that the oil film or conductive salts will be distributed across the entire surface.

A distinction is always made between solvent-based and water-based cleaning processes. Water-based cleaning requires the use of some additives, e.g. corrosion inhibitors. Selecting the medium, controlling the cleaning effect and maintaining the baths is also more labor-intensive.

6.6.3 Brushing

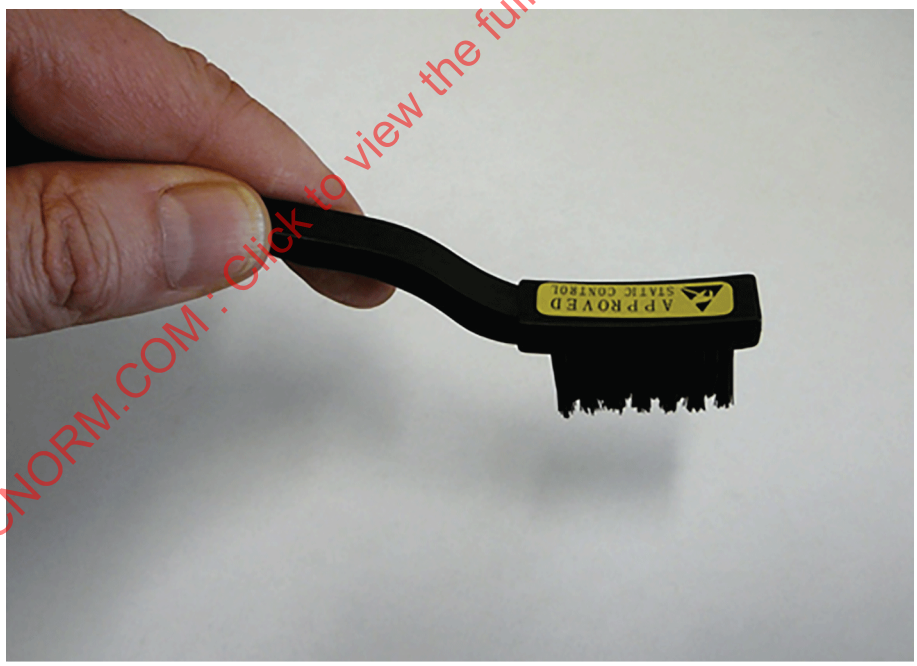
Brushes remove more firmly adhering particles from the surface (see Figure 67). However, particles may accumulate in the brush, which shall be cleaned regularly or replaced. Since the relative motion of insulators generates static electricity, it is advisable to use an ESD brush to ensure discharging via the hand and person to the ground (see Figure 68). When using ESD brushes with conductive carbon fibres, it is important to remember that these fibres might break and form a potential source of conductive particles. It could be argued that particles that have not fallen off after brushing have good, persistent adhering properties and are thus uncritical. Manual brushing always poses a risk as to how carefully it is executed by the operator. The frequently complex geometry of components and low system flexibility are not suited to automated processes.

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Figure 67 – Manual cleaning with brush and illuminated magnifier



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Figure 68 – ESD brush

6.6.4 Suction-cleaning

Suction-cleaning is always a good option since particles can be removed from the process in a targeted manner. One disadvantage is its low penetration depth and the limited vacuum or suction that can be created. Unfortunately, suction processes frequently involve increased noise exposure.

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6.6.5 Blowing

Blowing is another alternative which uses an air flow to clean the surface. This quick process is also effective at greater penetration depths.

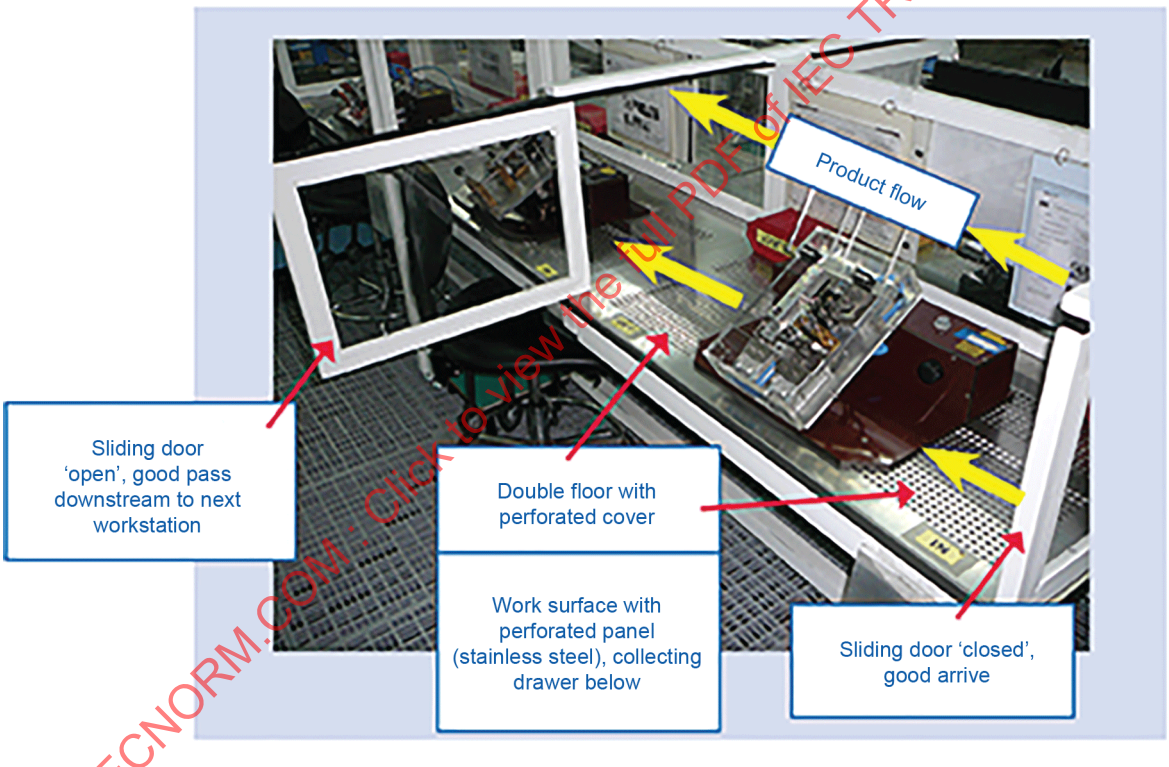
Compressed air is commonly used on the shopfloor. Make sure it is oil-free. Ionised air is typically used for blowing processes.

However, improper implementation may result in particle spread, e.g. to adjacent components or into the environment where it may endanger the operator's health (eyes, dust inhalation).

The smaller the metallic particles, the better they adhere to other surfaces owing to electrostatic forces. In this case, simply blowing off the particles is not sufficient; mechanical action such as brushing will be more successful.

A combination of blowing and brushing is widely used in practice.

6.6.6 Reducing carry-over and controlling cleanliness in workplace design



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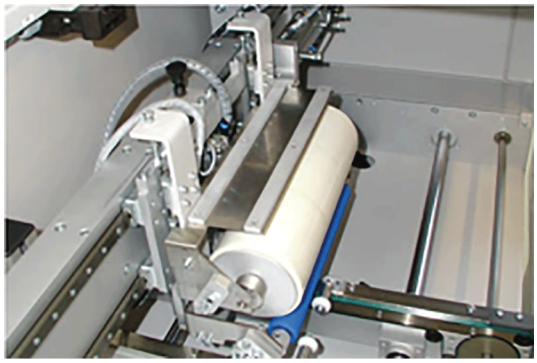
Figure 69 – Workstations designed for cleanliness control

The perforated system on the worksurface and floor ensure that particles are removed from the workspace with no additional effort or expense. Sliding doors between workstations provide 'particle-tight' barriers which are opened only to transfer products downstream. This setup limits particle carry-over and significantly reduces the amount of particles on the products
(see Figure 69).

Workstations like these designed for cleanliness control can be integrated into existing production areas and thus represent an affordable modular option for improving the particle count on products in the production line. This solution deals with particles generated by the process which drop down by gravity owing to their size and weight.

6.6.7 Adhesive methods

Adhesive methods such as rolling and stamping can be used to clean flat surfaces, e.g. PCBs (see Figure 70).



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Figure 70 – Adhesive roller system for PCB contact cleaning

6.7 Packaging and logistics requirements

- Packaging material that is in direct contact with the component shall meet the same cleanliness requirements as the component and effectively protect the component from external contamination which could impair functioning.
- The packaging shall ensure that no additional particles or other contaminants are generated which could impair functioning.
- It shall also prevent the recontamination of components during removal from the packaging, storage or further processing.
- Within the process chain, cost-effectiveness and efficiency shall be optimised to ensure that levels of cleanliness are maintained wherever possible.

7 Why do metallic particles in assemblies so rarely cause short circuits?

7.1 General

When we look at failure events in housed assemblies in the automotive industry, for example, and analyse the most critical group – metallic particles – in relation to an electrical short circuit, the findings do not match the number of metallic particles found in the extraction analyses.

This discrepancy can be graphically illustrated as a gap between the theoretical and actual field risk. It is generally assumed that the risk of an electrical short circuit caused by metallic particles rises sharply if the particle length is the same size or larger than the smallest electrical clearance between two current-carrying (live) areas. Investigations conducted by the ZVEI working group have shown that, in reality, the function is significantly flatter than one would expect from a purely theoretical analysis based on geometry. The volume of particles and their mobility during the operation of an assembly in the field largely determine the shape of the function (see Figure 71).

The theories and assumptions listed below have been proposed to explain this discrepancy, and will be considered in more detail in 7.2 to 7.5):

- Not all geometric short circuits are electrical short circuits (probability of short circuit).
- Liquid particle extraction indicates more "mobile" particles than are actually mobile under operating conditions.

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- During operation, mobile particles get permanently stuck in areas (particle sinks), thus rendering them immobile.
- Not every pair of adjacent contacts that is short-circuited by a metallic particle causes a problem or malfunction ("short circuits without consequences"). The probability of a short circuit decreases with the age of the contact elements (particle and electronics) owing to increasing oxidisation and accumulated layers of contamination.

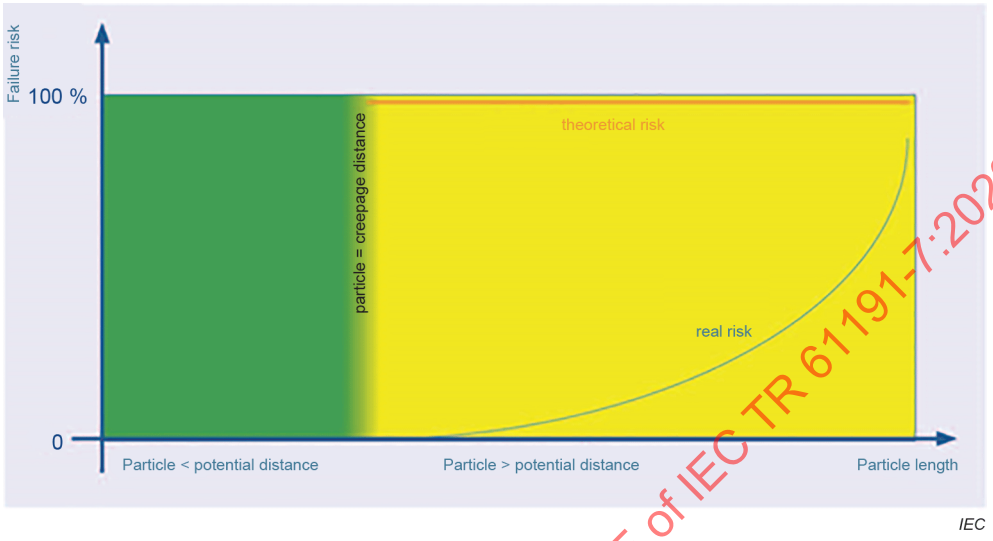


Figure 71 – Diagram showing failure risks based on metallic particles on assemblies

7.2 Probability of contact

7.2.1 Introduction and theory

An electrical contact is created when two current-carrying parts connect [1][7]. A short circuit caused by a conductive particle between two potentials in an electronic system thus creates two contacts (see Figure 72 and Figure 73). The assumption that a conductive particle which geometrically connects two conductors, contact points or similar inevitably creates an electrical bypass does not take account of all the physical circumstances. A theoretical deduction of the probability of contact is possible only to a limited extent, since not all influencing factors and their parameters can be fully measured and investigated.

Influencing factors:

- contact normal force;
- surface topography;
- surface oxidisation;
- duration of contact;
- electrical conductivities;
- voltage difference;
- films and other layers of contamination.

When two contact surfaces touch one another, only very small areas actually make contact due to surface roughness. These areas are referred to as the effective contact surface. The transfer resistance and accomplishment of the electrical contact is determined by the situation at these local contact points.

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7 Numbers in square brackets refer to the Bibliography.

Furthermore, in everyday situations layers of contamination can be found on the metal surface ([2], p. 413).

1) These layers of contamination may simply be composed of gas molecules that are deposited on the surface owing to Van-der-Waals forces, which are based on electrical phenomena (physisorption).
2) After a certain time, the gas molecules begin to disassociate, for example owing to the catalytic effect of the base metal, releasing gas atoms which bond more strongly with the metal (chemisorption).
3) Depending on the metal and the gas, metal ions can escape from the metal matrix and chemically react with the base metal and the chemisorpted gas atoms. Metal oxides or, in the case of silver and sulphur, sulphide layers are deposited on the surface as reaction products.
4) This layer of contamination continues to grow as additional metal ions and gas atoms migrate into it over time.

Not all metals follow these four stages in full ([3], p.23).

The gold-oxygen system merely saturates the metal surface with gas ions, while the oxidation that occurs with platinum-oxygen has a passivating effect, thereby limiting further growth of the contamination layer.

Given sufficient voltage, the gas layer formed in 1 and 2 offers no resistance to the flow of current since the tunnel effect enables electrons to tunnel through it loss-free. The layers of contamination formed in 3 and 4 significantly hinder the flow of current, resulting in total insulation in certain circumstances.

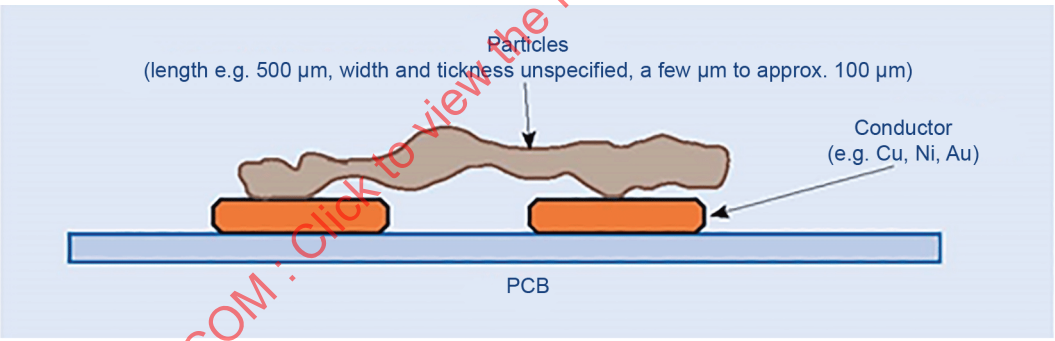
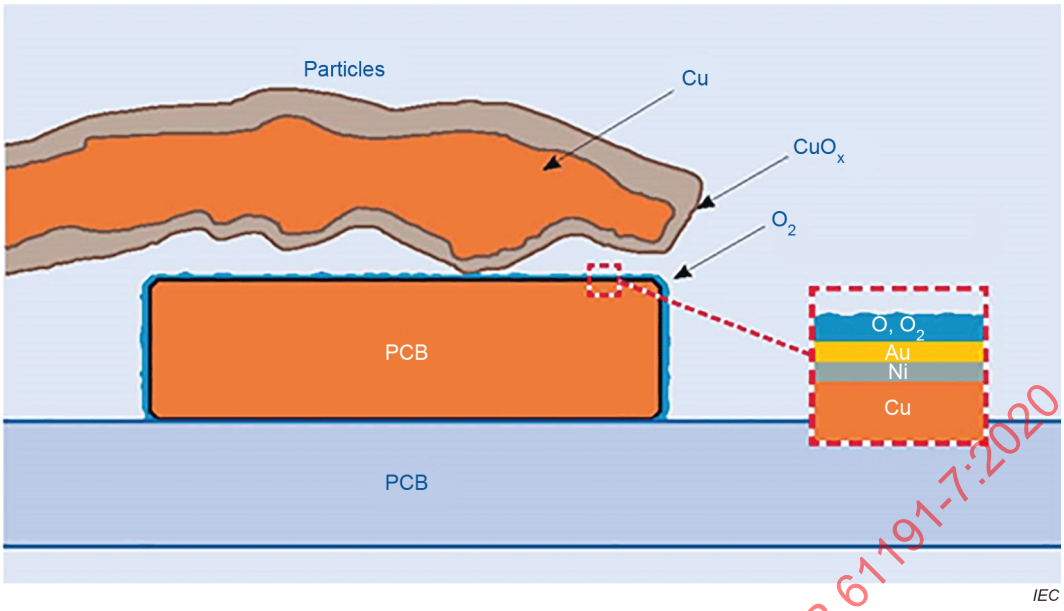


Figure 72 – Sketch of electrical arrangement (particle forming "bridge" between two conductors)

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Zoom image of Figure 72, sketch of principle, not to scale.

Figure 73 – Diagram showing contact point of a particle on a conductor – nickel-gold conductor and copper particle

The layers of contamination vary in thickness and hardness and correspondingly differ in terms of electrical breakdown. Gold, for example, produces an adsorbed gas layer of only approximately 1 nm to 10 nm which can be easily tunneled through and thus presents no barrier. Tin, which is an essential material in electrical engineering, has a passivating oxide layer of approximately 50 nm to 100 nm which is extremely hard and can only be penetrated by friction or plastic deformation ([2], p. 413). The copper oxides forming on copper are semiconductors which, with an ideal stoichiometric composition of 10 GΩ cm, have high impedance, but can easily achieve resistances in the kilo-Ω range if their stoichiometric composition deviates from the ideal ([2], pp. 36 & 413).

A fresh metal surface produces layers of oxygen, which are absorbed at different speeds depending on the metal. While copper was found to produce a few layers after 20 seconds and up to ten layers after ten minutes to several weeks, with gold only one layer was found after ten minutes and still only one layer was recorded after two days. Aluminium exhibits extreme behaviour in this context, producing seven layers after just 20 seconds (see [4], p. 106).

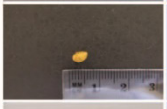
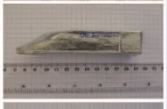
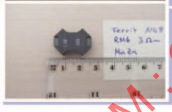
Correlations between contact force and contact resistance are known to exist from studies into switching contacts such as relays. However, it is doubtful whether these apply to the problem described here (a metallic particle lying between two contact surfaces, both sides of which may be contaminated). Studies in the literature ([4], p. 49) are based on minimal forces of $0{,}5 \times 10^{-5}$ N, whereas acylindrical copper particle with dimensions d = 50 µm, l = 600 µm has a contact force of only $5{,}2 \times 10^{-8}$ N on one side of the bridge. This type of small contact force produces only elastic deformations on the metal surface.

In addition to these phenomena, which can be found on contact surfaces under laboratory conditions, the supposed protective, or rather contaminating, effects encountered in everyday life shall also be considered, such as accumulations of dust, non-conductive particles, organic substances etc. on the contacts.

All these deposits insulate to a greater or lesser extent and, when pressure is applied, can be penetrated fully or, at the other extreme, not at all. In other words, they are additional variables in terms of actual behaviour.

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Table 28 – List of materials used in the test

	1	Cu	Copper	e.g. cables, power rails
	2	CuNiSi	Copper alloy	e.g. contact material, press-in pins
	3	Au	Gold	e.g. bonding wire, connector coating
	4	Sn	Pure tin	e.g. coatings
	5	SnAg3Cu0.5 (SAC305)	Solder material	e.g. solder paste, solder bars
	6	ZnAl4Cu1	Zinc alloy for die-casting	e.g. housings
	7	AlSi12	Aluminium alloy for die-casting	e.g. housings, covers, holders
	8	CuFe2P	Copper-iron	e.g. bus bars, lead frames
	9	FeSi3	Electrical steel	e.g. stators, rotors, transformers
	10	X10CrNi18-8	Spring steel	e.g. springs
	11	MnZn-Oxid	Ferrite	e.g. magenetic core, chokes, transformers

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7.2.2 Testing the probability of contact

Prior to assessing the probability of contact of metallic particles under realistic environmental conditions, experiments were conducted to examine more closely the short circuit risk. This was done by simulating one of the most likely short circuit situations in an electric circuit: a particle moves around on an installed electronic assembly and lands on two metallic contacts.

Test setup:

Representative metallic components used in electrical engineering were assembled. The selection was based partly on their use in typical electronic circuits and also on those materials which were found as particles in extraction analyses (see Table 28).

To obtain realistically shaped particles, the materials were filed to produce particles of 500 µm to 600 µm. The bonding wire was cut.

The following particle conditions were considered when determining the probability of short circuit:

- new condition (particle produced immediately before measurement);
- ageing in a dry climate (155 °C; 4h; as per IEC 60068-2-2);
- ageing in a humid climate (85 °C; 85 % RH; 4h; as per IEC 60068-2-67).

Test circuit boards with a comb structure were produced as counterparts. In the first case, the conductive structures consisted of fresh conductors (NiAu) and in the second case soldered conductor surfaces after a reflow process with SAC 305. The circuit boards had no solder mask in the gaps which might otherwise impede contact of the particles (see Figure 74).

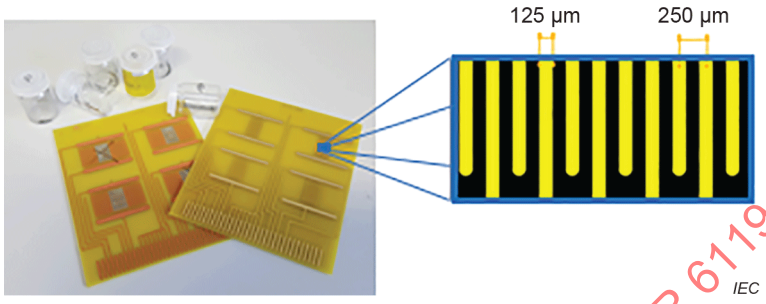


Figure 74 – SIR test circuit boards (interleaving comb pattern layout)

The measurements were performed with different configurations (see Figure 75 and Figure 76).

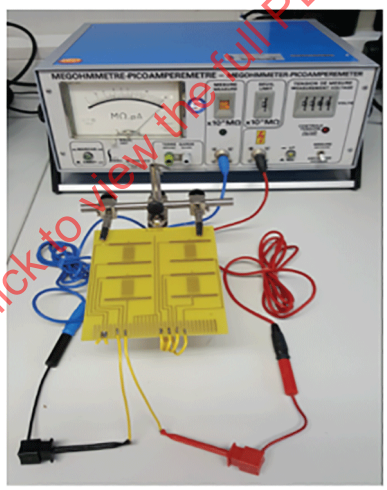
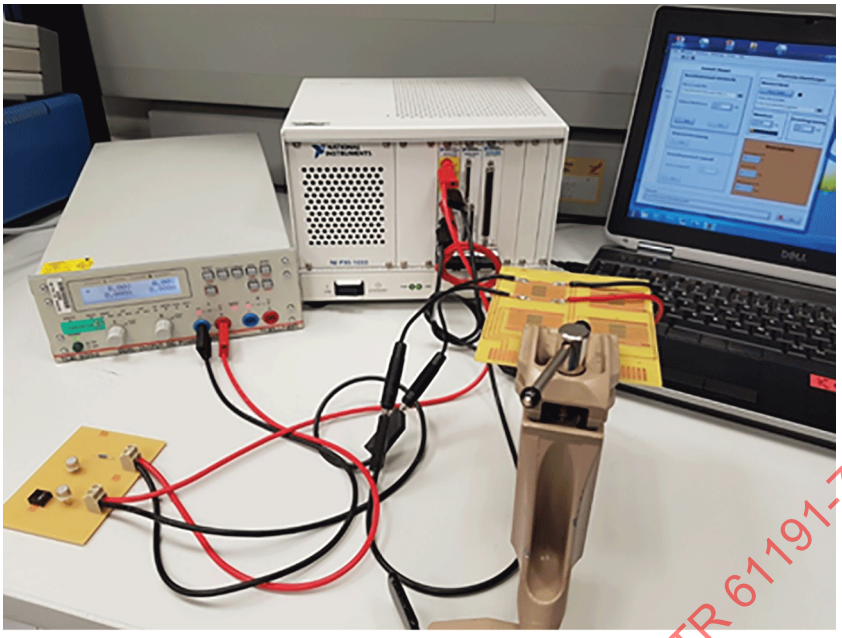


Figure 75 – Voltage source that measures current with an analogue picoamperemeter

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Figure 76 – Automated current measurement with software

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Test performance:

A particle was manually placed on top of two adjacent conductors in such a way that it could be assumed from a visual inspection that it was resting on both metal surfaces. Then, the DC voltage between the conductors was increased from a starting point of 1 V to maximum 60 V in increments of 1 V, with each voltage value sustained for approximately five seconds. When a significant current flow was recorded, the voltage applied at the time was noted as the measurement result, i.e. as the breakdown or fritting voltage. The current of the voltage source was restricted to maximum 2 mA. After repositioning the particle, the measurements were repeated. To obtain a statistically relevant basis, this process was repeated until 25 breakdowns were achieved. Together with the number of measurements for which no breakdown occurred when 60 V was applied, this gives the 100 percent cover. Since the effort required to achieve 25 breakdowns was too high in some cases, the maximum number of measurements was limited to 50. This meant that at least 25 and maximum 50 measurements were performed for each particle and position.

Particles were frequently observed to adhere slightly to the circuit board after breakdown. The micro-fusion of the metallic particles to the conductors of the circuit board observed in the tests indicate "fritting". This behaviour describes the electrothermal breakdown process whereby a layer of contamination suddenly reduces the resistance of megaohms in the ohm range as voltage increases. The semi-conducting layers and field behaviour are largely responsible for this. After the breakdown, metallic bridges form between the contact elements ([2], p. 38ff).

7.2.3 Results

The measurement results for copper particles on soldered PCBs are presented in the form of a bar chart (see Figure 77).

The probability of contact in relation to the different voltage ranges was calculated cumulatively as follows:

$$\text{Probability of contact} = \frac{\text{Number of breakdows}}{\text{Number of all measurements}} \times 100\ \%$$

A comparison of all the results shows how applied voltage, particle condition and material influence the contact characteristics (see Figure 78).

Some measurement results show significant variation, but they were based on realistic simulations and therefore reflect the complexity of the circumstances. However, some of the variation can probably be attributed to the fact that the tiny particle dimensions made the test performance particularly challenging.

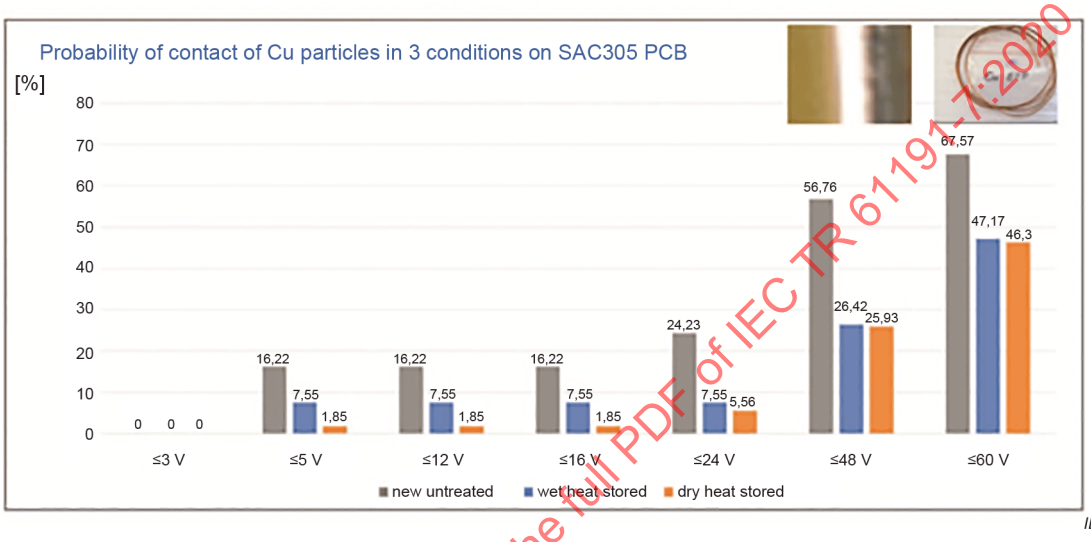


Figure 77 – Comparison of CU particles in three conditions on SAC305 PCBs

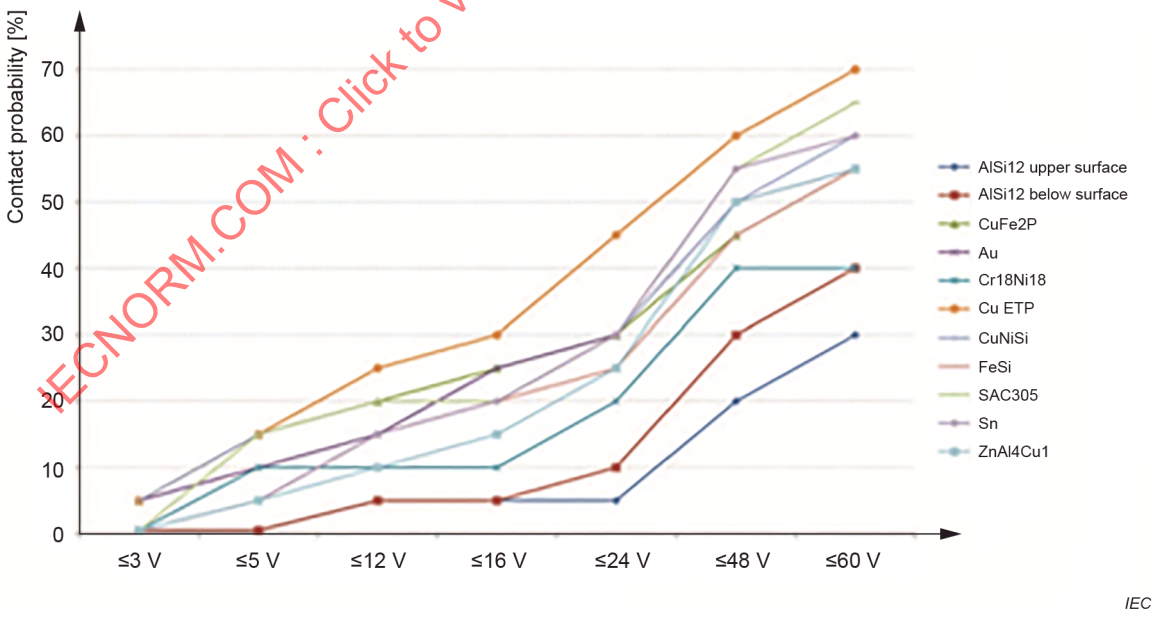


Figure 78 – Overview of all metals in the voltage classes, rounded

The results can be summed up as follows:

- The probability of electrical contact based on all the combinations tested is significantly below 100 percent.

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- The probability of short circuit varies depending on the materials, but the consistent underlying trend is that probability increases in line with increasing voltage.
- The probability of short circuit is very low for low voltages, but often increases significantly above 12 V. These significant differences should be considered with regard to standard 12 V applications and modern 48 V applications.
- Storage under aggravated climatic conditions such as dry heat or moisture reduces the probability, which suggests a surface reaction of the metals – for example, the formation of metal oxides.
- The probability of short-circuit tends to be higher with precious metals such as gold than with base metals such as aluminium, for example.

7.3 Rinsing extraction versus actual mobility

The cold-cleaning processes performed as part of a cleanliness analysis can detach significantly more particles than would realistically be possible during field operation, for example when exposed to vibrational forces in the vehicle.

This can be demonstrated in two ways:

1) In accordance with VDA 19, it is permissible to perform the cleanliness analysis by air extraction in addition to liquid extraction. Comparison of both extraction methods shows that the particle count tends to be lower with air extraction.
2) Vibrational forces acting on a product during operation in the field have been simulated in a simplified manner in laboratory tests:
   a) In a random test, ten powerful impacts (approximately 2 J) were consecutively applied to a vertically suspended assembly. After each impact, the particles that had fallen from the circuit board were quantified. When all ten impacts had been applied, the circuit board underwent a cleanliness analysis with cold cleaners. The ten impacts were found to have dislodged only 30 % to 50 % of the particles. The remaining 50 % to 70 % of the particles could only be removed by the cleanliness analysis with cold cleaners.
   b) In a further test, a PCB was placed on a vibration table and exposed to a typical automotive vibration profile. The particles detached by the vibration test were quantified. Then the circuit board underwent a cleanliness analysis with cold cleaners. Only approximately six percent of the particles were detached by the vibration profile. The remaining 94 % of the particles could only be removed by the subsequent cleanliness analysis with cold cleaners.

7.4 Particle sinks

Particles which find themselves on an electrical assembly are held there by various mechanisms, but this does not remain the case for all particles. The adhesive forces generated by Van der Waals forces, electrostatic or magnetic forces, for example, are influenced to some extent by material and particle size. Every vibration or impact may detach some particles; the mounting position plays a major role in this process. In a vertical mounting position, a significant proportion of particles will detach and fall down owing to gravity. In this case, the floor of the housing acts as a sink. The detached particles collect here, and further vibrations are unlikely to propel them back on to the assembly. In a horizontal mounting position, particles can roam around the assembly for longer, surviving many impacts and therefore remain active. Experience shows that many particles gather in a corner after more impacts, get trapped or, on reaching the edge of the assembly, drop down and are permanently ejected.

The smaller the particle, the higher the adhesive force in relation to the gravitational force. In terms of impacts, this means that the particle's mobility declines significantly as its size increases.

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7.5 Effect of short circuits on ICs

Owing to specific pin assignments, it is not possible to take a universal approach to examining the effects of short circuits on ICs. Nevertheless, some basic pointers are given below.

In ICs, voltages of 3 V to 5 V are normally applied between the individual component pins. This is significantly below the current market standard for ISO on-board power supplies of 12 V in vehicles, and thus correspondingly reduces the probability of contact (see 7.2).

It is also important to evaluate the extent to which electrical short circuits between certain potentials can be intercepted by the software used.

Ultimately, only a limited number of adjacent pins can result in functional failure. A pin FMEA can be used to identify these pins and analyse the functional failures.

7.6 Tool for estimating the risk of short circuit

7.6.1 Overview

Component specifications often include particle limits based on the smallest electrical clearance between two current-carrying areas. This has given rise to extremely strict requirements which are impossible to implement from either a technical or commercial point of view and furthermore, are unnecessary given the risk of an electrical short circuit occurring on the assembly.

Let's take an actual assembly as an example; a single circuit board contains hundreds of components. Often only a small number of these are fine-pitch components (pitch 0,4 mm/0,5 mm). Many other components have a pitch clearance of more than 1 mm. If the limits for tolerable metallic particles were derived on the basis of fine-pitch components, maximum permissible particle lengths would be in the 200 µm range (allowing for solder pads).

We can explore the usefulness of specifying such strict limits by performing the following thought experiment. According to the abovementioned approach, the following would apply.

Metallic particles on the PCB with a length of 199 µm pose no threat; but with a length of 201 µm, there is a potential risk of an electric short-circuit, although not a 100 % risk (failure of all assemblies due to the presence of only one particle with a length of 201 µm).

To make a knowledge-based assessment of this extreme difference between 0 % and 100 %, we have devised a sample application-specific risk assessment based on the electrical short circuit presented in the subclauses of 7.6. This approach takes into account the actual situation with regard to all clearances between current-carrying areas as well as the actual particle load on the product being assessed.

It enables us to deduce a probability of failure linked to different application-specific boundary conditions.

This is based on the assumption that an electric short circuit equates to a functional failure of the assembly. This would certainly not always be the case in reality.

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7.6.2 Model hypotheses

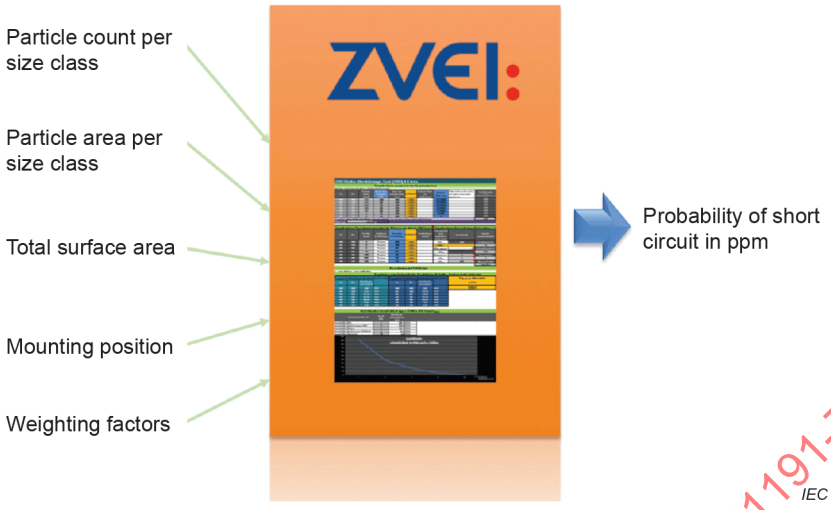


Figure 79 – Functional structure of risk assessment tool

The model design (see Figure 79) is based on the following hypotheses and simplifications:

1) a particle has a negligible width;
2) the conductors under consideration are located on different potentials;
3) the particles present are evenly distributed in the assembly;
4) the particles have geometrically "perfect" contact surfaces, i.e.:
   a) flat surface across their entire length;
   b) no curvature.
5) each geometric contact also results in an electrical contact;
6) particles are mobile;
7) a uniform voltage is applied to the entire assembly.

About 1 – Obviously, a particle extends in width and height in addition to length. But actual particles do not have a flat surface; in reality, their topological features create individual points of contact. So to take a line instead of individual points as the starting point is already a worst-case scenario.

About 2 – With regard to electrical clearances between two current-carrying areas, in reality some of these are on the same potential. The chosen hypothesis assumes that all current-carrying areas have different potential and thus also represents a worst-case scenario.

About 3 – As a general rule, particles can be evenly distributed throughout the assembly. In practice however, particles are influenced by gravitational and adhesive forces and therefore accumulate locally. The "equal distribution"' hypothesis may or may not be conservative, depending on whether the particle accumulations are close to adjacent, critical, current-carrying areas.

About 4 – Curved particles would not necessarily come into contact with both contact surfaces if solder mask, for example, was between the current-carrying areas. Thus the "no curvature" hypothesis is also a worst-case scenario.

About 5 – In practice, not every geometric contact results in an electrical contact. This depends on several boundary conditions (see 7.2), so this is also a worst-case scenario.

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