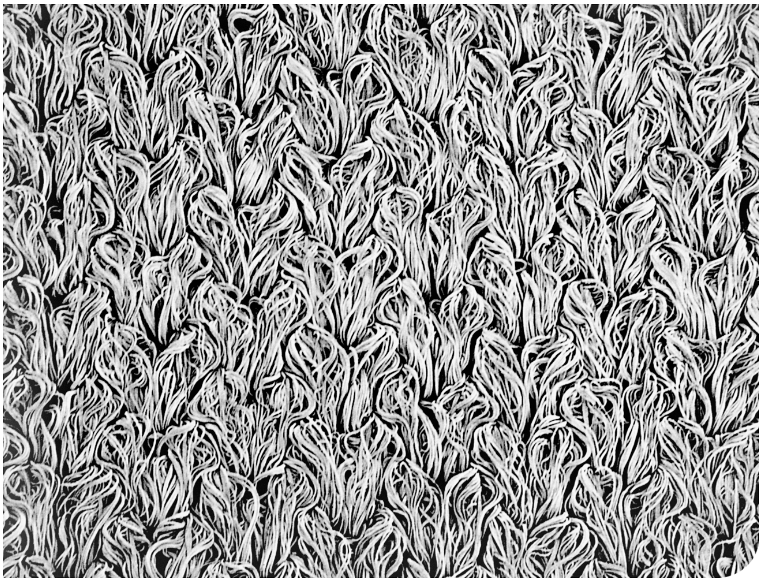

This essay describes a test method and a device for carrying out a standardised cleaning procedure with which precision cleaning wipers of different manufacturers and designs can be tested both as to their specific cleaning time for a specified standard contamination and as to their maximal cleaning performance. The test results allow the production engineer to optimise the cleaning wipers used in production operations with respect to cleaning time and cleaning performance.

Time Requirements and Surface Cleanliness in Wiper-Based Cleaning Procedures

A test method for determining the specific cleaning time of precision cleaning wipers

Win Labuda
Clear & Clean - Forschungslabor

Introduction

A not inconsiderable share of the cleaning of industrial surfaces, components, and devices is done by means of wiping procedures. For this purpose, cleaning wipers of various design and quality are used. Clean working techniques are increasingly being applied in the high-tech sectors of optics, microsystems technology, semiconductor technology, pharmaceuticals, biotechnology, implant production, display technology and lacquer and adhesives technology. That means the finished products must manifest a high degree of surface cleanliness during the production process in order to function faultlessly in their finished condition. Such products are usually manufactured in cleanrooms, clean chambers or clean work zones. The cleaning wipers used in these clean working techniques should be designed so that the highest possible degree of cleanliness of the surfaces can be achieved in as short a time as possible.

During a wiper-based cleaning procedure small amounts of the material contents of the cleaning wiper are transferred to the cleaned surface. These include particles, fibre fragments, tenside residues, knitting and spinning oil residues and also chemical residues from the textile production. Depending on the degree of cleanliness demanded, however, even the smallest amounts of contamination transferred from the cleaning wiper have an unacceptably detrimental impact on the desired surface cleanliness of the production component. We must therefore assume that even after a cleaning procedure, no surface will be absolutely clean. For that reason there is a need to know and qualitatively define the remaining contamination after a cleaning procedure. To draw a distinction to industry and household cleaning wipers – in which leaving residues of wiper contents on the cleaned surface is not critical – we thus refer to the wipers used in clean work processes as precision cleaning wipers

The economics of wiper-based cleaning

An essential parameter of every cleaning procedure is the average time needed per cleaning wiper used (cleaning time). This has high economic significance in particular for large-scale industrial users of cleaning wipers. For instance, a large company in the semiconductor sector uses about 10 million cleaning wipers annually. When the time for provision and access, dispensing, moistening and disposal is included, the duration of use for a cleaning wiper is estimated to be between 20 to 40 seconds. That adds up to a total work time with precision cleaning wipers to between 55 500 and 111 000 work hours per year. If we calculate workplace costs to be 50 euros per working hour, this amounts to cleaning costs of 2.75 – 5.5 million euros annually. By contrast, the material cost of each cleaning wiper used is on average only about 0.12 cents. This results in an additional 1.2 million euros for material costs. Thus the total cost for wiper-based cleaning amounts to between 2.95 and 6.7 million euros. In view of these figures it is meaningful to learn to understand the mechanisms of wiper-based cleaning and to promote the development of highly efficient cleaning wipers to ensure cleaning times that are closer to 50 000 than to 110 000 hours. This can be achieved by optimally adapting

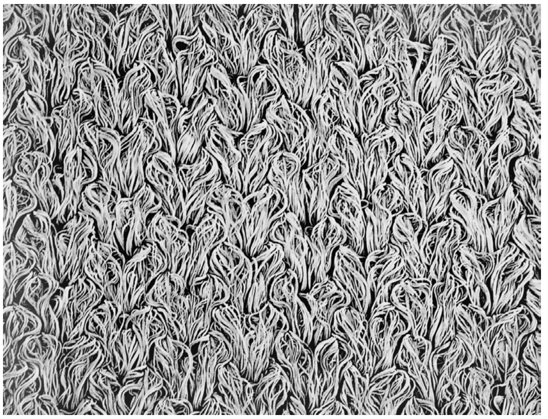

Fig. 1 Ultrafine knit Microweb UD-G

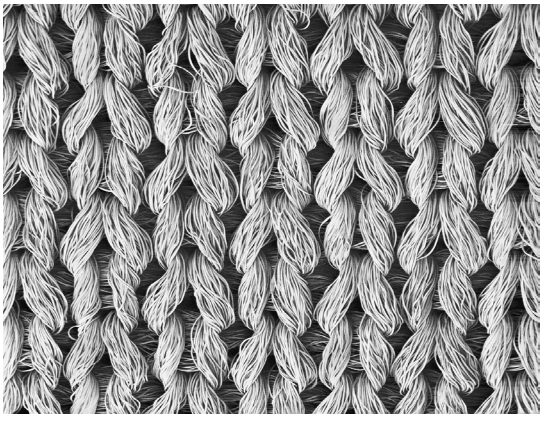

Fig. 2 Fine knit Sonit MD-M

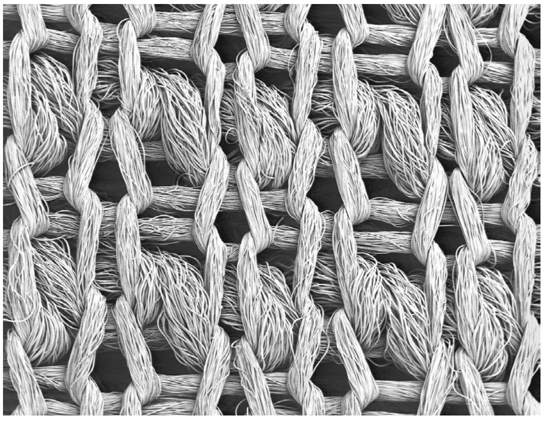

Fig. 3 Coarse knit Sibis GD-U

the use characteristics of the precision wipers to the cleaning task. The images in Figures 1, 2 and 3 show the different surface structures of various precision cleaning wipers viewed through an electron microscope. The differences in cleaning performance can already be inferred from these differences in structure. Regrettably, only a small portion of the big companies that use cleaning wipers are aware of these problems. The reason lies in their lacking willingness to systematically investigate the procedures of wiper-based cleaning according to Refa criteria and their reluctance to systematically shorten the cleaning times on the basis of the knowledge gained.

Fig. 4 KONTAVISOR laser fluorescencel detection system (Systektum GmbH)

Determination of the contaminant mass by means of laser fluorescence

In view of the described situation it makes sense to have an instrument at hand with which cleaning performance of the different cleaning wipers can be measured without spending a lot of time and effort. A method is needed with which the mass of contamination present on the surfaces can be measured quasi-continually in short measuring intervals. Laser-induced fluorescence spectroscopy (LIFS) offers this possibility. Laser-induced fluorescence is a physical phenomenon with the aid of which the mass of hydrocarbons, for instance in the form of oil or grease layers, can be measured down to the mass of just a few molecule layers. In this method, the contamination found on the surface is excited by a UV microchip laser in the spectral range at excitation wavelengths of 266 or 355 nm to emit light. The fluorescence then takes place in a spectral range of 405 nm. The intensity of the fluorescence is measured with the aid of a secondary electron multiplier and is roughly identical in mass to the aliphatic hydrocarbon portion of an applicable oil or grease-like material mass. Aliphatic hydrocarbons are – complementary to the aromatic hydrocarbons – non-polar hydrocarbons with lypophilic behaviour. Therefore if the fluorescing portion of a material compound is known, then on principle the total mass of the compound can be concluded from this. A group of scientists, formerly of the University of Kiel, has implemented the method in a practical device, which is sold under the industrial name Kontavisor™ (see Fig. 4) by Systektum GmbH, a company in Flensburg. This device appears to be especially suited to determining the mass of contamination layers on surfaces that contain hydrocarbons. The measuring time of the Kontavisor device is on average 1 second per measurement. Because this device is easier-to-use and faster than previous methods such as ellipsometry or microgravimetry, we can now, in principle, investigate different aspects of the cleaning-by-wiping procedure – testing different wipers, different structured surfaces, immersion of the wiper into different solvents and different cleaning times – all without spending the time and effort that used to be required. This has become possible by combining the Kontavisor method with the TIMEPORT – Cleaning Time Test Device, which was developed by the author and is presented here for the first time.

A suitable standard contamination

The method described above can be used for determining the efficiency of cleaning procedures and thus also the cleaning performance (quality) of precision cleaning wipers. The cleaning performance is calculated from the difference between the contaminant mass which has been applied to a test surface and the contaminant mass still present on the surface after a specified cleaning procedure. Critics of the method will first object that the described standard contamination can only be one of many possible contaminations. But it would be a mistake to assume that a contamination of technical surfaces e.g. would only exist from particles. This would presume that a surface of ideal cleanliness exists which is exclusively contaminated by the presence of particles. Experience shows, however, that the majority of contaminations in the production environment of high-tech industries mainly consist of a mixture of thin organic matter – layers and particles. As quintessential, practice-relevant contaminant mass we must therefore assume a thin-layered grease from process residues, atmospheric deposits, solvent residues from previous cleaning procedures and particle deposits. As practical substitute useful for measuring the different kinds of thin-layered grease, a medium viscous oil can be used, to which a small amount of tenside and a certain percentage of mass of a particle mixture has been added. When mixing this preparation, care must be taken

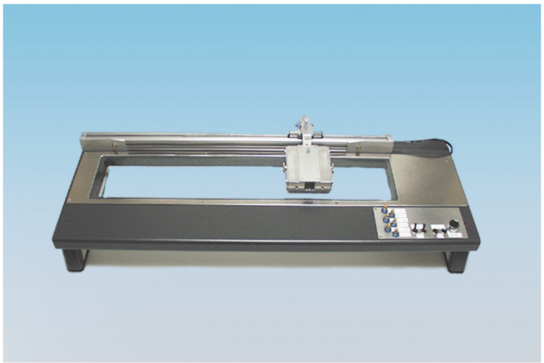

Fig. 5 Test device Labuda Linear Wiping Simulato Mark II

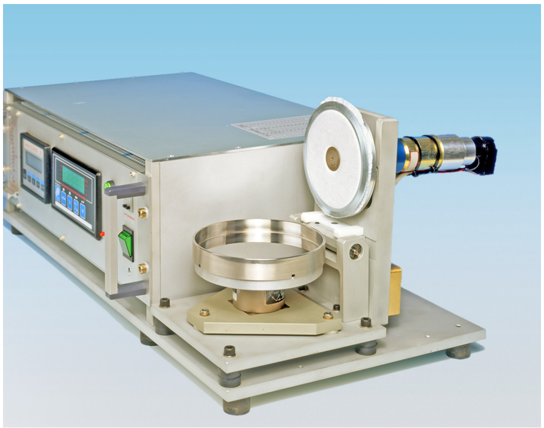

Fig. 6 Test device Labuda RotationWiping Simulator Mark II

that the mixture is homogenous and, if excited in the wavelength range between 266 or 355 nm, that the mixture fluoresces sufficiently.

To determine the cleaning performance of precision cleaning wipers on different surfaces, a possibility must first be found to apply always the same mass amount, e.g. of a fluorescent oil of the type RS-0W40, (here in the above mentioned preparation as FLUOROL), two-dimensionally to the test surface. Here it must merely be ensured that the application amount is within the set measuring limits of the Kontavisor device and that it always remains the same within the statistical limits. Using the well-known Labuda Rotation Wiping Simulator or the Labuda Linear Wiping Simulator, the above mentioned FLUOROL layer applied to the test surface can be removed by wiping under controlled conditions. Thus, the cleaning performance of the wiper can be determined in percentage of the applied contaminant mass.

The wiping simulators allow any wiper to be clamped, and the settings for the parameters wiping path, wiping speed and pressure can be varied. Moreover, parts of the metal plates on which the tests are to be made can be exchanged. In this way, for instance, test surfaces with different degrees of roughness can be used. From the data thus determined concerning the cleaning performance, the following findings can be gained:

- The duration of the cleaning procedure when using a specific wiper up to a predefined degree of cleanliness
- The cleaning performance in % (efficiency) of a specific cleaning wiper in a predefined cleaning time or the maximal cleaning performance of a specific wiper;
- The cleaning performance of wipers when using different solvents (in %)

The gained information is dependent on the following variables, which clearly contribute to the measuring results and which therefore may not be changed within a test series:

- Roughness Rz of the test surface according to DIN

- Saturation extent of the wiper with solvents (in %)
- Kind of solvent, e.g. acetone, benzine, DI water etc.
- Viscosity of the fluorescent oil (in cSt)
- Number of layers of the wiper in the cleaning procedure
- Number of wiping movements of the wiper
- Velocity of the wiping movements
- Vertical pressure on the wiper during the test
- Number of wiping movements of the wiper before and after changing the location where the wiper is used

This list of variables is possibly not yet complete and may have to be supplemented in the course of work on the project. The main advantage of laser-induced fluorescence spectroscopy during use of the Labuda Rotation and Linear Wiping Simulators for determining surface cleanliness is the brief measuring time of the method. Only through this has it become possible to determine the value of different factors influencing the test results and to gain fundamental new insights for the techniques of cleaning by wiping.

Labuda Timeport™ Test Device Measuring the specific cleaning time

The previously mentioned test methods with the Labuda Wiping Simulators work according to a discontinuous working principle, which does not allow showing the continuous decrement of the contaminant mass on a surface during the cleaning procedure. The challenge was thus to invent a method and appropriate instrument which would enable the determination of the specific cleaning time for different precision cleaning wipers on the basis of the standard FLUOROL contamination and defined mechanical stress for each precision cleaning wiper. The schematic diagram in Fig. 7 shows the construction principle, which is explained below:

The FLUOROL is applied to a rotating steel roller which has a groove approximately 10 mm wide and 20 µm deep. With the aid of a suitable metal coating blade the FUOROL is then pressed into the groove. The floor of the groove may be polished or alternatively provided with a predefined roughness. Next, a cleaning wiper (sample) is placed around the steel roller, which due to the construction has a contact angle of 90°. The wiper is attached above the roller to the spindle of a feed shaft motor. The other side of the wiper is weighted down with a weight of 1000 g. When the roller with the oil layer begins to rotate, the feed shaft motor pulls the wiper in the opposite direction of the roller rotation. In this way the continual feed of non-contaminated wiper material is ensured. From a simulation aspect, this process corresponds to turning over the wiper during cleaning when parts of the surfaces have already been used and contaminated and thus only have little cleaning effect.

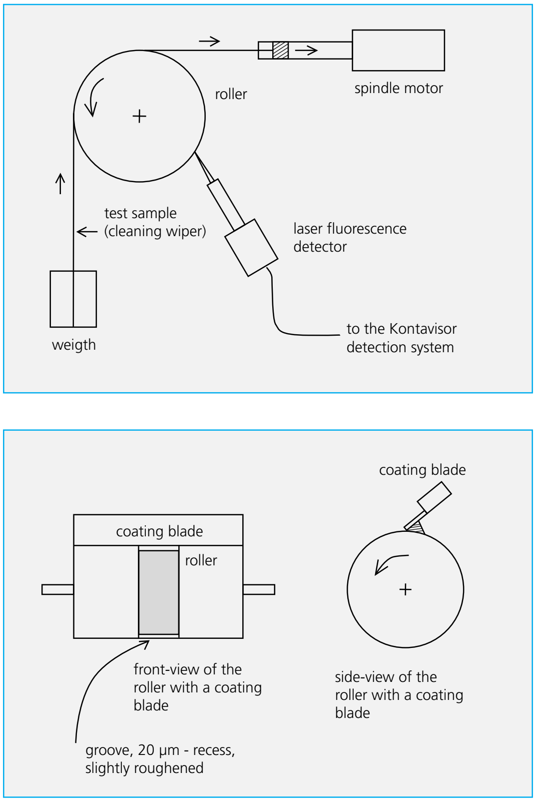

Fig. 7 Schematic diagram of the cleaning time test device Labuda Timeport™

Whilst the contamination of the roller is continually taken up by the wiper, the layer thickness of the contamination diminishes. The remaining layer thickness of the contamination is continually measured with a laser fluorescence detector and displayed on the KONTAVISOR device.

At the beginning of the measurement the diagram (Fig. 8) shows a high contamination thickness with FLUOROL, which then diminishes more and more during the cleaning. The number of seconds needed to achieve the 10 % time mark of the contamination – defined as the "specific cleaning time" – becomes the essential parameter of a cleaning wiper. However, this parameter only refers to precision cleaning procedures. (cleaning off of thin contamination layers of surfaces with a small degree of roughness, 0.... 20 mm Rz). It must also be noted that the displayed diagram refers to the cleaning procedure with dry wipers. With presaturated cleaning wipers the cleaning times are – as expected – much shorter. Additional tests will enable deeper insights into the differences in the cleaning-off times between solvent-saturated and dry wipers, in particular when considering rough surfaces

Illustration of how the TIMEPORT – test device functions

The initial position can be deduced from Fig. 9. The test sample (cleaning wiper) is found between the gripping jaws of the clamping lever S and the weight G. After the FLUOROL has been evenly applied to the roller W by the coating blade R, the clamping lever S is placed in 90° position. The test sample is thereby wrapped around the roller in the surface area

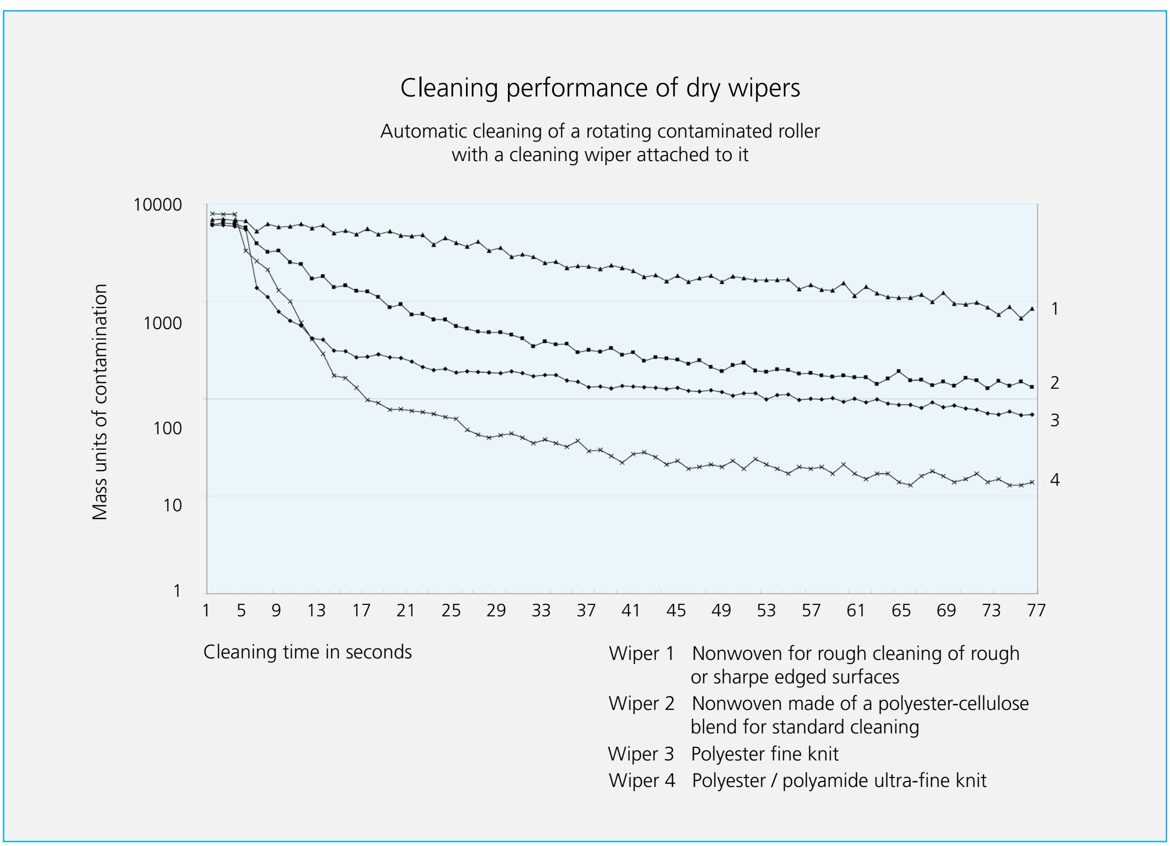

Fig. 8 Diagram

corresponding to a quadrant (90°) and the cleaning off of the FLUOROL begins (Fig. 10). Then the spindle motor S pulls the test sample in the direction counter to the rotation of the roller W to the endstop. The laser D continually detects the remaining contaminant mass on the roller and the Kontavisor device displays it. The diagram in Fig. 8 shows the results of pressing diverse precision cleaning wipers firmly against a rotating disc coated with fluorescent oil. Already in this diagram we can discern differences in cleaning performance as well as in cleaning time, which varies conspicuously from wiper to wiper. We can expect to gain much knowledge about the procedures of cleaning by wiping from the TIMEPORT test device which is now being constructed.

Fig. 9 The Labuda Fulling Simulator Mk III – Test Device (developmental status 2008)

9a) Initial position
The specimen is fixed in the upper jaw and weighted with the weight G. The roller is coated and can rotate.

9b) Operating position
The clamping lever S is brought into operating position while the oil-coated (Fluorol) drum rotates. The oil layer is removed slowly and subsequently measured.

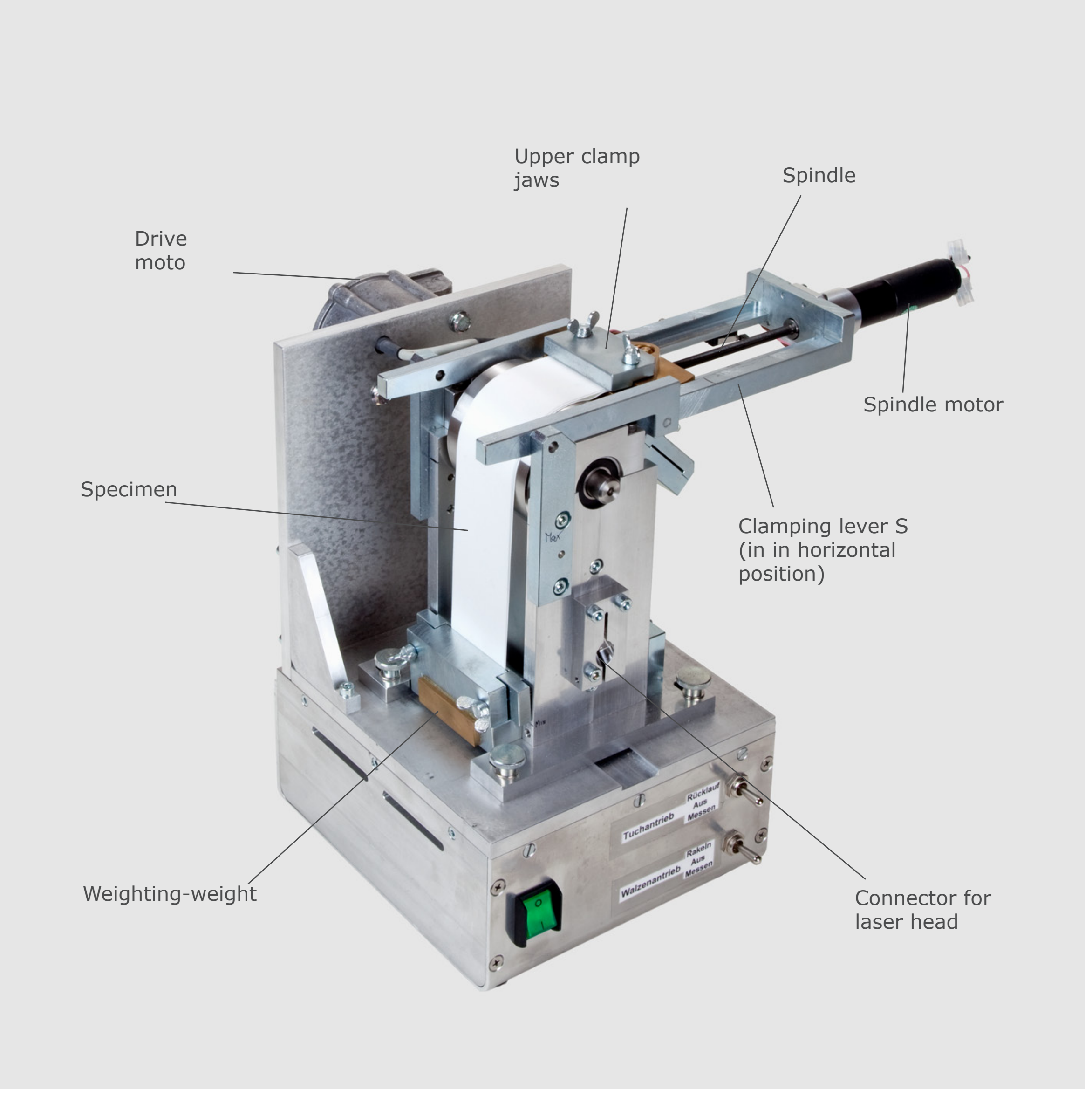

Fig. 9b (enlarged)

9b) In the enlarged Fig. 9b the essential construction elements of the Labuda Fulling Simulator Mk III can be clearly seen. The device is in the operating position. The upper clamp jaws are moved by the spindle motor in the direction of the engine block. It thus pulls the specimen over the rotating steel drum (Fig. 10b). The measurement is thus carried out while constantly feeding the material that has not already been previously contaminated.

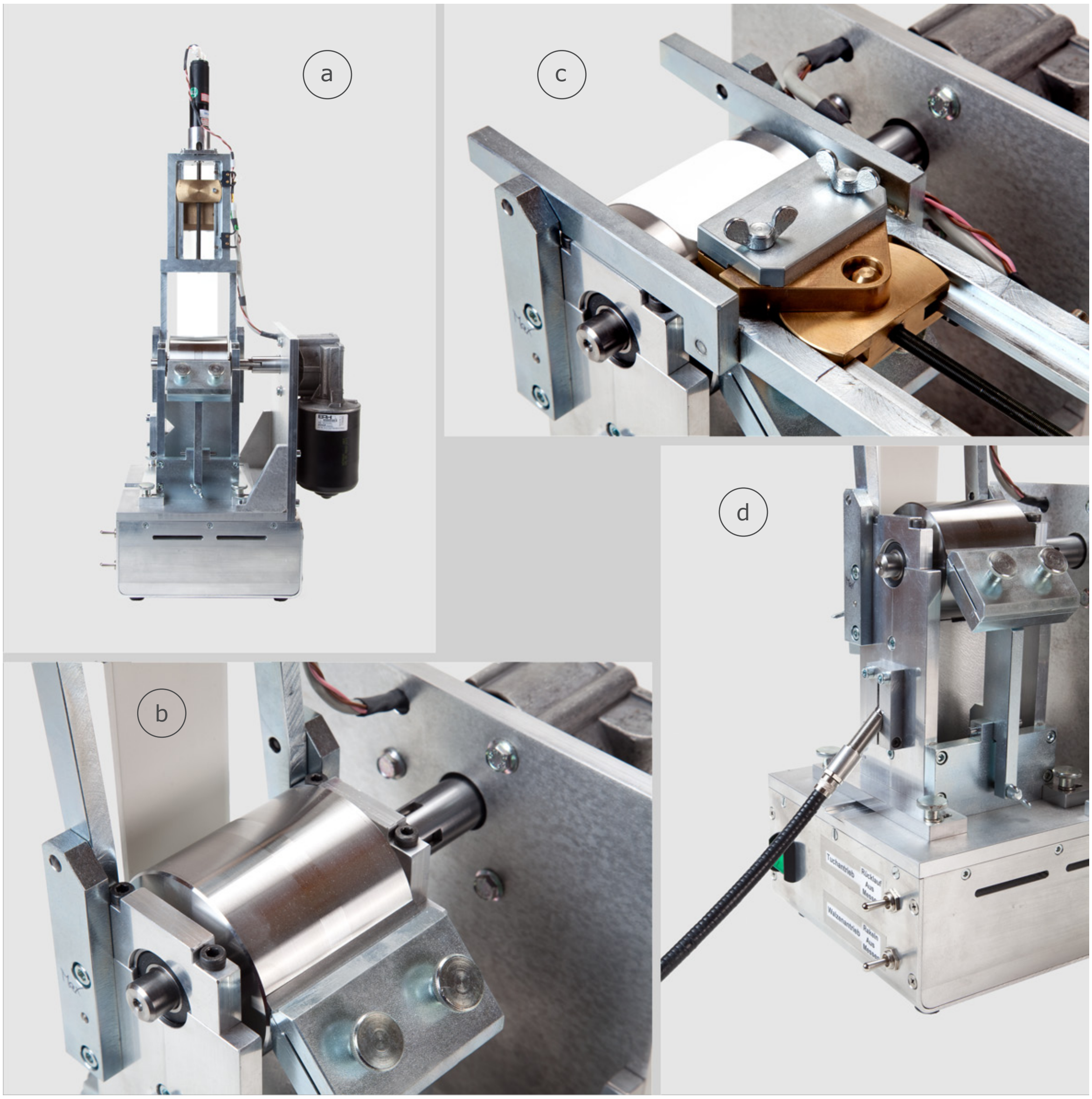

Fig. 10

a) The Labuda-Fulling Simulator Mk III in the initial position. In this state the specimen does not yet touch the applicator roller.

b) In this enlargement of the applicator roller and the test object, the levelling instrument with the steel blade can be clearly seen, which skims the grease film to the desired thickness.

c) After moving the lever S into the horizontal position, the test object encloses the applicator roller at an angle of 90°, and thus covers 25% of the applicator roller surface.

d) The fibre optic cable is introduce from the side into the designated clamping device and fixed there. The directed laser beam causes the fluorescence, the intensity of which is now measured with the Kontavisor device.

Note: This essay is the revised and supplemented text of the article published in the journal ReinRaumTechnik 2/2007 by GIT-Verlag, Darmstadt

Continuation and Part II: Time Requirements and Surface Cleanliness in Wiper-Based Cleaning Procedures

Results of this study

This essay shall demonstrate and discuss some of the test results obtained with the method described above. To obtain an overview of the general quality of fine and precision wipers available on the international market, various sealed bags with wipers were purchased from six well-known wiper manufacturers. Five wipers were taken from each bag and subjected to a test of both the parameters "specific cleaning time" and "specific cleaning efficiency" (see glossary). The measurement results were averaged and are listed in table (fig. 11 + 12).
The selected manufacturers are:

Berkshire Corp., USA
Clear & Clean GmbH, Deutschland
Contec Inc., USA
Dupont Inc., USA
ITW -Texwipe, USA
Milliken & Co., USA.

Initially, products belonging to the group of knit wipers were tested. Then the same test was performed with four nonwovens to obtain information about whether this group of cleaning wipers differs from the group of knit wipers with regard to the parameters "cleaning efficiency" and "cleaning time". (All names are brand names of the companies listed above.)

Knit wipers:

AlphaSorb10 -	Texwipe
AlphaWipe -	Texwipe
Anticon Goldsorb -	Milliken
Microseal 1200 -	Berkshire
Microweb UD-G -	Clear & Clean
Polynit -	Contec
Polynit Heatseal -	Contec
Sonit HD-M -	Clear & Clean
Super Polx 1500 -	Berkshire
White Magic -	Milliken

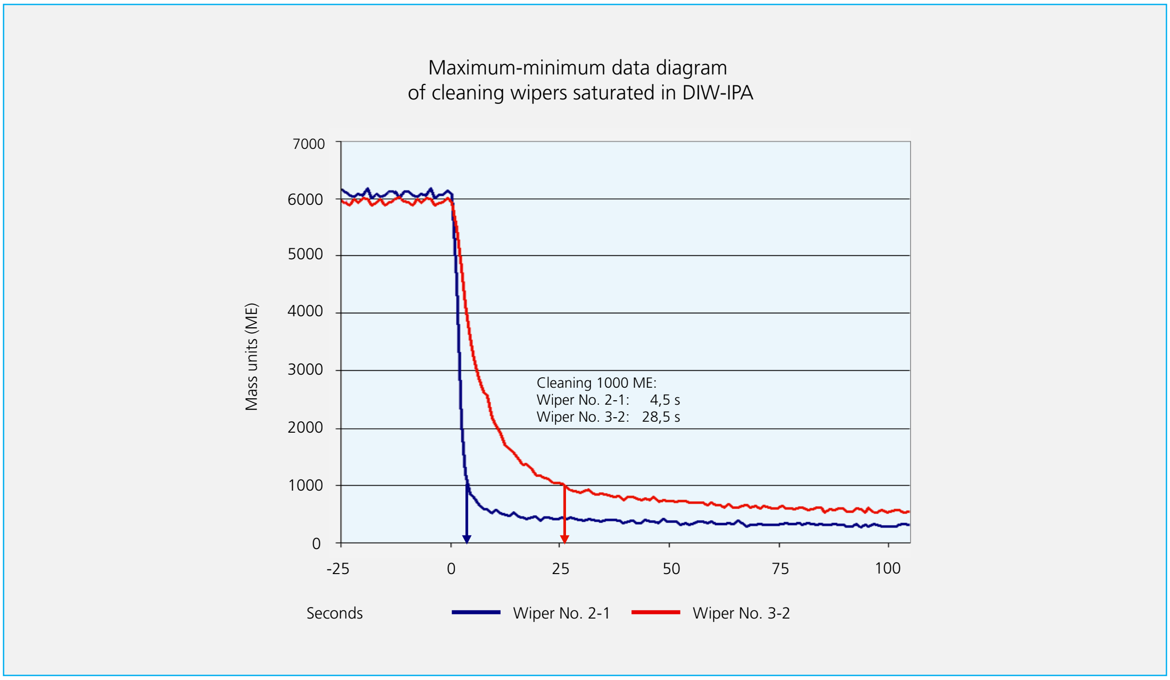

Fig. 11 Diagram: Comparison of the wiper with the highest and with the lowest specific cleaning time

Nonwoven wipers:

Drytech - Clear & Clean
Evolon - Freudenberg
Sontara - Dupont
Viscot - Clear & Clean

In the present study, all test results are shown in coded form because with this essay, the author only intends to present a workable test method and thus show a cross-section of the existing quality level of fine and precision cleaning wipers currently in use. Labelling individual manufacturers or products as "good" or "bad" had to be avoided. The results of the study are shown in the following tables, diagrams or pictures.

Measurement of cleaning time

A key finding of this study was that both the specific cleaning time within the group of the tested wipers as well as their specific cleaning efficiency vary considerably despite the same test conditions. The first fact is shown in the maximum-minimum diagram (Fig. 11). This diagram shows the cleaning/ time unit of the wiper with the shortest specific cleaning time in comparison to the wiper with the longest specific cleaning time. The measured specific cleaning times for both products are relatively far apart. While the reduction of a standard contamination by 5000 mass units took 4.5 seconds using the wiper with the code No. 2-1, the time required for the same cleaning procedure using the wiper with code No. 3-2 was 28.5 seconds. (ratio 6.3)
This proves that there are considerable differences in the cleaning wipers available on the market with regard to their cleaning effect per time unit. Ultimately, these are differences of quality that very much determine the time required for a cleaning procedure and thus the cleaning costs for the maintenance of machinery, apparatus and appliances.

Specific cleaning efficiency

In some wiper-based cleaning procedures however, the primary objective is not the reduction of the cleaning time, but the attainment of the highest possible surface cleanliness. This was taken into account in the development of the device described in this essay. It is now possible to accurately measure the mass of the contaminant residues down to the range of molecule layers. By knowing these values, it has become possible to integrate cleaning by wiping procedures into the group of the known methods of surface cleaning. Thus wiper-based cleaning, as far as methodological techniques are concerned, is hereby given its appropriate place. The lowest measured contaminant residue on the use

	A: in a dry state		B: DI-water-alcohol (70:30)		C: pure alcohol	
Cleaning wiper (product code)	Cleaning time in s for 5000 mass units	Contaminant residue in %	Cleaning time in s for 5000 mass units	Contaminant residue in %	Cleaning time in s for 5000 mass units	Contaminant residue in %
No. 1-1	11.7	6.2	6.5	5.64	80.3	11.3
No. 1-2	7.5	5.1	15.2	7.54	41.8	9.3
No. 2-1	3.2	4.6	4.5	4.24	11.8	5.5
No. 2-2	9.5	2.9	N/A	N/A	N/A	N/A
No. 3-1	22.8	7.9	15.9	8.28	71.7	10.6
No. 3-2	24.5	8	24.1	8.84	90.7	12.8
No. 4-1	3.8	4.1	5.3	5.33	28.5	7.8
No. 4-2	12.5	6.2	5.1	5.32	33.5	6.9
No. 5-1	4.2	4.3	5.3	5.96	42.5	9
No. 5-2	14.8	7.1	10.7	6.71	40.5	9.2

Fig.12 Table: specific cleaning time and maximum cleaning performance (as contaminant residue) for ten randomly selected cleaning wipers known in Germany in three different saturation states

surface after the described standard cleaning procedure is approximately 2.9% of the initial contamination for the wiper with the code number 2.2. The experiments showed that a further reduction of the contaminant mass was not possible even when the cleaning efforts were continued. One must always bear in mind that the initial contamination already has a thickness of below 4 µm. That corresponds to a mass of about 6.5 mg, which is reduced by the cleaning procedure to a value of 190 µg corresponding to the thickness of 100 nm. In the experiments, the roughness Rz of the test surface was 4 µm. Here the developers of precision cleaning wipers is given the opportunity to develop new materials and/or methods for wiper-based cleaning with the aim of further reducing the currently lowest measured contamination residue of 2.9 mass percent.

Ten wipers in a test

(Fig. 12 Tables A to C)

Ten fine and precision cleaning wipers of well known brands were initially selected for the test. All selected wipers belonged to the group of knits. For those the specific cleaning time and the cleaning efficiency were measured using the Labuda Fulling Simulator Mk III-test unit described in Part I of this essay. The specific cleaning time was assumed to be the time needed for the reduction of a certain contaminant mass on a metallic surface with a roughness Rz = 4µm from 6000 to 1000 mass units.

The specific cleaning efficiency was assumed to be the maximum attainable cleaning performance using a specific wiper, expressed as contaminant residue on the surface after the executed standard cleaning procedure. In practice, precision and fine cleaning wipers are often used in a solvent-presaturated state. To do justice to this fact experimentally, all measurements were first performed with wipers in a dry state and then with the same kind of wipers saturated in IPA (isopropylic alcohol). The wipers saturated in isopropylic alcohol were divided into two groups. The first group includes wipers with a saturation of a mixture of 98% isopropylic alcohol and 2% water. In the second group there is a mixture of 30% isopropylic alcohol and 70% DI-water.

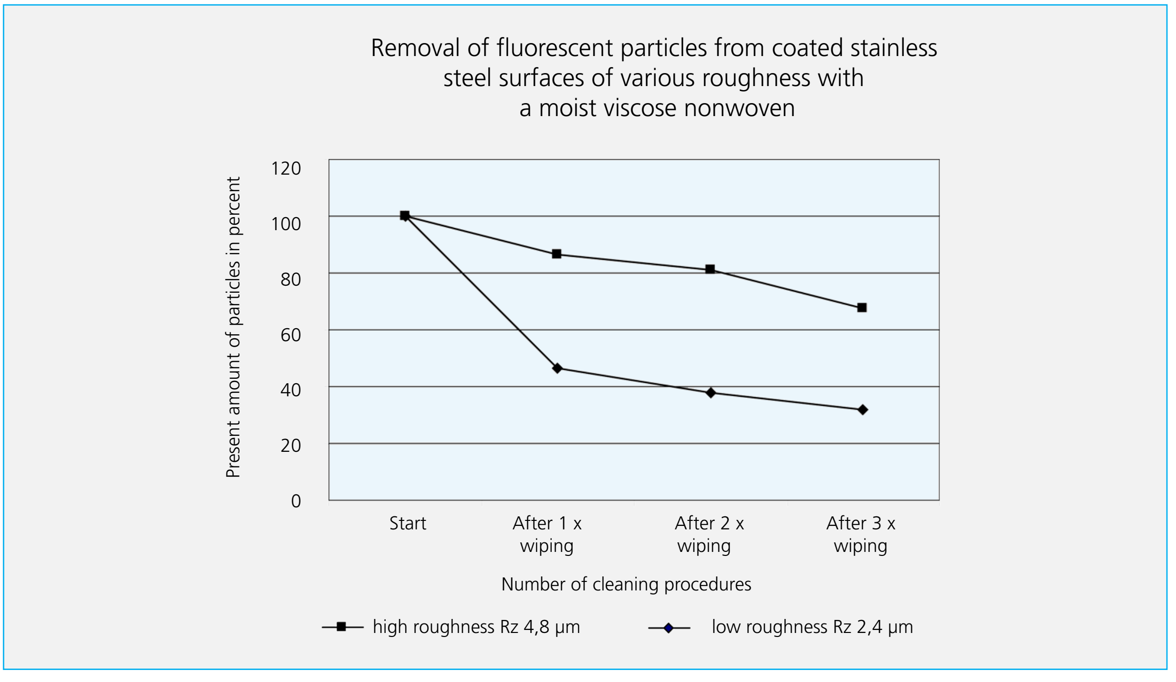

Fig.13 Diagram: Removal of fluorescent particles from coated stainless steel surfaces of various roughness with a moist viscose nonwoven

Knit and nonwoven wipers in comparison

As already mentioned, the present paper pertains to cleaning wipers made from decontaminated knits. However, the international offering also includes a large number of cleaning wipers made of nonwoven fabrics of different constructions. Because of the different textile structure of nonwoven fabrics, it cannot be assumed that either reduced cleaning times or higher cleaning efficiency are more achievable with these textile structures than with knit wipers.
However, to gain a measure of security for this, we conducted experiments the results of which are presented as follows: (Fig.14)
It thus follows that in general the group of nonwovens neither have the cleaning efficiency nor the comparatively low cleaning times of the group of knit wipers. This however is not to be expected because the fibres of the nonwovens are with very few exceptions usually thicker than the fibrils of the nonwoven fabrics, and also they generally have a lower package density, at least in comparison to knits with a high mesh count.

Layers and particles as common contaminants

The technical surfaces for daily use cannot be permanently clean in the physical sense. Rather, they are substantially characterised by two contaminant forms of matter: (1) the layered deposits (lubrication, oxides, atmospheric haze deposits from VOC) and (2) the coatings of particles and fibre fragments. In this essay, the term to clean is thus exclusively understood to mean „to remove layered deposits on technical surfaces". However, particulate contaminants can also affect functionality in technical systems. To date, the author is not aware of any studies that refer to wiper-based cleaning procedures with respect to the simultaneous removal of particulate and layered contamination on surfaces. We have therefore designed and performed several experiments in the context of this essay to learn whether and to what extent a reduction of the particles on the test surface occurs within the scope of a wiper-based cleaning procedure. First, for this purpose, at a cleanroom workbench a thin layer of mineral oil made of aliphatic hydrocarbons (Fluorol™) about 4 µm thick was applied

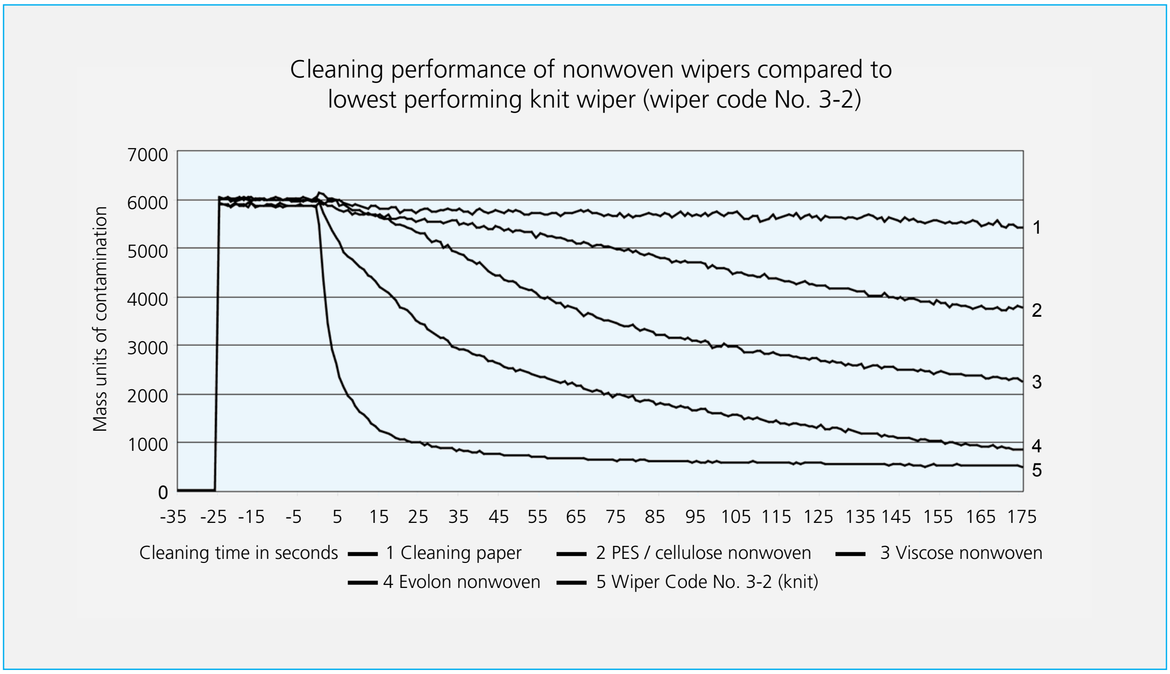

Fig.14 Diagram: Cleaning performance of nonwoven wipers compared to a knit wiper

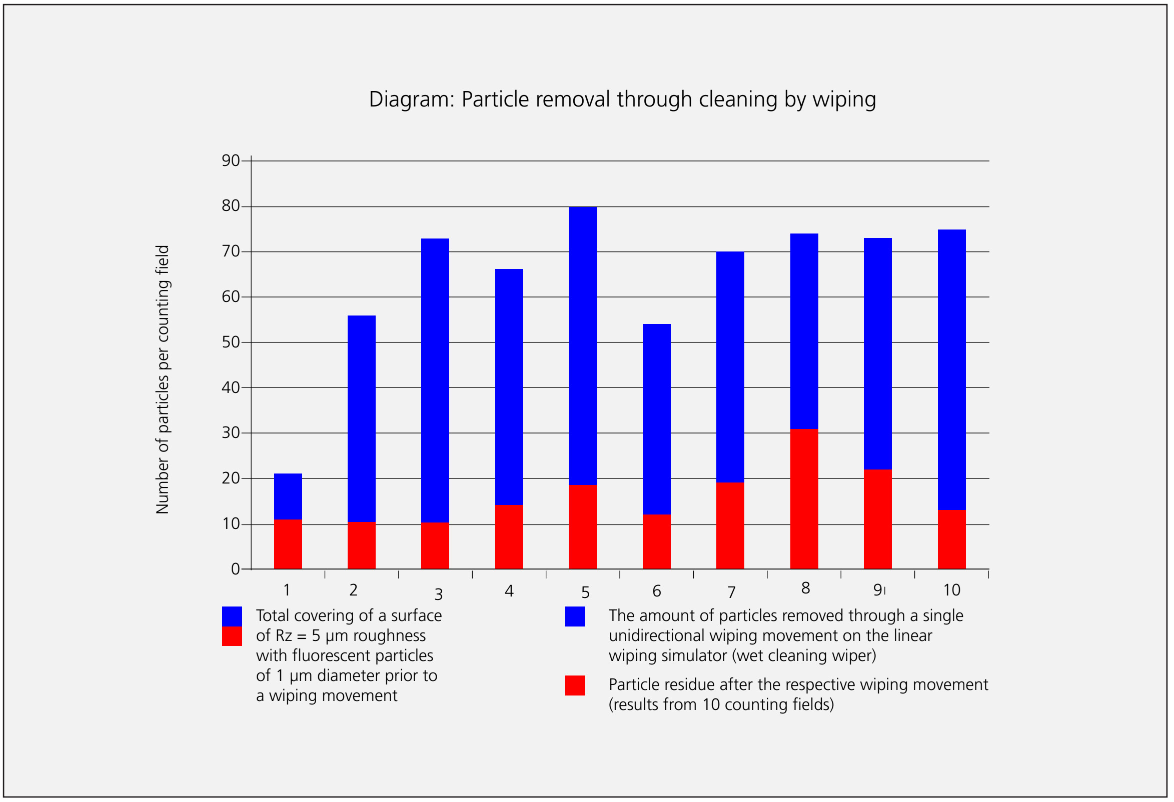

Fig.15 Diagram: Particle removal through cleaning by wiping

to the respective roller surface of the wping simulator Mark III. Following that, a sufficient quantity of fluorescent particles with a Feret diameter of 1 µm was applied by spraying to the thus-coated test surface in a clean workbench. The particle quantity in 10 randomly selected microscopical viewing fields was subsequently observed, counted and averaged using a fluorescence microscope. After one, or if desired, several controlled wiping procedures, the surface was observed once again. This time, too, 10 areas were randomly selected, in which the particle quantity was counted and averaged. Then the difference between the two counts was determined, and additionally the mass of the layered contaminants was determined. Thus, from the difference in particle quantity, the specific particle removal can be derived in relation to the removed contaminant mass.

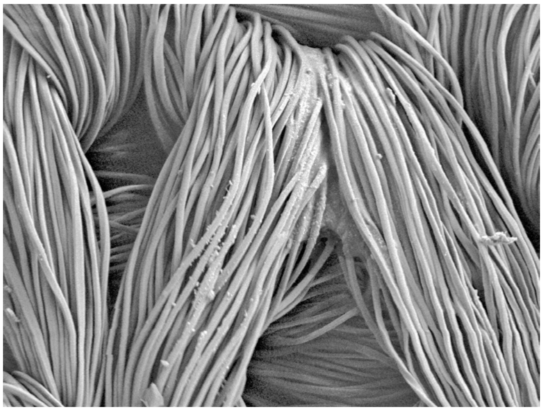

Fig. 16 SEM photo of a knit wiper after completed cleaning procedure. In the middle strand of yarn you can clearly see the accumulated particles.

In this context, after completion of the cleaning procedure, we took a SEM micrograph of a single precision cleaning wipers mesh. In the obtained image (Fig. 16) it can be seen that the mass removed from the surface consists of both a particulate and a layered contaminant. This fact supports the hypothesis that along with the mineral oil layer automatically a significant portion of the particles found on the surface are removed from it and are bound to the surfaces of the cleaning wiper. Likewise, after repeated cleaning procedures with new unused wipers, a portion of the particles remains bound to the surface and, from a certain particulate quantity on, cannot be further reduced through a wiper-based cleaning procedure. (Fig. 13) This suggests that the adhesion forces of the remaining particles are sufficiently high that through a possible particle release, a substantial impairment of the functional apparatus-based cleanliness of the cleaned systems would be highly improbable. We then raised the question of the remaining amount of particles relative to the roughness of the object surface. The measurement results allow the conclusion that the number of particles that cannot be removed through further cleaning attempts rises with increasing surface roughness Rz. (Fig.17 and 18)

The result of the observation of particle movement during a wiper-based cleaning procedure leads to the assumption that such particles are either deposited without adequate, anchoring forces or are already embedded in the organic contaminant layer on the surface. Another possibility is that such particles, by means of electric binding forces in their capacity as flight particles, have found the layer surface as random resting place. Due to the displacement forces of the wiper-based cleaning procedure, they have detached themselves from the object surface and subsequently found a new resting place on a fibril surface of the cleaning wiper. With the removal of a portion of the layered contaminant, the particle quantity is reduced considerably.

Further experiments are needed to confirm the hypothesis described above: Nevertheless, there is the possibility that the adhesive forces of the particles anchored on the surface are changed through external physical or chemical factors such as electrical fields or fluctuations in the relative ambient humidity, whereby the particles could lose their anchoring to once again become airborne.

Also of interest was the result of the experiments with respect to cleaning performance if the wiper with code No. 2-1 was saturated

Wiping procedures	Low roughness Rz = 2.4 µm	High roughness Rz = 4.8 µm
Start	100	100
After 1 x	9.14	87.8
After 2 x	5.6	86.3
After 3 x	3.83	89.1
After 4 x	3.81	64.6
After 5 x	3.94	75.7
After 6 x	3.87	63.6
After 7 x	3.91	67.5
After 8 x	3.77	50.9
After 9 x	3.85	47
After 10 x	3.79	31.7

Fig.17 Table: Reduction of particle concentration after linear wiping with a wet wiper of code No. 2-1

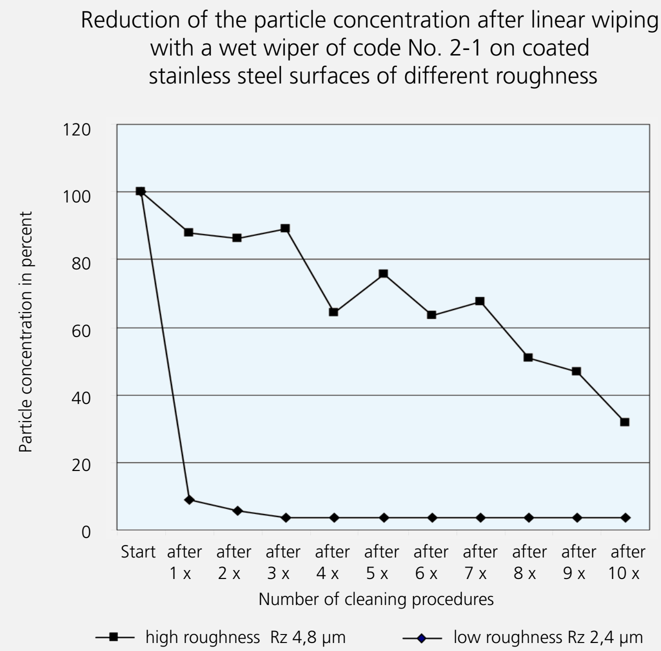

Fig.18 Diagram: Reduction of the particle concentration after linear wiping with a wet wiper of code No. 2-1

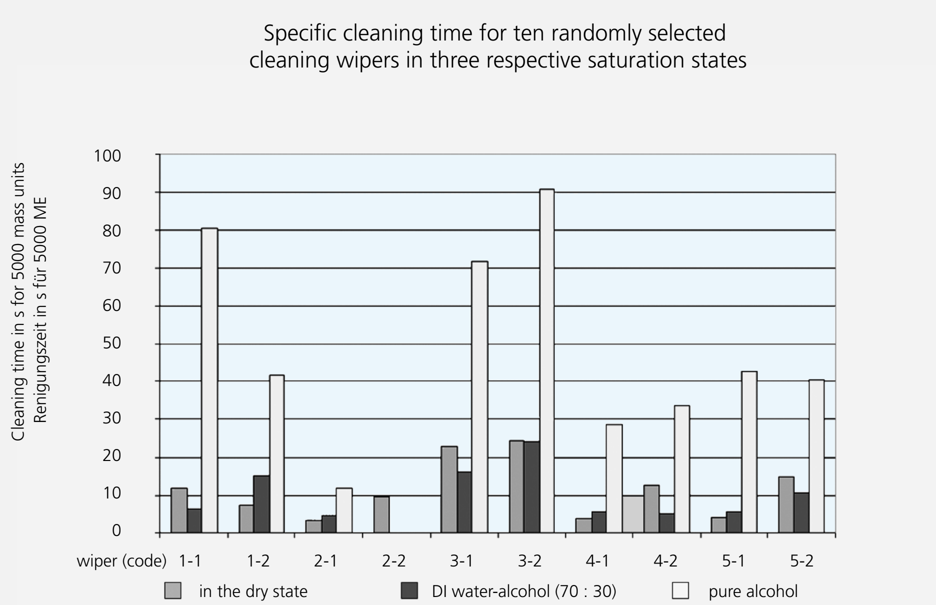

Fig. 19 Diagram: Specific cleaning time for ten randomly selected cleaning wipers in three respective saturation states

with various solvents and used on a relatively rough surface. To our surprise, an unexpectedly high cleaning performance was achieved using cleaning benzene as a solvent. (Fig. 23)

A classification for cleaning wipers

On the basis of the time values for the cleaning procedures with different wipers and saturation states shown in the diagram Figure 12, it has now become possible to classify fine and precision wipers e.g. in three or five performance classes, as can be seen in the following tables (Fig. 20 and 21). Based on the cleaning times obtained in the experiments it is now possible to calculate the costs of cleaning that arise for different wipers. (Fig. 22)

Conclusion

In the present essay we demonstrated that for fine and precision cleaning wipers normally used in cleanrooms it is possible to establish performance characteristics that allow an application-oriented, technical classification of this product group. The possibility of a careful classification of the products offered here in turn allows the assignment of different performance classes of such cleaning wipers to diverse, well-established cleaning applications. The insights gained will help reduce the uncertainty of users throughout the world in this area and aid in optimising the cleaning times and the results of the operational maintenance units. Above all, the present essay facilitates a departure from the unfortunate legacy of the inapprehensible simulation approach of the U.S. IEST – specification RP CC-004.2 from which to date no international standards body has distanced itself with the necessary justification. The founded working group "Cleanroom Consumables" of the Association of German Engineers founded in 2008 may, however, take up this topic in order to prepare a European initiative. Subordinate although not unimportant findings of the study are the cleaning results

Time classifications	Cleaning duration (in sec.)	Cleaning wiper (coded)
Class A	0.1 - 4.9	2-1, 2-4, 4-1, 5-1
Class B	5.0 - 9.9	1-2, 2-2
Class C	10 - 15	1-1, 4-2, 5-2
Class D	15 - 20	
Class E	> 20	3-1, 3-2

Fig. 20 Table: Classification of cleaning wipers in the dry state according to cleaning time

Performance classification	Contamination residue in %	Cleaning wiper (coded)
Class 1	1 - 2.49	
Class 2	2.5 - 4.99	2-2, 2-1, 2-4, 4-1, 5-1
Class 3	5 - 7.49	1-1, 1-2, 4-2, 5-2
Class 4	7.5 - 9.99	3-1, 3-2
Class 5	> 10	

Fig. 21 Table: Classification of cleaning wipers in the dry state according to contamination residue (cleaning performance)

in the experiments with different saturation states of the cleaning wipers. The results show that for thin contaminant layers of low viscosity, like thin mineral oil coatings, the cleaning performance of the dry wipers distinctly exceeds that of the pre-saturated wipers. Previously, this was not assumed. Apparently wet wiping is predominantly useful in the removal of highly viscous contamination. In terms of particle removal of different rough surfaces by wiper-based cleaning operations, once more the repeatedly published finding was confirmed that with increasing surface roughness of the object surface, the number of particles that can be removed by wiper-based cleaning procedures decreases.

In the end it was the desire of the author to elucidate the previously unknown law (s) of the mechanics of cleaning by wiping, which mainly determine the cleaning performance of fine and precision cleaning wipers. It was the principal hope that the cleaning performance of knit wipers would correlate with the wipers mesh count per unit area. Unfortunately, this approach could not yet be consistently confirmed and thus we need insights that until now have remained elusive.

Acknowledgments

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Glossary

Fine cleaning

In this essay, “fine cleaning” is defined as the removal of contaminant layers ranging from 10 to 100 μm thickness on all kinds of surfaces. (see also precision cleaning)

Quality of use

The term includes the favourable combination of a number of application-relevant parameters of a cleaning wiper for fine or precision cleaning. These include the specific cleaning time and the specific cleaning efficiency.

Mass units

In this context, mass units are mass identical voltage values of a fluorescence detector measured with the aid of a laser fluorescence system.

Cleaning wiper (product code)	in a dry state	DI-water-alcohol (70:30)	pure alcohol
No. 1-1	58.2	32.3	399.8
No. 1-2	37.3	75.6	208.1
No. 2-1	15.9	22.4	58.7
No. 2-2	47.3	N/A	N/A
No. 3-1	113.5	79.1	357
No. 3-2	122	120	451.6
No. 4-1	18.9	26.3	141.9
No. 4-2	62.2	25.3	166.8
No. 5-1	20.9	26.3	211.6
No. 5-2	73.7	53.2	201.6

Fig. 22 Table: Cleaning time costs per 1 million cleaning procedures in thousands of euros when using different cleaning wipers and saturation states. Basis: Operator -Wages in the state of Brandenburg in 2004 = 32,700 US$ / year, see References [2]. The wiperwith code No. 2-2 is a dry cleaning wiper

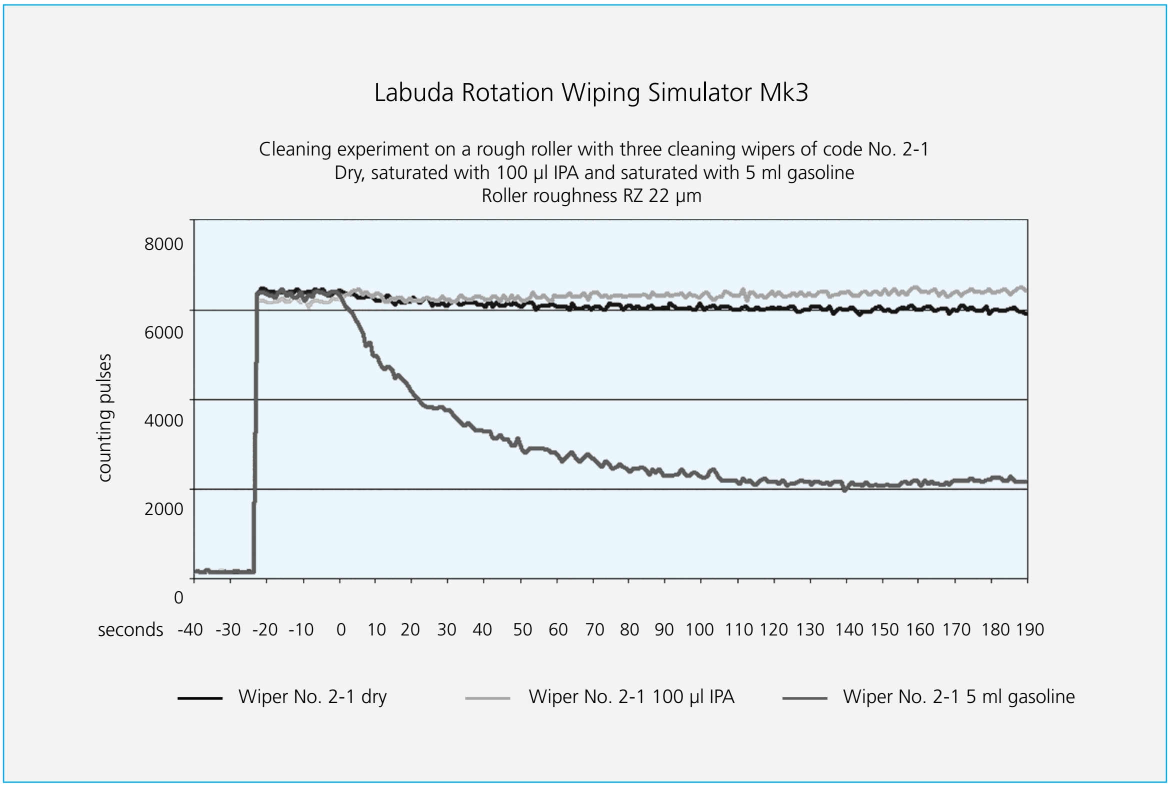

Fig. 23 Diagram: Different cleaning performances of the same knit wiper with a rough surface (RZ 22 µm) and varying kinds of solvents

Object surface
The technical surface that is to be cleaned or with the aid of which surfaces that have the same or similar properties shall be used for simulation to carry out appropriate measurement and testing procedures.

Precision cleaning
In this essay, "precision cleaning" is defined as the removal of contaminant layers of an average thickness of less than 10 µm on all types of surfaces. (see also under fine cleaning)

Cleaning efficiency
see cleaning performance

Cleaning performance
Removal of n mass units of the contaminant mass from a surface per time unit. The number of mass units is set in this essay at 5000. These are removed by means of a cleaning wiper depending on the type, construction and design in n seconds fixed to a rotating roller.

The cleaning performance is calculated with the formula:

$$\frac{5000\ (\mathrm{ME})}{t\ (\mathrm{s})} = \mathrm{ME/s}$$

Cleanroom wipers
Cleaning wipers used for the techniques of clean working, colloquially referred to as cleanroom wipers or cleanroom-wipes. So far, not a standardised term for textile fabrics whose intended purpose is cleaning by wiping for the techniques of clean working.

Specific cleaning time
The time in seconds that is needed with a cleaning wiper, i.e. to carry out a standardised, simulated cleaning procedure with the aid of a rotary wiping simulator. For this purpose, an aliphatic hydrocarbon in the quality of a fluorescent mineral oil (Fluorol) of about 4µm thickness is applied onto a rotating cylinder of the wiping simulator with a

surface roughness of Rz = 4µm. The mineral oil is distributed in layers until the application has reachrd a value of 6000 mass units in a special laser fluorescence measuring device. The time span required to reduce the contamination on the cylinder by 5000 mass units to a value of 1000 mass units is what we call the *specific cleaning time*. The term "specific" in this context means that the measured cleaning time specifically applies to the tested cleaning wiper. The specific cleaning time varies considerably for cleaning wipers depending on the base material, design, manufacturing processes, chemical finishing and degree of purity. Thus, the specific cleaning time is a measure of the cleaning cloths quality for fine and precision cleaning.

Standard cleaning
In this essay is defined as the removal of contaminants of medium layer thickness above 100 µm from all types of surfaces. (see also fine cleaning, precision cleaning).

Cleaning by wiping
This term refers to the removal of unwanted matter on a surface by relative movement. Wiper-based cleaning is the most used method of surface cleaning worldwide. The active components of cleaning by wiping are the object surface, the contamination and the means of wiping. The aim of the wiping cleaning procedure is to remove a sufficient mass of contamination from the use surface, so that the intended function of the use surface is not impaired. Normally, the use surface is the static component of the wiping cleaning procedure. Usually it is part of a device, a machine, an apparatus, a utility object or a room. The wiper is applied to the use surface in a relative movement and the result is the desired mass transfer. The wiper can be disposed of after a cleaning procedure, used several times or, after the wiper has been washed, can be used again.

Wiping materials
Any material suited for the procedures of wiper-based cleaning, e.g. cloths, nonwovens, sponges, felts, foams, flocks and brushes.

Abbreviations used in this work

ME – mass units
N/A – not applicable
VOC – volatile organic compound

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