

# Technical Cleanliness – a Requirement of Precision Manufacturing

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**Abstract:** Precision manufacturing requires a technically clean environment to ensure repeatability of production while maintaining the required quality. The current VDA 19.2 standard classifies clean environments into three classes. In the course of 2020/2021, the requirements for electromagnetically clean areas shall be added to these requirements. This article highlights the potential of measurements used in this field nowadays.

**Keywords:** *Technical cleanliness, measurement, solid microparticles, magnetic field.*

## 1. Introduction

The issue of technical cleanliness has emerged with the issue of precision manufacturing, whether it was in the field of mechanical engineering, electrical engineering, or in the requirements of the production of pharmaceuticals, chemicals, and health care. Technically clean areas will be an increasingly widespread requirement in technologically precise processes [1].

Increasing automation and robotization of manufacturing requires minimization of the factors affecting cleanliness of products, in particular by creating technically clean areas, which helps reduce the risk of contamination to an acceptable level [2]. Even particles with the size of 5  $\mu\text{m}$  can cause damage and deterioration of the precision bearing in an engine or an electromotor. It is therefore necessary to maintain the required cleanliness in the bearing area. It is worth noting that the first precision ball bearing was made in Japan in 1916 [3]. It was in post-war Japan where the 5S method was implemented, especially in the automotive industry by Toyota.

The article aims to point to the new trends in the field of technical cleanliness. Up to now, the technical cleanliness has been perceived as a tool of prediction of the physically contaminated environment. The new VDI 19.2 standard [4] already incorporates the concept of an intangible environment that can cause low quality manufacturing, i.e. electromagnetic fields, which can also significantly affect the precision manufacturing. From this point of view, the present concept of the technical cleanliness is considerably wider than in the past. Magnetic field measurements are used in precision production, where it is required to know the magnetic field after machining e.g. bearing. They are used e.g. in aviation and automotive industry

## 2. The development of views on technical cleanliness

The periods of WWI and WWII are considered significant milestones in the development of technical cleanliness and quality in the mechanical engineering

industry. In the US military production during WWII, the first requirement for creation of clean areas was imposed due to precision manufacturing in mechanical engineering. The clean areas that met the required parameters allowed the development of new manufacturing processes in the industry. Similar requirements for the technical cleanliness have also emerged in other sectors of the industry, e.g. in electrical engineering, chemistry, optics, etc. Czechoslovakia also experienced a rapid development of the mechanical engineering industry. In 1943, the German company SUMAG built the ball-bearing factory ZKL (Závody kuličkových ložisek) in Klášterec nad Ohří, and later the roller-bearing factory ZVL (Závod valivých ložisek) in Považská Bystrica. In 1992-1993, after its separation from the base, a separate organisation for manufacture of bearings – ZVL AUTO spol. s r.o. was established in Prešov, and has been a functioning company up to now.

### 3. Technical cleanliness standards

Nowadays, the most important standards for technical cleanliness in the automotive industry are the standards VDA 19.1, VDA 19.2 and ISO 16 232. The first one dealing with this issue was the US standard US FED STD 209E, which defined the number of dust particles that may be present in the air in order to classify individual cleanliness classes. Today its revised version can be found under the name US FED STD 209E. There are several related standards, such as VDI 2 083. Until 2003, the valid standard used in the Slovak Republic was STN 125 310. After the accession to the EU, the Slovak Republic was required to introduce the common European harmonized standard STN EN 14 644 consisting of 7 chapters. Its first and second parts are considered to be the most important [2].

Standard STN EN ISO 14 698-1 Cleanrooms and associated controlled environments - Biocontamination control - Part 1: General principles and methods, drawn up in 2003 and published in May 2004, describes the principles to be followed in order to establish and operate a clean controlled area. ISO 14 698 is a guide to controlling biological contamination. Hygiene in some sectors of industry has to reach the required level in order to avoid manufacturing of dangerous and unstable products [5]. It is the first international standard for the control of biological contamination. Even in the automotive

industry, e.g. grease from hands on a component may cause a serious malfunction in its functional area [5].

The presence of particles from the manufacturing and assembly, which may be of different nature, causes increased system wear, and may cause machine malfunctions. In order to achieve high reliability and functionality of the system components, it is necessary to control the amount of particles dispersed during the manufacturing and assembly process. The ISO 16 232 Road vehicles - cleanliness of components of fluid circuits standards have been designed for practice in a way to always meet the requirements of the automotive industry, since the functionality and performance of fluid circuits of vehicles is dependent on the presence of one or more contaminants of critical size.

Since the introduction of the VDA 19.1 standard in January 2004, the importance of the technical cleanliness has been steadily increasing and has become an integral part of quality assessment in the automotive industry. Over the years, since the first publication of the VDA 19.x series, these standards have found a widespread application in various industries. In 2015, the VDA standards were reviewed and amended. The VDA 19.1 Inspection of technical cleanliness [6] has been revised to improve the reproducibility of the results of the technical cleanliness analysis, including new extraction and analytical methods.

The VDA 19.2 is seen as a guide and aid for designers and quality engineers in planning and optimizing processes in cleanliness-sensitive assembly areas and in their surrounding areas. In systems for fluids circulation (e.g. braking circuit, fuel system, air conditioning and cooling systems) but also in mechanical and electronic modules, particulate contamination may lead to their malfunction. There is a risk in manufacturing that the originally clean parts become contaminated again during transport, storage and especially during assembly. If it is not possible to clean the critical areas after assembly, there is a high risk of contamination by particles remaining on the product, which may be critical and the cleanliness specifications may not be guaranteed despite the previous cleaning of parts [4].

The latest edition of the VDA 19.2 standard from June 2019 focusing on the approval of processes and products in the automotive industry, which shall be

adopted in 2020/2021, also includes requirements for electromagnetic cleanliness, especially in plants with precision manufacturing, healthcare, etc. This issue can be considered in detail when measuring electrical and magnetic fields in a particular assembly of machines and in manufacturing processes. It should be kept in mind that any mechanical machining of metallic materials in the Earth's magnetic field creates a magnetized layer on the surface. The movement of the spindle and/or mobile sources in the Earth's magnetic field create local gradient fields in factories. These fields create a local magnetically-contaminated environment. Such workpieces need to be demagnetized in order to achieve desired parameters in the subsequent machining.

#### 4. Tools used for identification of technical cleanliness to date

The cleanliness of the technical environment can be determined to the extent needed – from simple tests to the use of complex equipment. Monitoring of contamination of the manufacturing environment can be carried out on working machines, premises, or storages. The simplest testing tool is a stamp test. This is done by applying and then removing a transparent double-sided adhesive tape on the tested area. The adhesive tape contains the contaminating particles on one side and its other side is taped to a mat, which provides an adequate contrast to the particles on a particular product or area. The evaluation of the stamp test is carried out using an optical microscope (Fig. 1). The shape and dimensions of the particles are evaluated.

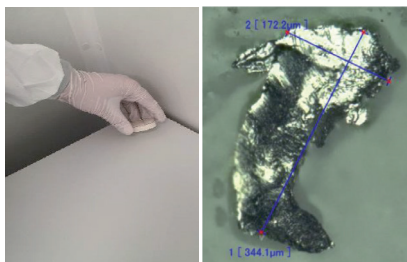


Figure 1: Stamp test and contaminating metal particles in mechanical machining.

Measurement of the degree of contamination and particulate sampling in accordance with the requirements of the ISO standards may also be carried out by means of designated measuring equipment, e.g. particle counters, for measuring the

concentration of solid aerosols in the area (Fig. 2).



Figure 2: Measurement of the environment dustiness with a particle counter.

Part of the evaluation of contamination of the environment and (internal) surfaces is sampling of contamination using particle traps (Fig. 3), and their subsequent microscopic testing to identify the particles quantities and sizes. Subsequently, it is possible to use statistical tests to determine the contamination of analysed areas or processes.



Figure 3: Particle traps.

The new VDI 19.2 standard requires the identification of the electromagnetic compatibility. Knowing this state presupposes knowing at least the state of electric and magnetic fields in the environment. The following chapter deals with low-frequency magnetic fields in detail. To date, low-frequency magnetic fields, which are gaining interest because they can be considered as a source of information about objects or processes.

#### 5. Local gradient fields in the workspace – background

If it is needed to know the technical cleanliness, it is necessary to know not only the impact of the device on the environment, but also the effect of

the environment on the device, i.e. to know the background on which the measurement is carried out. In comparison with the fields of media flow (e.g. water, air), magnetic and electric fields are different in nature. In general, it is not possible to see or feel them, and especially in the case of magnetic fields to stop them with a material barrier. Magnetic fields comparing with electronics field penetrates thru all materials.

Magnetic low-frequency fields propagate in all kinds of environment. Frequencies of up to 20 Hz are mainly used to distribute signals under water. The 50 Hz and 60 Hz frequencies are known as the industrial frequencies used to distribute electricity. In technical practice, different frequency bands are used. Natural frequencies caused by rotating, moving of machine parts create local magnetic fields, which are predominantly in dozens of Hz.

Fig. 4 shows the time development of magnetic field during the closure of a metal door of a machine tool. The movement of this door in the Earth's magnetic field created an increase in magnetic field. This signal was identified at a distance of 1,5 m from the moving door. The x direction was oriented towards the door area and the machining area, while the z direction was oriented down to the floor area. Sensors measuring magnetic field were placed in the measuring prism, and their position formed an orthogonal dextrorotary system.

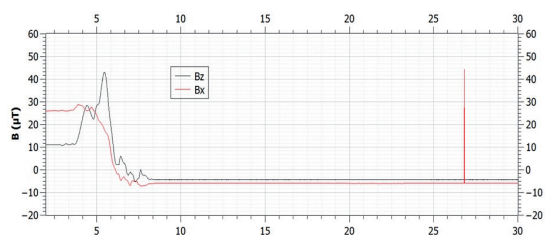


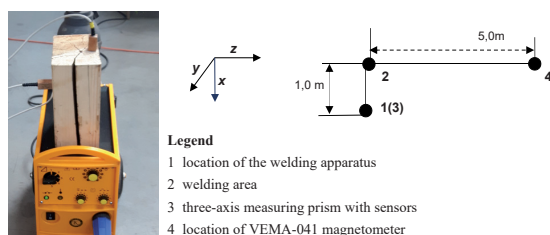
Figure 4: Recording of magnetic field during the closure of the machine tool doors.

Fig. 4 clearly indicates that the door was closed between the 3rd and 5th second. At the point of about 27 seconds, power circuits of the machine tool drives were connected. As can be seen in Fig. 4, a local magnetic field is created in the vicinity of each machine with movable, rotating elements. If the machine also has electrical elements, e.g. electric circuits, it is possible to observe the connection of circuits, or in the case of a continuous flow of electricity, also the corresponding changes in the

magnetic field.

### Welding apparatus

Mechanical engineering factories are usually equipped also with welding equipment. Welding apparatus in technical cleanliness production is measured as a source, which causes that area is not technical clean with regard on magnetic field, even if this area can be located in an immediately adjacent space. Producers publish oftentimes completely different frequency ranges of magnetic field like reality us. In the following examples, the magnetic fields which are in the vicinity of these devices are shown. It is important to understand that a magnetic field is a function of process. The location of the magnetic field source (welding machine) and the measuring prism (a wooden prism with perpendicularly located magnetic inductive sensors) is shown in Scheme 1. Measurements were made for several processes from switched-on equipment without welding to welding with the highest performance. Only selected measurements are given as an example.



Scheme 1: Location of the measuring prism on the welding apparatus.

### Measurement of magnetic field when welding machine is switched on

The measured magnetic field values in the x direction were 850 nT/50 Hz, 200 nT/150 Hz, in the y direction: 350 nT/50 Hz, 80 nT/150 Hz, and in the z direction: 120 nT/50 Hz, 50 nT/150 Hz.

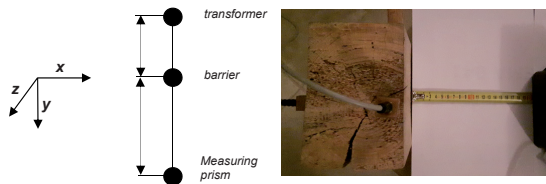
### Measurements during welding were carried out in a similar manner

In the area of welder's head, at the welding current of 70A, a characteristic frequency below 10Hz was measured in all directions. In the process of DFFT analyses, a variety of frequencies below 50Hz were found in the frequency spectrum. A steady harmonic frequency of 100Hz in all spectra is excited by 1D geometry of the surrounding environment (cables). The maximum values measured in the x direction were 5 000 nT/6 Hz, 5 000 nT/100 Hz, in

the y direction: 2 800 nT/6 Hz, 2 800 nT/100 Hz and in the z direction: 1 000 nT/6 Hz, 1 000 nT/100 Hz.

#### **Engineering structures and measurement of decrease of the magnetic field B**

The source was an Epson M34PB transformer with the following parameters: input - 230V/50Hz, 0.2A, output – 33V/1A. It is a sample of transformer used for powering printers. Our task was to verify the decrease in the value of the low-frequency field (Scheme 2).



**Scheme 2: Measurement of attenuation using different materials.**

Table 1 shows the percentage of magnetic fields decrease for individual directions and distances from the source.

Table 1 clearly indicates that the magnetic field drop of the source is observed within 20 cm.

As can be seen from the experiments, there are enough sources in the environment with the potential to influence manufacturing. In precision manufacturing, in which a clean technical environment is required, it is possible to measure this kind of fields and quantify their changes with regard to the dynamics of the surrounding processes.

## **6. Technical cleanliness audit – a technical cleanliness management tool**

Technical cleanliness has an impact on the economic aspects from the point of view of customer complaints due to the non-functioning of the contaminated product. It is important to realize that technical cleanliness has to be seen as one whole unit in the manufacturing process – a

unit which ensures a bearable limit of acceptable environmental contamination. The requirements for acceptable contamination of the technical environment are determined by the customer and can be identified in manufacturing drawings of each component, e.g. in the form of maximum permissible mass of contaminating particles obtained from a number of components, which were subject to a technical cleanliness analysis in accordance with the VDA 19.2 standard.

Audit evaluation method – through elaborated software Soft-TC [7], it is possible to independently and impartially assess the probability of the level of contamination directly in practice, where part of the output includes photo-documentation of the tested areas. Characteristic outputs are the areas in which technical cleanliness is assessed according to the VDI 19.2 standard (Table 2).

**Table 2: Evaluation of the area according to the VDI 19.2 standard requirements.**

Area	conformity %	Non-conformity %	Notes
Quality assurance	60	40	-
Environment	20	80	-
Component cleaning	45	55	-
Staff	38	62	-
Logistics	30	70	-
Assembly devices	62	38	-
Electromagnetic fields	-	-	applied in case of the VDA 19.2 valid from 2020/21
Contamination probability 75,2%			

## **7. Conclusion**

Technical cleanliness, in accordance with the new requirements of VDI 19.2, also requires knowledge of field characteristics of the magnetic and electric fields. If precision manufacturing is required, it is necessary to know the rate of change and the direction of the field in addition to the limit field values. It is similar to the air flow, in case

**Table 1: Percentage decrease of field.**

Direction	Background [μT]	Value of magnetic fields [μT] / distance [cm]							
		0	% change	10	% change	20	% change	30	% change
X	7,9604	9,73	22,22	10,75	35,07	10,37	30,22	10,63	33,49
Y	-41,4366	-40,71	1,75	-39,75	4,07	-39,73	4,11	-39,96	3,56
Z	-19,9601	-19,08	4,39	-17,33	13,20	-17,34	13,11	-17,31	13,28
Total	46,6747	46,00	1,44	44,68	4,28	44,58	4,50	44,83	3,96

of which not only the direction but also the rate of change and gust wind is decisive.

Performing cleanliness audits and technical cleanliness analysis in accordance with VDA and ISO standards brings new stimuli to technical cleanliness, which should contribute to the improvement of the current state of the particular issue in the organization. These can be system, organizational or technical improvements as well as reduction of the cost of complaints and measures related to the failure of complex systems.

With consideration to time and technical equipment has been shown measuring of the magnetic field.

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