Practical experiences in particle deposition monitoring

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Abstract

The rate of deposition of airborne particles determines the risk of product contamination and demonstrates the operational quality of a cleanroom. The particle deposition rate at a particular location and time depends on the deposition velocity and the concentration of particles. The concentration of particles larger than 10 µm cannot be measured easily; therefore the deposition rate of falling particles should be measured.

Specific particle deposition meters, that measure the particle size distribution and rate of particle deposition, have been available since the end of 2013. In the past, particle deposition measurements were complicated and expensive and were therefore only carried out in specific cleanroom applications or to investigate contamination problems. Nowadays it is easy to carry out particle deposition measurement in various cleanrooms where operator activities are important. The new instruments also make 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.

Introduction

The most important reason for using cleanrooms is to prevent particle contamination of vulnerable product surfaces. Contamination occurs through particle deposition and by contact transfer with less clean surfaces such as gloves, equipment, tooling, packaging and workbenches.

In relation to the control of particles, the ISO 14644 series of standards (Cleanrooms and associated controlled environments) provides cleanliness classifications of air (Part 1) and surface (Part 9). There are various additional Parts like measurement methods (Part 3) [1, 2].

Particle deposition determines the rate at which the surface cleanliness at a location will change.

Up until 2013 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 have been available for a long time and accepted in the space industry. Particle deposition in cleanrooms, based on particle size distributions, has been investigated by various research programs [3, 4, 5].

The first easy to use particle deposition meters made use of silicon or glass witness plates [6, 7, 8].

In 2013 the digital holographic measurement [9] of particle deposition was implemented in a commercial available cleanroom monitoring instrument.

Holographic measurement of particle deposition

When a broad coherent laser beam passes through a volume with a low concentration of particles towards a detector most laser beams will reach the detector without meeting a particle. However a few laser beams (a light wave front) will meet a particle and that will disturb the wave front and create a new wave front from each point on the surface of the particle. This leads to a delay in the time for the beam (light wave) to reach the detector, which causes an interference pattern. The interference pattern contains information on the various particles in the path of the light.

By using Fourier transformation techniques these diffraction patterns can be analysed and it is possible to reconstruct a three-dimensional holographic picture of the particles in the volume that the laser beams are passing. When scanning the holographic picture it can be seen that the particles sit on the various surfaces of the inclined glass plates.

This method is used in the APMON system, developed by TNO (Dutch Institute of Applied Physics) and Technology of Sense b.v., to measure particles deposited on inclined glass plates (see Figure 1).

Six glass plates are placed in a sensing device at an angle of 45°. This way both particle deposition and holographic imaging can be performed.

Small particles that fall onto an inclined surface will stick to the position where they hit the glass surface and are kept at this location by van der Waals forces. Only large spherical particles (> 300-500 µm, depending on their specific density) can travel for a certain distance over the inclined glass surface.

By taking a holographic image at regular intervals and comparing these images subsequently, the particle size

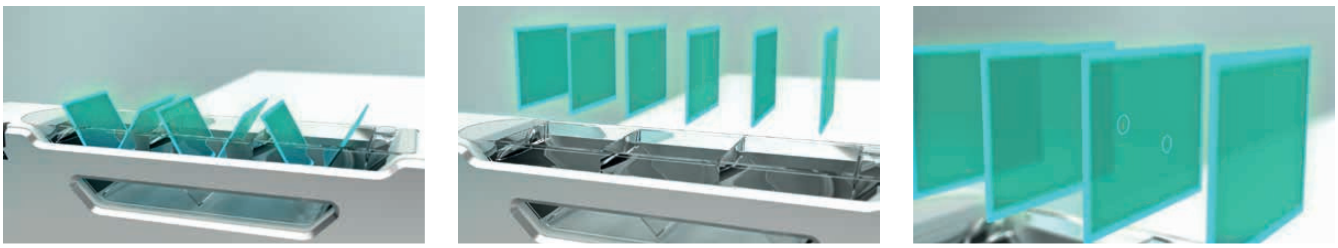

Figure 1: Glass plates that collect depositing particles and are imaged holographically, APMON system courtesy Technology of Sense b.v.

distribution of the deposited particles at each interval can be determined (see Figure 2).

The various sensors can communicate with a base computer through a network or wirelessly. The base computer can show the real-time measurement results on the network. In that way the particle deposition can be monitored at any computer connected to the network.

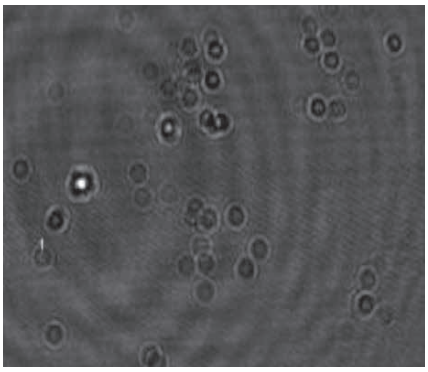

Figure 2: Holographic picture on one glass plate, courtesy Technology of Sense b.v.

Particle deposition measurement results

To show the potential of this particle deposition monitoring method a practical example will be described.

The sensor was placed in an ISO 8 cleanroom where various assembly activities are carried out. Measurement data were collected over a period of one week (7 to 11 April 2014).

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

In Figure 3, the number of particles ≥ 20 μm deposited on the sensor every five minutes is recorded (blue line). Sometime high peaks occur. These can arise from cleaning, logistic activities or high activity of the people near the location of the sensor.

The cross-sectional area of each particle is measured and accumulated to calculate the total area coverage. The increase in coverage by particles is shown on the same graph (red line). The scale is given on the right hand side. The resulting coverage after a certain exposure time can be compared with data from a particle fall out meter as used in the space industry.

The particle size distribution can be analysed over a defined time which can be continuous or made up of separate periods. In this example the differential and cumulative particle size distributions per dm² over the total measurement period of one week are shown in Table 1. The size bins between 20 and 100 μm are divided in steps of 10 μm and above 100 μm in steps of 100 μm. In ISO 14644-9, the surface cleanliness by particle concentration is classified for particles up to ≥ 500 μm but the table and graphs in this example include larger particle sizes. The differential distribution, shown in Figure 4, is the distribution of the number of particles in each individual size bin. The cumulative distribution is calculated by adding the number of particles of each size bin larger than the observed size.

It can be seen that many large particles can deposit in a cleanroom. Often relatively high numbers of particles > 100 μm are found. This is caused by insufficient cleaning. Similar results are found in many ISO 6 and ISO 7 cleanrooms.

The number of particles in each size bin can be used to calculate the particle deposition rate in terms of the number of particles ≥ D μm per dm² or m² per hour.

To determine the Particle Deposition Rate (PDR) the number of particles per area should be divided by the time of exposure. As particle deposition of particles ≥ 20 μm only occurs when the cleanroom is in operation, particles are only counted during working hours. The APMON has a timing system that provides for this.

In a cleanroom the airflow will remove most particles < 20 μm and the concentration of those particles can be measured with a particle counter. To determine the (lower) concentration of particles ≥ 20 μm it is better to measure the particle deposition. To be able to derive the PDR for particles ≥ 20 μm sufficient measurement (deposition)

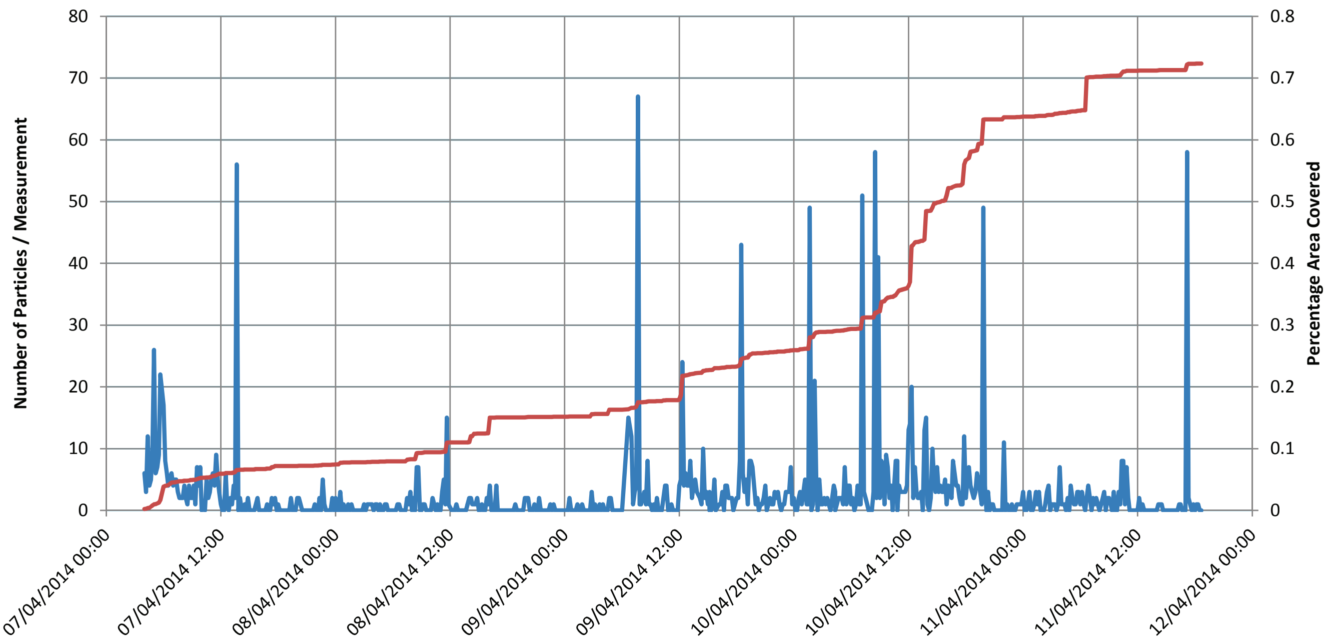

Figure 3: Record of particle deposition events in a cleanroom

area and time are required to be able to detect a statistically significant number of particles.

The author has experience with a measurement system using a XY scanning system with different illumination methods. The cumulative particle size distributions acquired over many years at many different cleanrooms and different applications are summarised in Figure 5. These show the impact of the cleanroom air below 20 µm and a transition between 20 and 30 µm.

In Figure 6 the cumulative particle size distribution of the PDR is shown. A log-log graph is used. Particle sizes are from 10 to 1000 µm. The PDR is expressed in number of particles ≥ D µm per dm^2 per hour.

The particle deposition data can also be expressed in terms of Particle Deposition Class (PDC) as described in [10, 11]. The upper tangent to the PDR curve determines the PDC of the monitored location. The value is determined by taking the maximum of RD^*_D. R_D is the number of deposited particles per m^2 per hour and PDC = $\log_{10} RD^*_D$. In this example the PDC is 5.1. The number of particles ≥ 200 µm determines the PDC.

In the same way a lower tangent can be drawn and a lower PDC can be determined. In this measurement a PDC value of 4.9 is found. The lower value can be reached by improving the operational quality.

Three zones can be observed in the graph shown in Figure 6:

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

Table 1: Particle size distributions per dm^2 sensor surface

Total number of particles on the sensor		
Particle size in µm	**Differential/dm^2**	**Cumulative/dm^2**
20	2,972	7,104
30	1,384	4,132
40	596	2,748
50	268	2,152
60	192	1,884
70	140	1,692
80	108	1,552
90	84	1,444
100	444	1,360
200	380	916
300	128	536
400	84	408
500	60	324
600	44	264
700	56	220
800	28	164
900	136	136

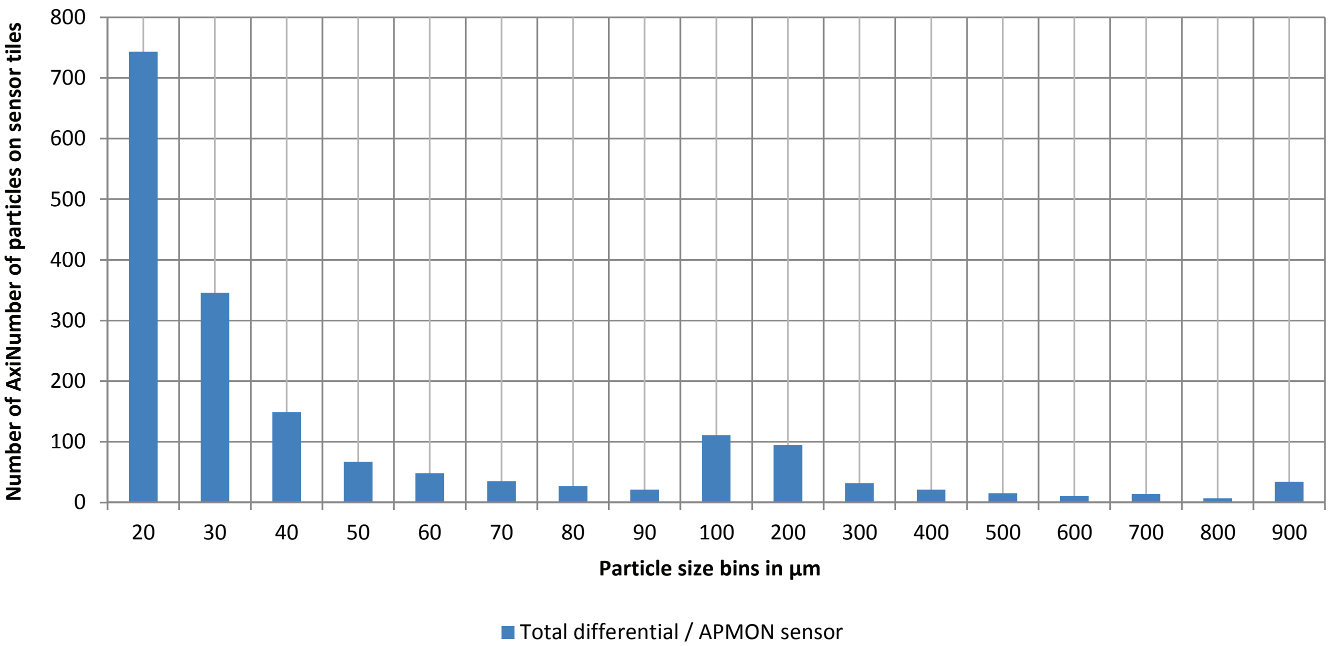

Figure 4: Particle size distribution of deposited particles on the sensor. Note: The sensor is 1/4 dm^2

Potential application of particle deposition measurement

Deposition of particles > 20 µm is determined by the operational aspects of the cleanroom.

There is no deposition of particles > 20 µm in the at rest occupancy state of the cleanroom. Therefore only measurements carried out during 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
- Machinery that generates large particles
- Etc.

All these aspects concern cleanrooms in which people are working.

There are many potential applications where measurements could be useful. Examples of potential industries are:

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

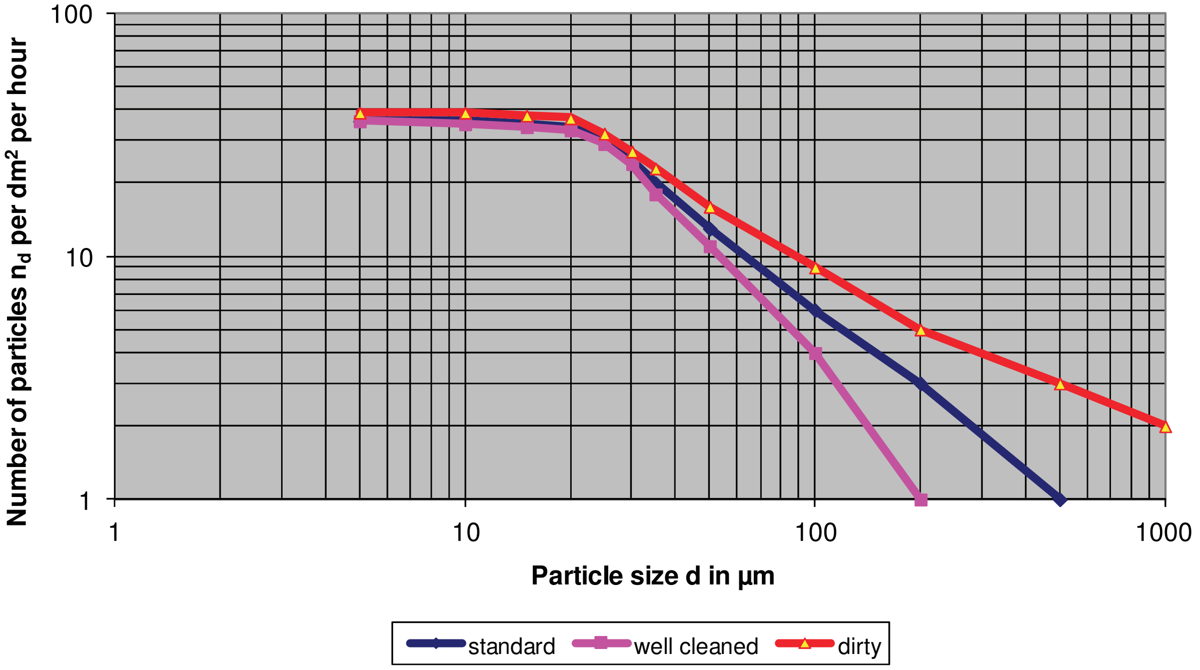

Figure 5: Typical particle deposition distributions

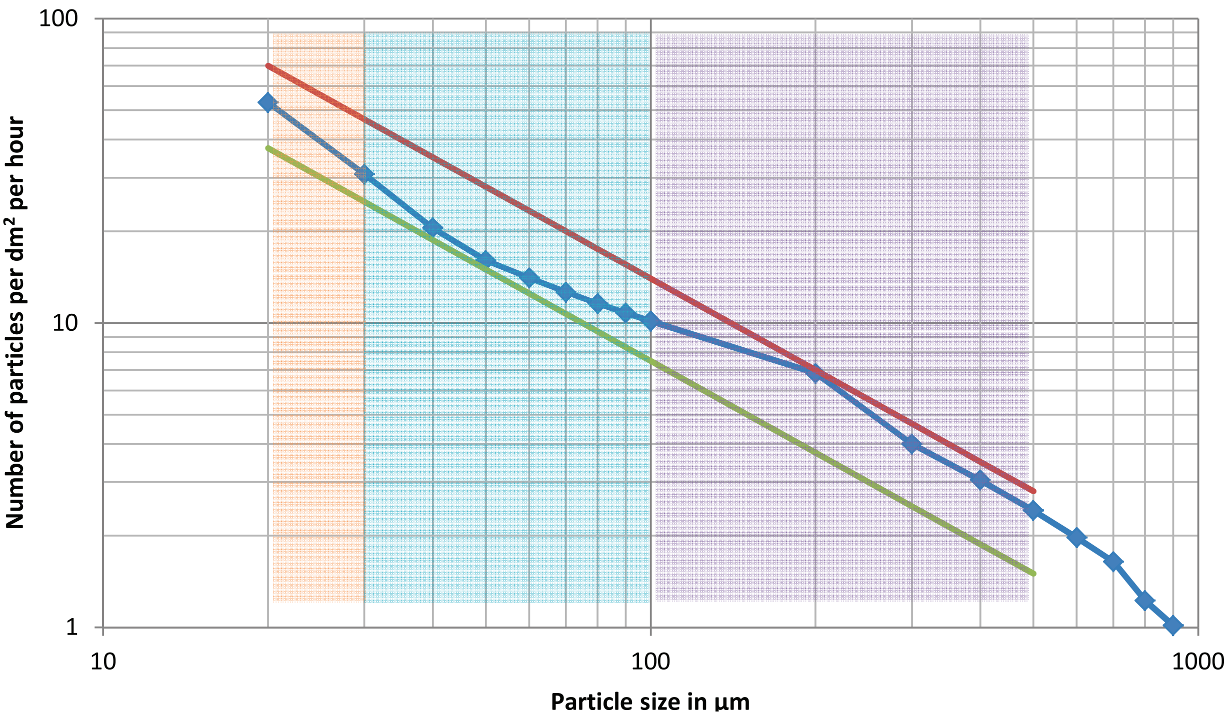

Figure 6: Particle deposition rate shown as cumulative distribution including Particle Deposition Class lines

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

The data can also be used to optimise the cleaning program. According to ISO 14644-9:2012, the cleanliness of a surface can be expressed in a Surface Cleanliness by Particle concentration class SCP.

SCP = $\log_{10}(C_D*D)$, where C_D is the number of particles ≥ D µm per m^2 and D is the considered particle size.

After cleaning a particular surface, a surface cleanliness of, for instance, SCP 4.7 can be reached. If the maximum allowable surface cleanliness is SCP 6, the time interval between two consecutive cleaning campaigns can be determined from the particle deposition data. The number of particles 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 $10*10^6$-$0.5*10^6$ = $9.5*10^5$ 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 the surface reaches SCP 6 and cleaning is required.

The PDC values for particular particle size can be used to perform risk management. In the example shown, where 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 PDR of 125,000 particles ≥ 1 µm per m^2 per hour. Therefore the deposition of particles ≥ 25 µm is 125.000/25 = 5,000 unwanted particles per m^2 per hour or 1 particle ≥ 25 µm per product (2 cm^2) per hour. Since the exposure of the product is only 10 minutes, the risk is a factor of 1/6 = 0.2 per product.

The showing of real time particle deposition events on screen 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.

Conclusions

The development of the 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 the 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. Some of these particles are redistributed through the cleanroom and contribute to the particle deposition. Particle deposition data can be used to optimise the cleanroom cleaning program.

Particle deposition can also be used to determine the risk of particle contamination at specific locations and specific times and help to select the right moment to expose 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.

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