Practical experiences in Particle Deposition Monitoring

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Abstract

The rate of particle deposition of particles determines the risk of product contamination and demonstrates the operational quality of a cleanroom. The particle deposition rate depends on the deposition velocity and concentration of particles at a certain location and time. The concentration of particles larger than 10 µm cannot be measured easily; therefore the particle deposition rate of falling particles should be measured.
Since the end of 2013 specific particle deposition meters, that measure the particle size distribution and rate of particle deposition, are available. Particle deposition measurements were complicated and expensive in the past. Therefore these were only executed in specific cleanroom applications or to investigate contamination problems. Nowadays it is easy to apply particle deposition measurement in various cleanrooms where operator activities are important. The new instruments make also real time particle deposition measurements possible. Practical experiences with these instruments in various applications are described in this article.

Key words: Cleanroom, Cleanroom monitoring, Particle Deposition, Surface Cleanliness, Operational quality.

1. Introduction

The most important reason to use cleanrooms is to prevent particle contamination of a vulnerable product surface. Contamination occurs through particle deposition and by contact transfer with lesser clean surface of equipment, tooling, packaging and workbenches.
In relation with the control of particles ISO 14644 on cleanrooms and associated controlled environments provides cleanliness classifications of air (volume 1) and surface (volume 9) and various additional volumes like measurement methods (volume 3) [1,2].
Particle deposition determines the rate the surface cleanliness at a location will change.
Up to last year particle deposition measurements were laborious or expensive and did not provide information that could help to reduce the risk of particle deposition.

Particle fall out measurement based on the increase of mass or surface coverage by particles are available for a long time and accepted in space industry. Particle deposition in cleanrooms based on particle size distributions are investigated by various research programs [3,4,5].
Using machine vision the first easy to use particle deposition meters, that make use of silicon or glass witness plates, were developed [6,7,8].

Last year the digital holographic measurement [9] of particle deposition was implemented in a commercial available cleanroom monitoring instrument.

2. Holographic measurement of particle deposition

When a broad coherent laser beam passes a volume with a low concentration of particles towards a detector most laser beams will reach the detector without meeting any particle. However a few laser beams will meet a particle and can pass this particle by moving around it. This leads to a delay in the time the beam reaches the detector. Mixing the various laser beams that meet particles or no particles at all will generate a diffraction pattern.
By using Fourier transformation techniques these diffraction patterns can be manipulated. This way is it possible to reconstruct the 3-dimensional holographic picture of the particles in the volume the laser beams were passing.
This method is used to measure particles deposited on inclined glass plates (see figure 1).

In a sensor 6 glass plates are put under an angle of 45^{O}. This way both particle deposition and holographic imaging can be performed.

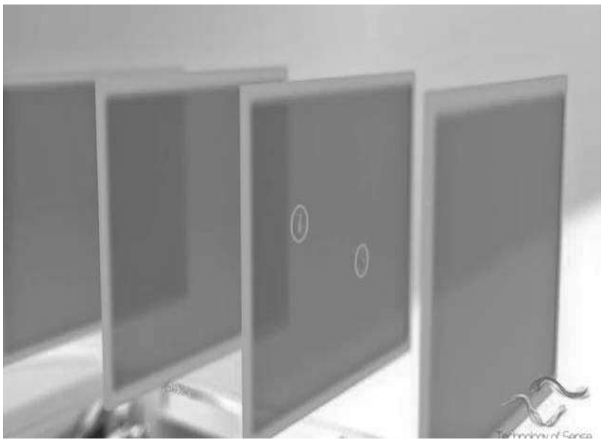

Figure 1 Glass plates that collect depositing particles and are imaged holographic.

Small particles that fall onto an inclined surface will stick to the position they hit the glass surface and are kept at this location by Vander Waals forces. Only large spherical particles (> 300-500 µm, depending on their specific density) could travel for a certain distance over the inclined glass surface.
By taking a holographic image at regular interval s and subtracting these images subsequently the particle size distribution of the deposited particles at each interval can be determined (see figure 2).

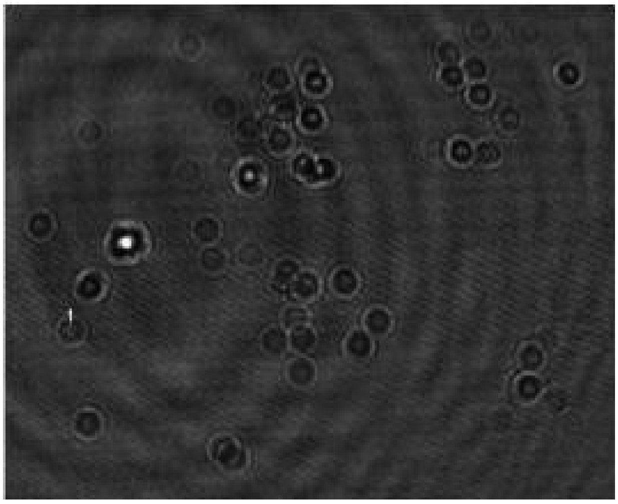

Figure 2. Holographic picture on one glass plate.

When various sensors communicate with a base computer through a network or wireless any computer connected to the base computer can show the results of the particle deposition monitors.

3. Particle deposition measurement results

To show the potential of this particle deposition monitoring method a practical example will be demonstrated.
The sensor has been placed in an ISO 8 cleanroom were varies assembly activities are executed. Measurement data were collected over a period of one week (7 to 11 April 2014).

The results of this measurement are shown in figures 3, 4 and 5. First of all the particle deposition events can be displayed in a real time screen. Of each deposited particle the dimensions, shape and cross section are known. For convenience only one dimension is selected to determine the size of the particle. This is the length (largest size) of the particle. This size is larger than or equal to the optical diameter of a particle.

In figure 3 the registration of the particle deposition events is shown. Sometime high peaks occur. These can arise from cleaning, logistic activities or high activity of the people near the location of the sensor. In the same graph the increase coverage by particles is shown. This is the sum of the areas of the individual cross section of the particles. The resulting coverage after a certain exposure time can be compared with data from a particle fall out meter as is used in space industry.

Over a certain time span (one interval or longer) the particle size distribution can be analysed. In this example the differential particle size distribution over the total measurement period of one week is given in figure 4. The size bins between 20 and 100 um are divided in steps of 10 um and above 100 um in steps of 100 um. The surface cleanliness by particle concentration in ISO 14644-9 is classified for particle up to ≥ 500 µm. In the distribution of figure 4 the sizes up to ≥ 900 µm are shown.
It can be seen that in a cleanroom many large particles can deposit. Often relative high numbers of particles > 100 µm are found. This is caused by insufficient cleaning.
The same type of results is found in many ISO 6 and ISO 7 cleanrooms.

The number of particles in each size bin can be calculated into particle deposition rate as the number of particles ≥ D µm per dm^2 or m^2 per hour.
These data can be used to calculate a cumulative distribution like commonly is used in cleanrooms.

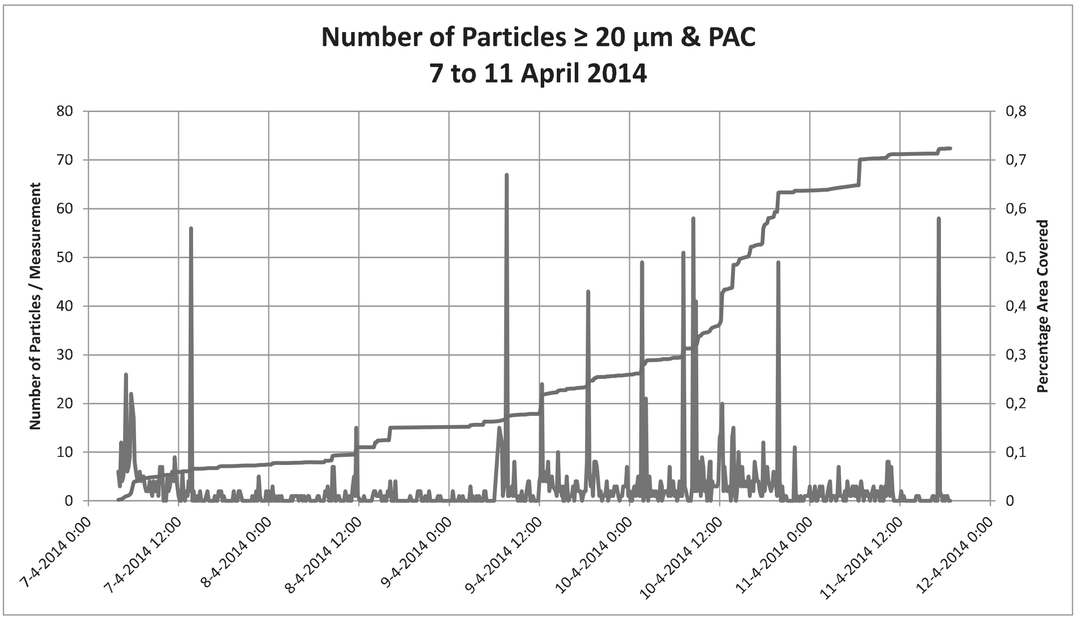

Figure 3. Registration of particle deposition events in a cleanroom.
Every 5 minute the number of particles ≥ 20 µm deposited on the sensor are shown. Of each particle the area of the cross section of each particle is measured and used to calculate the area coverage. The development of the area coverage is shown also in the graph, the scale is given on the right hand side.

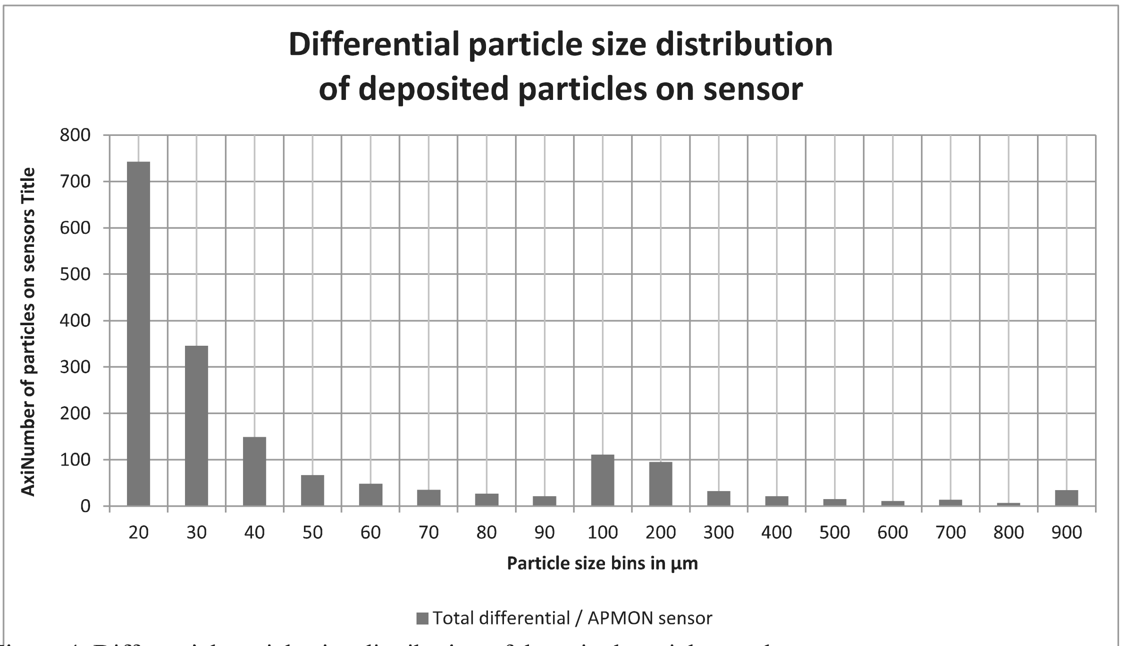

Figure 4. Differential particle size distribution of deposited particles on the sensor.

In figure 5 the cumulative particle size distribution of the particle deposition rate is shown. A log / log graph is used. The particle size is given from 10 to 1.000 µm. The deposition is given in number of particles ≥ D µm per dm^2 per hour.

The particle deposition data can be expressed in term of Particle Deposition Rate (PDR) or Particle Deposition Class (PDC) as described in [10, 11].

The tangent to the upper particle deposition rate distribution determines the Particle Deposition Class of the monitored location. The value is determined by take the maximum of R_D*D. R_D is the number of deposited particles per m^2 per hour and PDC = $^{10}\log R_D$*D.
In this example the PDC is 5,1.
Also a lower PDC can be determined. In this measurement a PDC value of 4,7 is found.

In the particle deposition graph 3 sections can be observed:

a) Particles ≤ 30 µm,
b) Particles between 30 µm and 100 µm or equal to 100 µm,
c) Particles > 100 µm.

The increase of particle deposition from 30 µm size to the ≥ 20 µm size is influenced by the local air flow.
The middle part is mainly influenced by human contamination (number of people, garments, discipline and working methods).

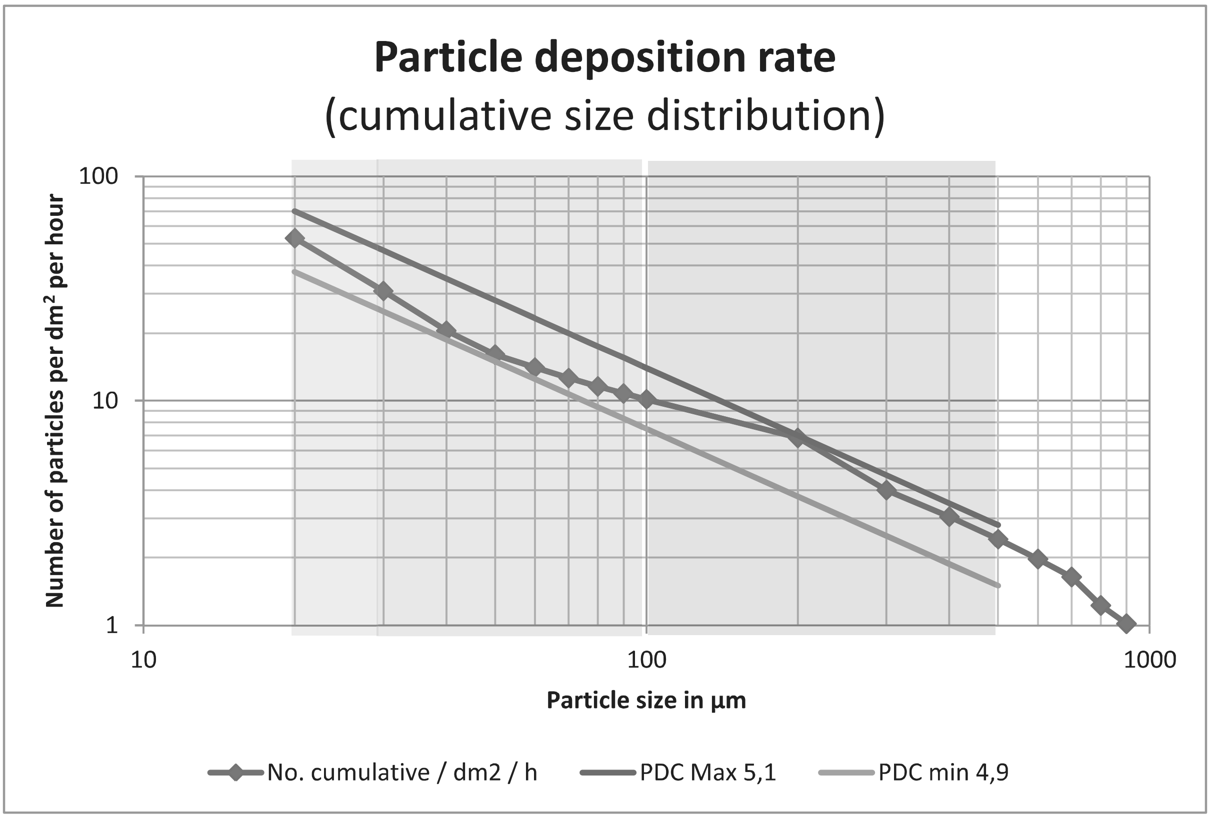

Figure 5. Particle deposition rate shown as cumulative distribution including Particle Deposition Class lines.

The right hand part of the graph shows the deposition of the very large particles. This part is influenced by the total cleaning program. With total all cleanroom surfaces, equipment, tools and incoming goods are meant.

4. Potential application of particle deposition measurement

Deposition of particles > 20 µm is determined by operational aspects of the cleanroom.
There is no deposition particles > 20 µm in the at rest occupancy state of the cleanroom. Therefore only working hours are important. Operational aspects are:

- The number of persons,
- Their garments
- Their discipline,
- Their working method,
- The cleaning program,
- Cleaning of incoming goods.
- Logistics
- Etc.

All these aspects concern cleanrooms in which people are working.

In many potential application measurements are performed. Examples of potential industries are:

- Space industry
- Automotive industry
- Electronic devices
- Medical devices
- Display industry
- Optical devices
- Operating theatres
- Etc.

Particle deposition monitoring can be used to investigate potential sources of contamination and to monitor the operational quality.

The data can also be used to optimize the cleaning program. After cleaning a particular surface cleanliness of for instance SCP 4,7 can be reached. In case the maximum allowable surface cleanliness is for instance SCP 6 from the particle deposition data the time between two subsequent cleaning moments can be determined. The number of particles, that is allowed to deposit, is determined by the difference of the achieved and maximum surface cleanliness (SCP 6 – SCP 4,7). The result is equivalent to $9{,}5*10^5$ particles ≥ 1 µm per m^2.
In case the PDC is 5, which is 10^5 particles ≥ 1 µm per m^2 per hour. This means that after 9,5 working hours cleaning is required.

The PDC values for particular particle size can be used to perform risk management. In case of the shown example were PDC is 5,1 the risk of deposition of particles ≥ 25 µm on a product surface of 2 cm^2 during 10 minutes can be calculated.
PDC 5,1 gives a deposition of 125.000/25 = 5.000 unwanted particles per m^2 per hour or 1 particles ≥ 25 µm per product per hour. Since the exposure of the product is only 10 minutes, the risk is a factor 0,2 per product.

The showing of real time screen of particle deposition events can have a positive effect on the awareness of the discipline and activities of personnel. Daily or weekly reports on average PDC values can be displayed in monitoring graphs.

5. Conclusions

The development of particle deposition monitor opens the possibility of real time monitoring of particle deposition. Data can be used to find causes of particle deposition and to develop means to reduce particle deposition at a specific location.

The particle deposition monitor can be used to control the applied solutions.

In many cleanrooms the number of large particles is high. A part of these particles are redistributed through the cleanroom and contribute to the particle deposition. Particle deposition data can be used to optimize the cleanroom cleaning program. Particle deposition that can also be used to determine the risk of particle contamination at specific locations and times and help to select the right moment of exposing vulnerable product surfaces to the cleanroom environment.

Demonstration of particle deposition events, PDR or PDC values and analysis will help to improve personnel awareness and motivation.

Acknowledgements

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