White Paper Pegasor Mi3

Background - Particle size is not well defined

Fine and nanoparticles can be defined in many ways. Especially when defining the particle size and concentration. Particle size can be measured either off-line or on-line. Off line techniques typically give out particle filter mass concentration. Off-line techniques are seldom used to define particle size. When this is done, electron microscopy is typically used to measure particle geometric size. When measuring particle concentration with off-line techniques, several artefacts enter into play. When particles, especially from engine exhaust are collected on a filter, the filter media itself reacts with the exhaust gas particles thus having an effect on the final result. This effect is relatively larger for small concentrations. This filter artifact is shown in Fig. 1. DPF means Diesel Particle Filter, CVS means Constant volume Sampler and PPS is Pegasor Particle Sensor, which forms the core of Pegasor Mi3. PM means Particulate Mass measured by gravimetric filter.

On-line techniques measure particles in several different ways and extract different metrics out of the particles depending on the technique used. When measuring particle size and concentration simultaneously, most commonly used detection methods are optical or electrical (electrical mobility, aerodynamic particle size). In electrical detection the extracted data is converted into size and concentration information using known conversion formulas. Formulas enable the user to extract one or more of the following quantities; particle size distribution, total particle mass, total particle surface area or total particle number concentration.

It is very important to know what metrics are measured and that those seldom match with each other 100%.
Fig. 1. Filter artifact when measuring small Particle Mass (PM) concentrations. Filter reading becomes random when measuring DPF equipped vehicles. Pegasor Mi3 (with PPS as its core measurement cell) maintains linearity over the entire concentration range.

Pegasor Mi3 Technical Description

The Pegasor Particle Sensor (PPS) is based on the electrical detection of aerosol following the “escaping current” technique, which was first described by Lehtimäki [1]. A sample of the exhaust gas is charged by a corona-ionized flow as it is being pumped by an ejector diluter built in the sensor’s construction. While the majority of the corona ions return to the grounded sensor’s body due to their high electrical mobility, a small quantity is lost with the charged particles exiting the sensor. This “escaping current” is a measurement of the particle concentration in the exhaust gas. The sensor responds to particle size and concentration with a function that lies between the response to particle number and mass [2, 4].

The purpose of Mi3 is to protect the PPS-M sensor from contamination and misuse in all conditions. Pegasor Mi3 using PPS-M as core is calibrated to for both total particle mass and total particle number concentration according to the formulas for PPS-M generated by Laboratory of Applied Thermodynamics in Thessaloniki, Greece [2]. The operation principle of the Pegasor Particle Sensor (PPS-M) is shown in Fig. 2. A picture of PPS-M is shown in fig. 3. and PPS-M inside Pegasor Mi3 is shown in fig. 4.
Fig. 2. Pegasor particle sensor (PPS-M) operational principle

Fig. 3. Pegasor Particle Sensor (PPS-M) forms the core of Pegasor Mi3
Pegasor Mi3 features the world’s fastest fine and nanoparticle measurement technique giving out simultaneously total ultrafine particle mass and total particle number concentration in real time from 10 nm and up. Additionally, Pegasor Mi3 is a non-collective, flow through device which enables it to work continuously without maintenance for extended periods of time. Pegasor Mi3 is designed to measure raw and hot engine exhaust. Typically, no dilution is needed, but for very polluting sources Pegasor Mi3 has an internal dilution function that can be used to dilute the raw exhaust up to 1:5. This dilution extends the continuous service free operation time of the Mi3 and enables the sensor to be used in exhaust concentrations higher than $1 \times 10^9$ $1/cm^3$ for number and higher than 300 mg/m$^3$ for mass. Pegasor Mi3 has no consumables. The most important features and benefits are given below.

**Benefits**

Pegasor Mi3 has very low operational cost. Periodic cleaning of the insulators is enough when sensor is used according to instructions. Annual calibration at manufacturer’s site is provided for some customers Q&A purposes.

PPS-M has extensive self-diagnostics to ensure correct measurement results at all times. Sensor informs the user when cleaning of the sensor is necessary (10 x before the contamination has any effect on the result). Additionally, all critical parameters (corona current, corona voltage and trap voltage) can be recorded on the data file with alarm message attached, if out of set range.

Pegasor Mi3 is designed so that misuse of the instrument is very difficult. Sample flow is not possible before the sensor has reached the set operation temperature. Corona can be lit only when the supply air (Nitrogen) is dry, particle and hydrocarbon free. Sample flow is enabled only when supply
air (Nitrogen) is within the set pressure range. Mi3 stops operation and closes all valves, if supply air is switched off or does not fulfill set quality criteria.

Mi3 has possibility for manual operation (start, stop, standby) push buttons in the unit itself or automated/remote operation through AK Protocol, CAN bus or Ethernet. Digital and analog inputs and outputs and relays are available.

Pegasor Mi3 Specifications

- Real time measurement
  - the fastest ultrafine particle measurement device in the world \((t_{0\%}-t_{95\%} \, 0.2 \, s \, response \, time)\)
- Measures ultrafine particle concentration from 10 nm and up. Lower measured particle size can be set with an adjustable trap from 10 up to 90 nm
- Multi-parameter measurement
  - simultaneous total ultrafine particle mass and total ultrafine particle number concentration measurement
- Portable (l 720 x w 495 x h 240) and weight 37 kg
- Ingoing sample temperature max 200 °C
- Heated sampling lines (minimum length 1 m, 2-3 meters recommended) condition the sensor ingoing sample to 200 °C at the sensor inlet
- Extracted sample temperature at the sampling point from as low as -40 °C up to 850 °C
  - Sensor temperature self-regulated to 200 °C. Mi3 cabin must be placed in an environment where the temperature range is from -20 °C to +50 °C. Placing the Mi3 cabin in higher temperatures may cause permanent damage to Mi3. Placing the cabin in lower temperatures may unable the corona to be lit
- No dilution needed
- Raw undiluted hot measurement possible. For very high exhaust ultrafine particle concentrations internal 1:10 diluter is available
  - mass concentrations from < 1 µg/m³ to 300 mg/m³
  - number concentrations from 300 1/cm³ up to 1*10⁹ 1/cm³
- Continuous operation and low maintenance
  - flow-through design
  - only periodic cleaning of the insulators when sensor used according to instructions
  - annual calibration at manufacturer’s site recommended for some customers Q&A purposes
- Low initial investment
- No consumables
- Smart
  - sensor informs user when cleaning is necessary (10 x before the contamination has any effect on the result)
  - extensive self-diagnostics to ensure correct measurement results at all times
- High accuracy? +/- 24% for total ultrafine particle number and +/- 38% for total ultrafine particle mass. This data is for 90 % confidence interval. See fig. 5.
Fig. 5. Max theoretical error of Pegasor Mi3 (not engine specific). This map covers all engine emissions found in the literature with wide range of GSD (Geometric Standard Deviation) and Geometric Mean Particle Diameter (GMD). Reducing the error requires engine-specific calibration. Then the max error is easily below ± 5% since GSD and GMD of one engine do not vary that much.

Data Communication

- Graphical User Interface (GUI) PPS Plotter Software
  - PPS plotter software can handle several sensor data simultaneously. Additionally, all critical parameters (corona current, corona voltage and trap voltage) can be recorded on the data file.
  - connection with USB or Ethernet (distance limited to same segment)
- AK-protocol over Ethernet
- Freely programmable analog outputs
  - 4 channels
  - current loop or voltage output
- 2 signal relay outputs
  - ‘measure ok’
  - ‘alarm’
- 6 signal inputs
  - 5-30 V optoisolated inputs
  - ‘stop’
• ‘standby’
• ‘measure’
• 3 time stamp inputs (for plotter software files)
• CAN-bus output
  • 4 signals freely programmable
  • 16 bits per signal
• Operating voltage AC 100-240V, 50-60 Hz, 500 W max or DC 24 V 20 A max
• Continuously self-diagnosed for sensor loading (+several other parameters)

Pegasor Mi3 Strengths

Pegasor Mi3 has been designed for affordable aerosol concentration measurement from variable locations. Mi3 is especially handy in engine exhaust and stack emission measurements. Competing devices are typically labor consuming and require frequent service and plenty of consumables and user attention.

Pegasor Mi3 has no cross sensitivity to compounds such as NOₓ or O₂. Pegasor Mi3 is measuring aerosol, which is a particle suspended in gas, whether in solid or liquid phase or the combination of both. Instrument cross sensitivity can sometimes make data analysis difficult. E.g. gravimetric filter can react with the exhaust gas. Some other instruments are known to be cross sensitive to e.g. NOₓ and O₂, Pegasor Mi3 is measuring aerosol concentration. It is well defined with no interference nor material dependence in the aerosol itself. In fig 6. The measured parameters of three most common engine exhaust measurement devices is shown. Pegasor Mi3 is shown as PPS-M since this is the core of Mi3.

![Diagram of measurement devices](image)

Fig. 6. An example of what different measurement devices measure. The result with Pegasor Mi3 (with PPS-M as its core) measurement is well defined since it measures aerosol.

Pegasor Mi3 requires no sample conditioning. In devices that use sample conditioning hot exhaust gas is cooled to room temperature by diluting the sample with cool air. This causes time delay to the measured results and additionally preventing formation of new particle modes such as nucleation
mode or heterogeneous condensation of semivolatile on existing particle surfaces is difficult. And particle size and concentration is often altered. The fact that sample conditioning is not needed is considerable cost savings for Pegasor Mi3. No extra sampling system is needed and no sampling artifacts exist.

Mass and Number Calibration Instrumentation and Experimental Layout

The sensor was calibrated at the Laboratory of Applied Thermodynamics for mass and number particle concentration measurement using aerosol produced by a Toyota 1ND-TV 1.4L Euro 5 compliant light duty diesel engine (Table 1). In actual vehicle installations, this engine is used in combination with exhaust aftertreatment, including a DPF. We have utilized no aftertreatment in our case but direct engine-out emissions as an aerosol source for calibration. A schematic of the experimental setup is shown in Figure 7. PPS-M, which is inside Pegasor Mi3 was installed in the tailpipe of the engine, some 2 m downstream of the exhaust manifold, directly sampling raw exhaust. The probe inlet and short transfer line of the sensor were maintained at 200°C by means of a wall heater to avoid condensation and thermophoretic losses.

Figure 7. Experimental setup used for the mass and number calibration of the sensor.

For more detail, please see PPS-M white paper paragraph ‘Mass and Number Calibration Instrumentation and Experimental Layout’
Further Information

Adjustable Trap Voltage. Pegasor Mi3 has trap voltage range from 0 to 2kV. This corresponds to lower particle cut diameter from 10 nm up to 90 nm. Please see PPS-M white paper for further details. PPS-M white paper also has plenty of measurement data with the PPS-M sensor, which would be the same result for Mi3 since PPS-M is inside Pegasor Mi3.

Summary

Pegasor Mi3 offers world’s fastest fine and ultrafine particle concentration measurement. Mi3 measures particle number concentration and mass concentration simultaneously from 10 nanometers and up. Mi3 has been designed so that user error that damages the Mi3 unit is very difficult to make. Clean air/Nitrogen supply pressure is continuously monitored and set to 150 kPa overpressure before entering the sensor. For clean air there is moisture and hydrocarbon removal devices inside the Mi3. Inlet and outlet ports are protected by valves that can be opened only when all operation parameters are within set range. This means sensor temperature, clean air supply pressure and humidity, clean air flow to the sensor is open thus protecting the corona from damage due to particle containing sample entering the corona chamber.

Pegasor Mi3 operates up to 200 °C thus eliminating negative effects of semivolatiles such as nucleation mode. Pegasor Mi3 does not require any sample conditioning such as dilution. However, dilution 1:5 is available, if measurement of very high concentrations is needed or if the user wants to extend continuous operation of the sensor without cleaning the insulators.

Flexible sampling line is self-regulated to 200 °C. Minimum sample line length is 1 meter and maximum 8 meters. 2-3 meters is recommended for ease of use. 2 meters or longer heated sampling line conditions any sample from -40 °C to 850 °C to 200 °C at the sensor inlet. In very hot sampling uninsulated tube must be used at the sampling point to cool the sample to 200 °C before entering the heated flexible sampling inlet line so that no damage is caused to the conductive tube media.

Pegasor Mi3 includes PPS Plotter graphical user interface to set up the sensor operation parameters, monitor and record data. Several other data communication possibilities are also available. CAN Bus, AK Protocol, analog/digital output, digital input and ethernet. This enables easy integration of Mi3 into existing communication and data collection infrastructure. Pegasor Mi3 is self-diagnosed and it informs the user on any action needed to keep the sensor data reliable and accurate. Pegasor Mi3 in case of supply air failure protects the sensor from contamination (soot entering the corona chamber).

Scientific Publications


• Chung, MC et al. “Comparison study on characteristics of nanosized particle number distribution by using condensation particle counter calibrated with spray and soot type particle generation methods”. In: International Journal of Automotive Technology 15.6 (2014), pp. 877–884.


Conference Presentations


• ZHANG, Qi-Jun et al. ‘On-road Emission Characteristics of Logistics Transportation Vehicles in Chengdu’. In: International Conference on Social Science. 2014.


References


