SENSIRION
THE SENSOR COMPANY

Sensor Specification Statement

How to Understand Specifications of Sensirion Particulate Matter Sensors

Preface

This document gives details on how the terminology concerning Sensirion particulate matter (PM) sensors specifications is to be understood. Since there is no common agreed standard procedure between PM sensor manufacturers for specifying PM sensors, nor is there a standard setup for measuring them, it can be difficult for users to clearly understand and compare the declared performance parameters of different products. It is the purpose of this document to clarify specifications of Sensirion PM sensors.

1 Particulate Matter Specifications

1.1 Basic Considerations

Sensirion Particulate Matter (PM) sensors are optical particle counters (OPCs) based on laser scattering. All OPCs guide ambient, suspended particles to a measurement cell inside the device. The measurement cell consists of a light source (e.g., a laser) and a photodetector. Due to the interaction of particles and light, part of the incoming light is scattered towards the nearby photodetector (see Figure 1).

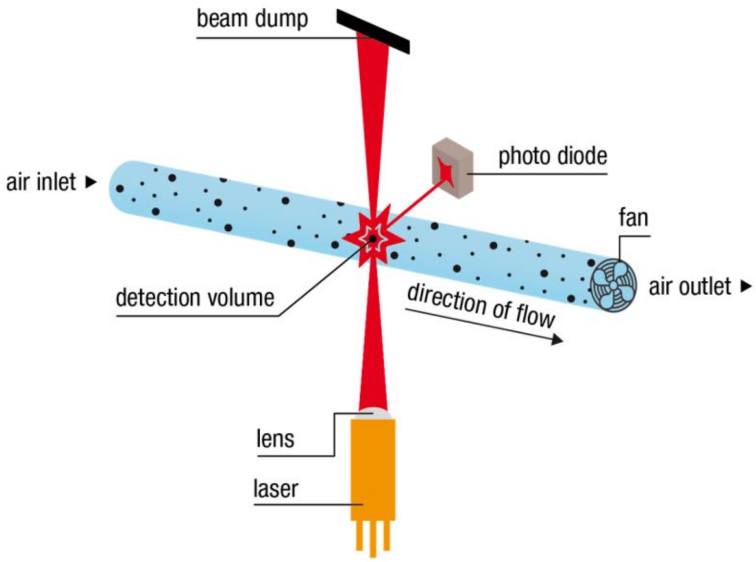

Figure 1 Measurement principle of Sensirion PM sensors.

The collected signal is converted into real-time particle count and mass concentration values, respectively given in #/cm^3 and in µg/m^3. Although OPCs are fairly comparable in performance when counting particles, the algorithm converting the measured signal into a mass concentration is a real performance differentiator among different sensor manufacturers. The reason behind this is that optical parameters of particles (such as refractive index and shape) have a big influence on the estimation of the particle mass. Therefore, the indirect optical (laser-based) measurement has an intrinsic discrepancy when compared to the more accurate direct gravimetric (weight-based) methods.

However, in order to make PM sensors applicable to commercial products and ease our lives at reasonable cost, OPCs are the most convenient and practical technology implementation.

In order to understand clearly how a PM sensor performs, specifications must be brought to a simple understanding that can be tested with standard equipment. It is clear that such a simple understanding leaves some grey areas, which are not fully covered. Still, a specification shall give the user a reliable tool to understand the sensors and design his own devices accordingly.

1.2 Sensirion PM Sensor Calibration and Reference Equipment

Sensirion PM sensors are calibrated using regularly maintained and aligned high-end reference instruments (e.g., the TSI Optical Particle Sizer Model 3330 or the TSI DustTrak™ DRX 8533), in order to guarantee the smallest possible batch-to-batch variation. For this reason, it is always possible to measure and reproduce the sensors specification values on Sensirion's measurement equipment, as well as compare the sensors' output to the output of these reference instruments. However, although the user might use reference instruments with the same model number and manufacturer as Sensirion to compare numerically such outputs, there might be situations those instruments show considerable output differences among each other (often more than 20% of the measured value). This can be caused by many factors like different reference instrument configurations, reference drift over time, heavy dust exposure during usage, irregular or missing maintenance or even differences in the recalibration procedures used by different laboratories during regular device maintenance.

In order to provide the user with a practical and easily reproducible tool to verify Sensirion PM sensors performance, "precision" is chosen as main sensor specification, instead of "accuracy". Nevertheless, each and every outgoing Sensirion PM sensor is verified and sorted after calibration using the regularly maintained and aligned reference instruments and aerosols as indicated in the datasheet.

For a simple but thorough understanding, the precision of PM sensors may be divided into two different contributions: calibration precision and long-term drift.

1.3 Calibration precision

Calibration precision, also referred to as "precision error", "between-parts variation" or "device-to-device variation" (short "D2D"), is the main component of the precision specification. It provides information on the output deviation of an individual sensor compared to the average output of a group of sensors, such as a batch, at the time of calibration. Major causes for tolerance on calibration precision are physical variations such as aerosol homogeneity, environmental conditions, repeatability and stability of the calibration reference, and stability of the sensors. Using this definition, the calibration precision is independent of the individual reference characteristic, as long as it delivers repeatable readings.

Sensirion specifies calibration precision in the following way:

Precision: measured output deviation of an individual sensor against the output average of a sensor batch. The product complies with the specification, if the measured values are located inside the precision limits (Conditions: 25°C and nominal supply voltage, unless otherwise stated).

1.4 Measuring calibration precision

Calibration precision is determined by running all the sensors in the batch simultaneously and in the same decaying aerosol concentration transient (from high to low concentration). For the determination of calibration precision in a certain concentration range, a time-averaged concentration is extracted from the same time period for all sensors. In order to filter out the impact of the statistical noise of the measurement, the time period for the average needs to be at least 150 seconds long, starting from any time instant after the aerosol in the test chamber is homogeneous and stable. An example of the extraction of the time-averaged concentration value for precision evaluation is shown for one sensor in Figure 2 and for several sensors (e.g., all sensors in a batch) in Figure 3.

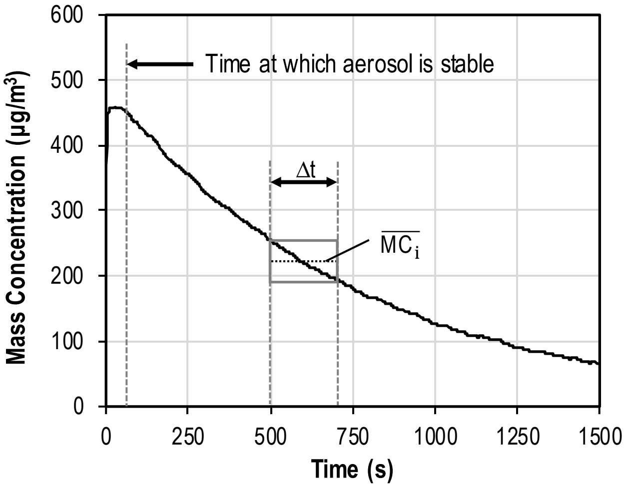

Figure 2: Extraction of the time-averaged mass concentration value ($\overline{MC_\iota}$) for a Sensirion PM sensor. In order to filter out the impact of the statistical noise of the measurement, concentration is averaged over a time period Δt.

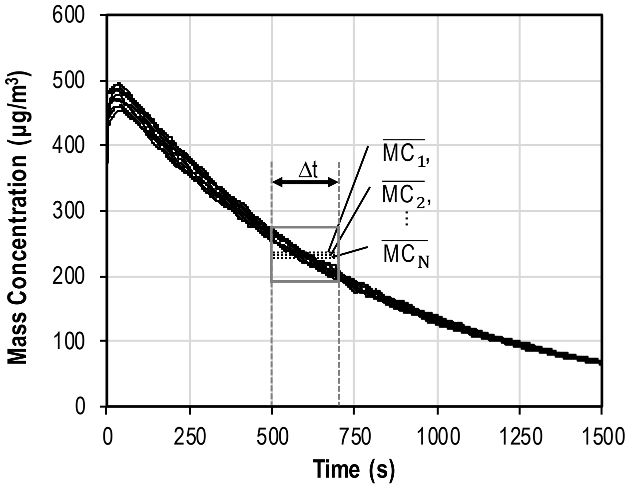

Figure 3: Extraction of the time-averaged mass concentration values ($\overline{MC_\iota}$) for several Sensirion PM sensors. In order to evaluate precision, sensors are individually averaged over the same time period Δt and $\overline{MC_\iota}$ values are collected in a distribution.

From a group of sensors an average value and maximum deviation of the time-averaged concentration values can be determined. The deviation from the average value is defined as "precision". With these values the compliance of precision limits can be checked – see Figure 4 and Figure 5.

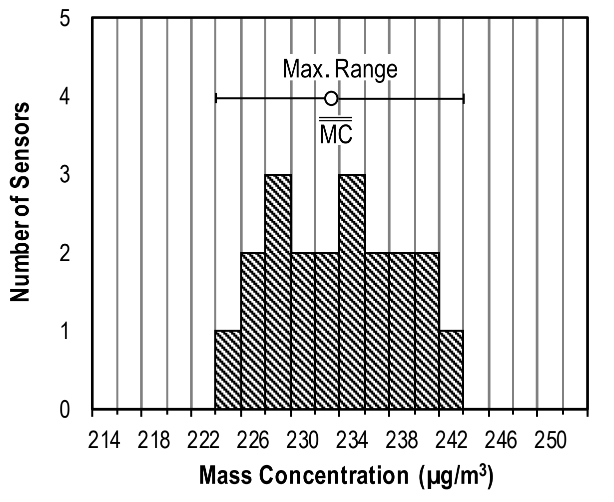

Figure 4: Extracted distribution of sensor deviation around average. *Max. range* must fit into specification band (see also Figure 5). $\overline{\overline{MC}}$ denotes the sensor sample average.

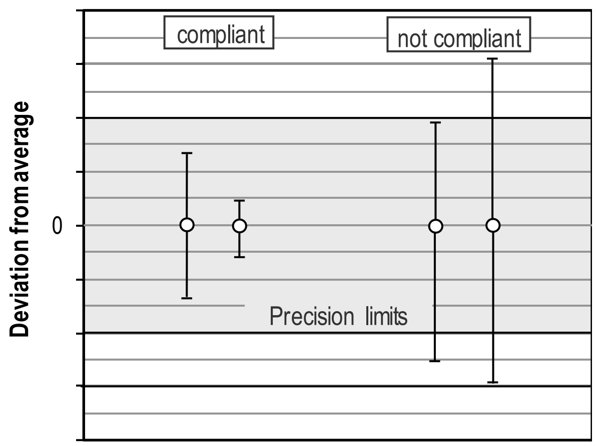

Figure 5: Examples for sensor distributions complying (left side) or not complying (right side) with the specified precision range. Open dots represent average values. Error bars denote *max. range* and must stay within precision limits.

1.5 Verification aerosol and calibration accuracy

As mentioned above, it is often not possible to quantitatively compare the sensors output to the output of different high-end reference instruments around the world, as these high-end devices might show considerable output differences among each other (often more than 20% of the measured value) if not properly configured and maintained.

Sensirion ensures proper maintenance and alignment of internal reference instruments in order to verify and sort 100% of the sensors after calibration. This verification process takes place by comparing the numerical output of the sensor to the numerical output of Sensirion's regularly maintained and aligned reference instruments, using the sensor output and aerosol as indicated in the product datasheet (e.g., PM2.5 and KCl). Aim of this process is to verify the sensor deviation against these references, or, in other words, the calibration "accuracy".

1.6 Performance of PM4 and PM10

One of the limiting aspects of today's laser based particulate matter sensors is their limited detection rate with respect to the actual sampling volume. While more expensive instruments are often configured to count each and every particle in the sampling volume, low cost sensors only capture a much small fraction of the aerosol particles (e.g.3-5%) and therefore heavily rely on statistics and extrapolation. The number count density of the PM10 fraction of typical aerosols is extremely low; therefore, PM10 cannot be measured directly by low cost PM sensors.
To give an example, an artificial aerosol with particles having a diameter of 8µm contains 500 times less particles compared to an aerosol with 1µm particles at the same particulate mass level. In order to measure PM10 with the same precision as PM1.0, a low cost PM sensor would have to integrate over many hours to obtain enough statistics. Therefore, the PM4.0 and PM10 outputs of Sensirion's PM sensors are estimated from PM0.5, PM1.0 and PM2.5 measurements considering typical aerosol profiles instead of being based on "real" raw data events from large particles.

2 Electrical specifications

2.1 Supply voltage

The ***Supply Voltage (VDD)*** range is defined with an upper and a lower limit plus a typical value. Any supply voltage in that range may be used for continuous operation. Absolute maximum voltages, which may be applied during limited time, for some sensors are specified in the respective Datasheet. The typical value defines the supply voltage at which the sensors are calibrated and at which outgoing quality control is performed.

2.2 Current and Energy Consumption

In operation the sensor pulls a certain ***Supply Current, IDD***. This current is different for different modes, e.g., sleep, idle and measurement. Furthermore, in the sample of sensors there is a certain variation of current consumption – the average is specified as typical value while with minimum and maximum values the upper and lower limit is defined.

3 Acoustic Emission Level

3.1 Basic Considerations

Acoustic emission level provides information on the acoustic sound pressure level (SPL) caused by the sensor. The main sources of acoustic noise for OPCs and PM sensors for the mass-market are the mechanical moving parts, such as the blower fan, as well as the vibrations of the enclosure of the package. Sensirion high precision manufacturing assembly line ensures high quality packaging, limiting acoustic noise arisen from vibration of the sensor enclosure. For what concerns the fan, best-of-class components are chosen for Sensirion PM sensors. Then, it is important to note that an additional and unwanted external source of acoustic noise may come from the mechanical coupling between the sensor and the fixations, which can be reduced by a proper mechanical design and assembly[2].

3.2 Acoustic Emission Level

SPL is a logarithmic measure of the effective pressure of a sound relative to a reference value, and it is defined by the formula:

$$L_p \text{ [dB]} = 20 \log_{10}\left(\frac{p}{p_0}\right)$$

p is the sound pressure, and p_0 represents the reference sound pressure (i.e., 20 µPa), which is often considered as the threshold of human hearing. Note that the lower limit of audibility corresponds to 0 dB. To match the human perception of sound, the so called A-weighting, abbreviated as dB(A), is applied to the measured SPL, which is valid for SPLs up to 55 dB. The SPL is typically characterized according to IEC 61672-1 standard inside an anechoic chamber with very low background noise.

The acoustic emission limits of SPSxx products are specified at 25°C, nominal supply voltage and normal measurement mode, unless otherwise stated.

For this characterization method, an acoustic analyzer Brüel & Kjaer 2250 with calibrated microphone 4189 is operated in an anechoic chamber with a background noise of < 19 dB(A). Each sensor is suspended in the air with the blower outlet centered below a microphone (see Figure 6).

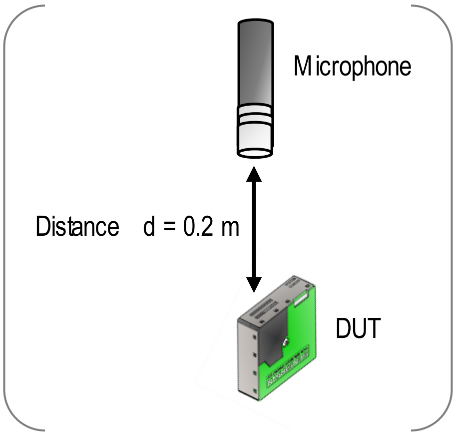

Figure 6: Measurement setup for the acoustic emission level test.

The sound emission of the module is logged every second over a period of 90 s (i.e., 90 data points) with a recording quality of 20 kHz and a resolution of 24 bit.

Fluctuations of the sound pressure are smoothened by using the equivalent continuous sound level LAeq. LAeq is the logarithm of the ratio of a time-mean-square, A-frequency weighted sound pressure for a stated time period (1s for our measurement) to the square of the reference sound pressure of 20 µPa.

While the first 70 s of the measurement are used for stabilization (warm up, stabilizing the fan speed), the successive 20 s (i.e., 20 data points) are taken to calculate the median of the LAeq.

An example of acoustic emission level measurement for a Sensirion PM sensor is shown in Figure 7. The y-axis shows the LAeq value in dB(A) whereas the x-axis shows the time elapsed from the beginning of the test in seconds.

[2] For further details, please refer to the document "Sensirion Particulate Matter Mechanical Design and Assembly Guidelines".

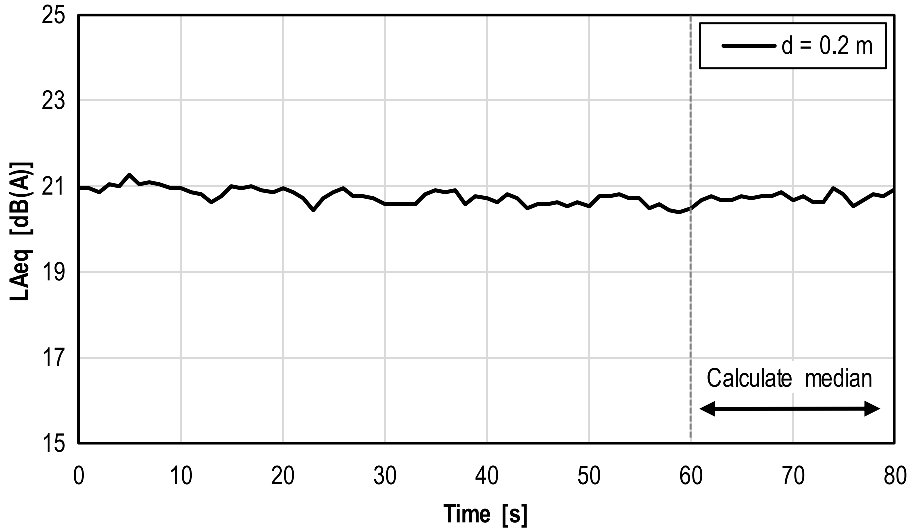

Figure 7: Measurement data for acoustic emission level in dB(A) for the typical SPSxx PM sensor at a distance of 0.2 meters.

4 Long-Term Drift

4.1 Basic Considerations

Long-term drift applies to *precision* and *acoustic emission level* specifications.

Concerning *precision*, the sensor aging may lead to drift of the measured value compared to initial operation. Such a long-term drift may move to the upper or lower side or may change direction in the course of time. The long-term drift value denotes the drift (i.e., the increase) of the precision limits per year.

Concerning *acoustic emission level*, the sensor aging may lead to drift of the measured level compared to initial operation. Such a long-term drift is usually positive: it moves to the upper side in the course of time, i.e., the sensor acoustic emission level increases. The long-term drift value denotes the drift (i.e., the increase) of the level limit per year.

4.2 Verification of Long-Term Drift

In the case of Sensirion PM sensors, long-term drift is verified by exposing a sample of sensors to several aging tests, as described below.

4.3 High Temperature Operating Lifetime (HTOL)

HTOL is a thermally activated aging test where sensors are operated at elevated temperature for a defined test duration (e.g. 60°C, 1000 hours) in order to simulate a much longer lifespan at typical operation conditions (25°C). The test duration for accelerated aging conditions can be calculated following JESD22-A108F.

4.4 High Temperature Humidity Bias (THB)

THB is a temperature and humidity activated aging test where sensors are operated at elevated temperature and humidity levels for a defined test duration (e.g., 60°C , 90 %RH, 860 hours) in order to simulate a much longer lifespan. The test duration for accelerated aging conditions can be calculated following JESD22-A101D.

4.5 Temperature Cycling (TC)

TC is a thermo-mechanically activated aging test. Sensors are operated in repeated low and high temperature cycles (e.g. 380 cycles, -40 °C/ +60°C, 30 minutes, each) to simulate typical cyclical exposure over lifetime. The typical temperature difference that is being simulated can be calculated following JESD22-A104E.

4.6 Resistance to Dust (RD)

RD is an environmentally activated aging test, where sensors are exposed to a very high PM concentration level in order to simulate dust exposure over lifetime. The test conditions are calculated such, that an indoor PM concentration of approx. 44 µg/m^3 over 10 years is achieved. This level corresponds to a literature level of average indoor PM concentration during operation in Beijing[3].

[3] From "Characteristics of PM2.5 mass concentrations and chemical species in urban and background areas of China: emerging results from the CARE-China network" (Liu et al, 2018): https://doi.org/10.5194/acp-18-8849-2018.

Revision History

Date	Version	Page(s)	Changes
23. March 2020	1	All	Initial version

Important Notices

Warning, Personal Injury

Do not use this product as safety or emergency stop devices or in any other application where failure of the product could result in personal injury. Do not use this product for applications other than its intended and authorized use. Before installing, handling, using or servicing this product, please consult the data sheet and application notes. Failure to comply with these instructions could result in death or serious injury.
If the Buyer shall purchase or use SENSIRION products for any unintended or unauthorized application, Buyer shall defend, indemnify and hold harmless SENSIRION and its officers, employees, subsidiaries, affiliates and distributors against all claims, costs, damages and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if SENSIRION shall be allegedly negligent with respect to the design or the manufacture of the product.

ESD Precautions

The inherent design of this component causes it to be sensitive to electrostatic discharge (ESD). To prevent ESD-induced damage and/or degradation, take customary and statutory ESD precautions when handling this product.
See application note "ESD, Latchup and EMC" for more information.

Warranty

SENSIRION warrants solely to the original purchaser of this product for a period of 12 months (one year) from the date of delivery that this product shall be of the quality, material and workmanship defined in SENSIRION's published specifications of the product. Within such period, if proven to be defective, SENSIRION shall repair and/or replace this product, in SENSIRION's discretion, free of charge to the Buyer, provided that:

- notice in writing describing the defects shall be given to SENSIRION within fourteen (14) days after their appearance;
- such defects shall be found, to SENSIRION's reasonable satisfaction, to have arisen from SENSIRION's faulty design, material, or workmanship;
- the defective product shall be returned to SENSIRION's factory at the Buyer's expense; and
- the warranty period for any repaired or replaced product shall be limited to the unexpired portion of the original period.

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