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Purity as a System Parameter

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During long periods of human history the concept of purity and cleanliness has been used in an absolute sense. The designation "pure" has always meant the maximum conceivable purity, in marked contrast to the experience of "impurity" in everyday life. In former times there was a clear analogy to the „purity of Heaven" in contrast to „earthly dirt" (Franz Kafka, Letters to Milena Jesenská).

The conception of purity however changed with increasing scientific knowledge and with the possibility to detect material-bound contaminants with technical instruments. This particularly applies to the microscope, which was introduced at the beginning of the 17th century by several inventors, including Gallileo Gallilei.

The concept of purity and cleanliness

This essay is based on the idea that for every purity-dependent system there is an optimum purity that at the same time characterises the optimal economics of the system (see fig. 1). Purity is therefore (in the sense of this essay) the degree of contamination that would impair the functionality of the system if it were slightly exceeded. This likewise applies to sociological, biological, ecological and technological systems.

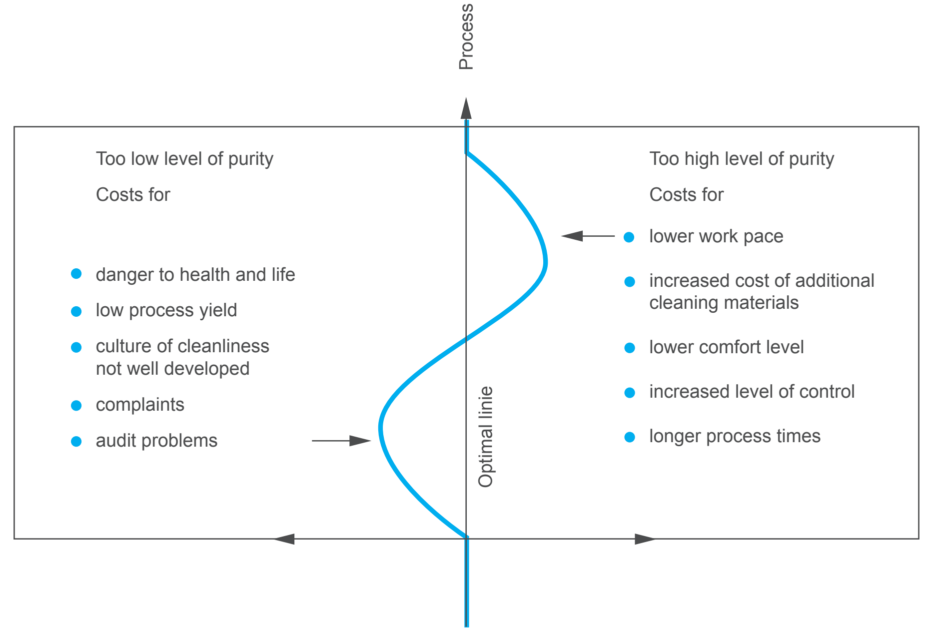

Fig. 1 In every process dependent on specific purity criteria there is an optimal level of purity. Deviations from this always increase the production costs. Table 1 shows the various types of costs that arise due to a too high or too low level of purity.

Fig. 2 Ignaz Philipp Semmelweis, copperplate engraving by Jenő Doby, 1860

The word purity is ambiguous in our language. In childhood, the bothersome personal hygiene is associated with it; later purity is associated with the sexual abstinence of the young girl. For the believers of different religions, spiritual purity is achieved through ritual baths or ablutions before prayer. The consumer is familiar with the term "purity" through the detergent advertising of the chemical companies. If you enter the word "purity" in the Google search engine on the Internet, about half of the search results refer to spiritual purity and the other half to phenomena of technical purity. In the technical era towards the end of the 19th century, people first became confronted with the necessity for hygiene and cleanliness when they became aware that certain contaminants could cause life-threatening diseases and epidemics. A significant event in this context was the discovery in 1847 by the Hungarian gynaecologist Ignaz Philipp Semmelweis (fig. 2) that biological contaminants (fig. 3) caused childbed fever. He is so-to-speak the father of Contamination Control. The hand washing measures he developed for attendant physicians reduced the mortality rate due to childbed fever in his hospital to 1%, whereas previously up to 12% of women who had given birth died from it.

With the spread of industrialisation, science and technology were increasingly faced with the problem of chemical purity. Here purity is a term for characteristics of chemical substances with respect to the contaminant content, which strongly influenced their possibilities for use. In chemistry various grades of purity are distinguished, such as raw, technical, pure, ultra-pure, chemically pure and analytically pure.

Pure manufacturing processes – new contaminants

In the second half of the 20th century surface cleanliness became the essential prerequisite for several modern manufacturing processes. These include e.g. the production of vaccines, artificial hip joints, tempered optical lenses, integrated semiconductor circuits, recording media, storage disks, or the provision of ultrapure receptacles for chemical substances. But also in the maintenance of equipment and devices, surface cleanliness is often an essential system component. Good examples for this are the maintenance cleaning of deflection mirrors for laser equipment and the etching chambers in plasma etching machines. Under current requirements, the above-mentioned products can only be produced in an environment characterised by both a high surface purity and high purity of the ambient air. On the basis of these increased purity requirements, cleanroom technology came into being at the end of the 20th century.

At the beginning of the 21st century, cleanroom technology came to include nanoparticles, single ions or molecules, which have gained in significance as potential contaminants in modern manufacturing processes. Here a considerable need for research has arisen because the removal of such materials from surfaces has not yet been adequately secured.

Abb. 3 Bacterial contaminant (Streptococcus pyogenes), cause of child bed feve

Accompanying this development, the technical standardisation organisations focused on the problems of purity and described the requirements for cleanroom workplaces and products in labour policies, which give the engineer good guidelines for the techniques of cleanroom work. In Germany this took place through the activities of the Association of German Engineers (VDI), which provided much valuable information in its Guideline VDI 2083.

However, cleanliness in the context of the new technologies is not only a material-oriented parameter of many technical and biological systems. It can also refer to matter-free contaminants such as electric and magnetic fields, ions or ionising radiation. These „contaminants" may also influence the functionality of systems, and thus matter-free contamination is steadily gaining industrial importance. One example is the phenomenon of electrostatic discharges (ESD), which already today have significant effects on technical production.
In recent decades, many industrial cleaning tasks which were previously performed manually have been automated. Examples are cleaning processes in sheet glass production, in mass-produced precision-engineered parts, in the cleaning of PCBs and the cleaning of glass surfaces in precision optics. In the areas of plant and equipment maintenance, however, cleaning-by-wiping procedures are more established than ever. Worldwide, the market for cleaning wipers has developed into more than a billion dollar business. Research into the effectiveness of various textile constructions of cleaning wipers and into the required cleaning times of various types of surfaces and contaminants is still in its infancy.

How clean is a surface?

To do justice to the phenomenon of technical cleanliness, a distinction should be made between purity of the cleaning media and the cleanliness of the surface. Whereas measuring the purity of liquids and gases has become largely automated due to analytical methods on the one hand and particle counters and analysers on the other hand, the practical measurement of surface cleanliness is still limited to visual inspections, estimations and projections or to surfaces with small dimensions. This is basically due to inadequate measurement technology. The reason for this is the seemingly enormous difference for example between a technical surface of one square meter relative to a particle size of 0.5 µm. If such particles were laid next to each other to cover a square meter of surface, there would be 4 billion particles on the surface. In reality, however, as measured in this example, there are only relative few particles present on the surfaces. To detect the exact quantity using measurement technology, researchers would need the microscopic view of about 44 million frames which would have to be evaluated microscopically to gain reliable information about the particles covering a surface. In practice, this is not possible, and thus a variety of methods have been presented which, however, already lose their meaningfulness e.g. for

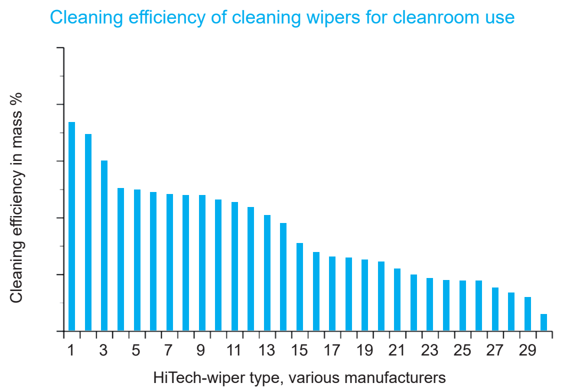

Fig. 4 shows the measured cleaning efficiency of a representative spectrum of internationally known manufacturers

surfaces with low surface roughness. In practice, there is a number of misconceptions and company statements abound on the subject of surface cleanliness. These are often closer to mere presumptions than based on facts, and they refer both to the touted measuring devices as well as to the quality of use of the industrial products that were designed to bring about the desired surface cleanliness. These are primarily the cleaning-by-wiping media in roll or wiper form. In this context, fig. 4 shows the measured cleaning efficiency of a representative spectrum of precision cleaning wipers of internationally known manufacturers. The considerable difference between the most and least efficient wiper is reflected in the state of uncertainty of both the supplier and the user. This state is also reflected in the American test recommendations for cleaning in cleanrooms. In an extensive expert review, the DTNW Textile Research Centre, an institute at the University of Duisburg, advises against following the recommendations of the American national standards institutes IES and ASTM as a basis for assessing the performance characteristics of cleaning wipers for use in cleanrooms.

Surface cleanliness as a system parameter

If we consider the maintenance of a laser cutting system for steel plates (see fig. 5 and fig. 6), our cleanliness-related parameter is the continuity of surface cleanliness of the laser mirrors. If the mirror contamination exceeds a certain level, first the cutting width of the laser beam changes due to the altered beam focussing properties, and later a catastrophic failure occurs. The mirrors burn up due to the increased heat absorption. This in turn causes a system failure, and the mirrors must be replaced. Thus, in this case, cleanliness is an important system parameter that impacts the continuity of the plant operation. A preventive strategy would be the regular maintenance of the mirrors (fig. 7). This would inevitably lead to a planned machine downtime depending on the cleaning time. The cleaning time, however, is directly dependent on the material quality of the cleaning media.

In the analogy of a control loop, the surface cleanliness would be the control variable here, and the gradual contamination of the mirrors would be the disturbance factor. What is missing in this control loop system is a sensor for the surface purity and as actuator a cleaning device, which depending on the measured degree of contamination automatically initiates a cleaning procedure. In practice, however, this disturbance factor is anticipated and prevented by manual, preventive machine maintenance. This takes place at set intervals which - based on experience - ensure that the faulty condition remains under the threshold of catastrophic system failure.

For some purity-bound production systems, the control or regulation loop does not work for the following reasons: If a set point deviation is recognisable, the damage to the process is no longer avoidable: This applies for example to the plasma etching process in the systems of semiconductor production: If in the etching chambers sufficiently thick contamination layers have formed, more or less large parts of these fall on the wafer found in the etching process. Thus, the wafer would be completely or partially destroyed. Up to the end of the process wafers are so-called partially finished products. The manufacturing process takes place in over 200 process steps over a period of about 4-8 weeks. If a wafer with several hundred chips is destroyed at any time, this also involves the destruction of the material value of the wafer including the value of the partial production up to the time point of the destruction.

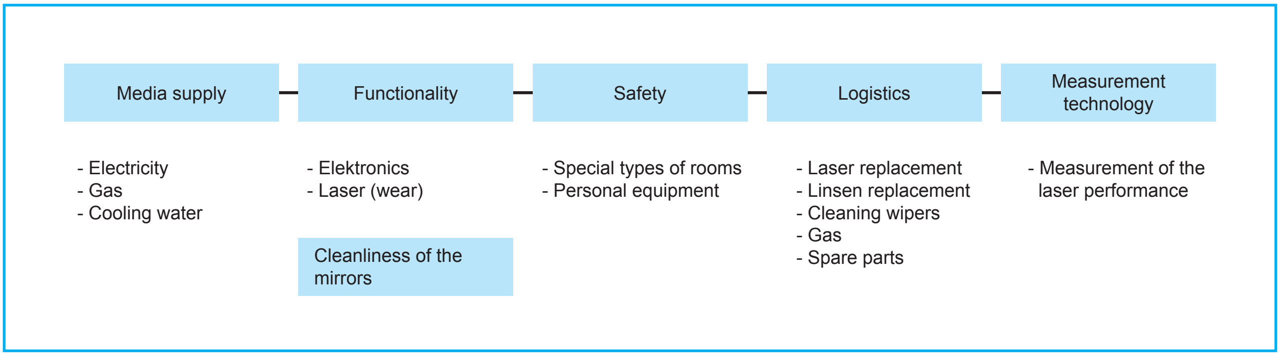

Fig. 5 System parameter to maintain continuous operational readiness of a laser cutting system for sheet metal

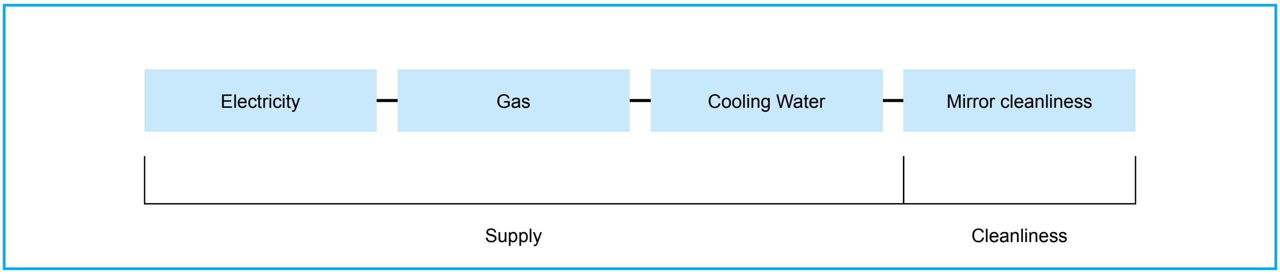

Fig. 6 Function parameters to maintain the laser cutting system for sheet metal

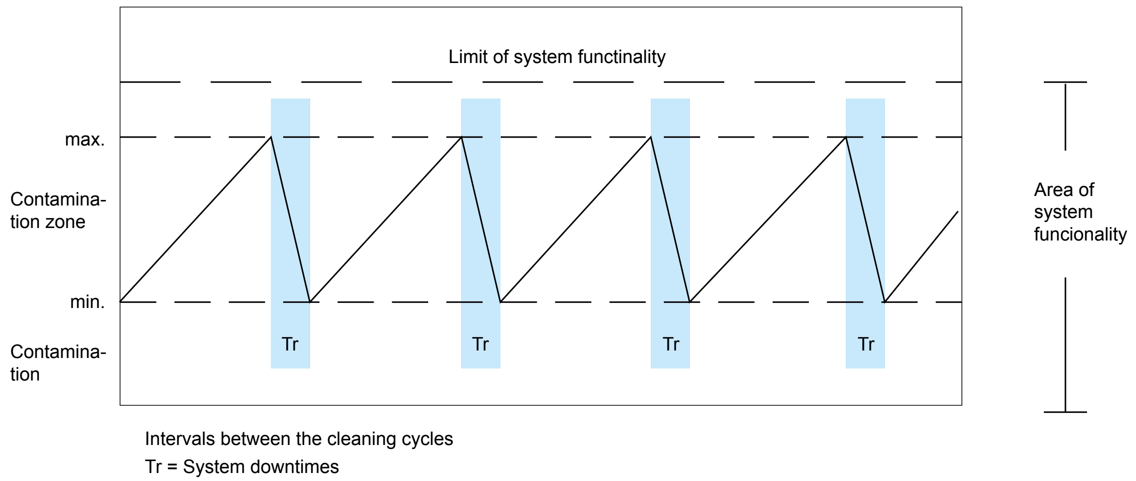

Abb. 7 Prevention strategy through coordinated cleaning intervals

The example clearly shows that not all cleaning-related processes can be automated in an economical manner and that manual cleaning procedures can have their place. However, such procedures have a comparatively high cost. This is due to:

- the labour costs of maintenance
- the application-related efficiency of the cleaning media
- the duration of the machine downtime

Homework for users and suppliers

If the untapped potential of manual cleaning procedures and their indirect costs are to be determined, specific comparative tests are required. To provide statistically relevant and robust information, a large number of cleaning procedures must be performed and various cleaning media must be used. Tests should therefore be planned on an appropriate scale and clearly documented. In our experience, such extensive tests are not overly popular with the maintenance staff, which is why it makes sense to adequately prepare for such a test and to instruct and motivate the maintenance staff. However, this alone is not enough. Such testing should not take place without the involvement of well-known manufacturers of cleaning media, because the user may not be familiar with all of the details regarding their proper application. An example for this is the hopeless oversaturation of cleaning media with solvents during cleaning until there is no longer any cleaning effect. This means that before beginning such a test, the application of solvents needs to be specified and training in their application needs to be provided. Otherwise, the obtained

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results may not be significant. The same applies to precision cleaning wipers, which must be properly folded according to the manufacturer's instructions prior to each use. The training level of the maintenance staff with regard to the application of the cleaning media is a crucial prerequisite for proper and cost-reducing maintenance. In semiconductor production it is possible to carry out the suggested test in conjunction with the maintenance of the plasma etching machines. This would appear to be a good option because in any case a log is kept about the downtimes of these systems, and thus it is possible to compare the downtimes following the use of different media.

The system to maintain the operational readiness reacts in various ways to the manual cleaning procedures, which here are among the system parameters that incur the most costs. How the system reacts under the various conditions must be explored. Conversely, however, an important point should not be neglected: If it must be assumed that system functionality is dependent on the functional properties of the cleaning media and at the same time no worldwide agreement can be achieved in the near future about the test methods for these media, there is a danger that market forces will prevail over the forces of reason. In the end, through downgrading, a slight reduction in material costs will be offset by a marked increase in production costs – and this will often occur without being noticed.

Last but not least, it must be the task of all manufacturers of cleaning media to specify the key parameters such as cleaning efficiency and particle attrition on the basis of meaningful test methods. Otherwise, if this does not happen soon, the standardisation bodies must develop a DIN-ISO standard for this.

Conclusion

- Media for manual cleaning procedures influence the maintenance-related downtime of a system
- During system downtime, the system does not produce any profit per unit time
- For cleaning media, the balance must be weighed between their material price and the potential shortening of system downtimes through their use
- The material price of cleaning materials can be viewed from two perspectives: These are:

  a - the measurable shortening of downtime

  (or, if the downtime is unchanged,)

  b - the lower consumption of cleaning media
- The level of knowledge in the industry about the process and the economic potential of manual cleaning procedures is too low. Corresponding studies should be carried out.
- Slight reductions in material costs for products can have a significant effect on the downtimes of the systems and thus lead to significantly higher production costs, without this being noticed.

> ***Cleanliness is the degree of contamination which if slightly exceeded would impair the functionality of a system.***

Translation: Carol Oberschmidt