Measurements of Engine Exhaust Gas with a PMP System and a Fast Automotive Particle Emission Spectrometer (FAPES)

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1. Introduction

With the EURO5b/6 regulations measurements of particle number concentrations in engine exhaust gas are obligatory. The measurement systems were standardized by the particle measurement programme (PMP) and consist of a condensation particle counter with a 2 stage dilution system (PMP system). Such systems provide total number concentrations with a limited time resolution; however, particle size distributions (PSD) with better time resolution are very useful to characterize engine performance or the efficiencies of diesel particulate filters.

2. Setup and Measurement Principle

The GRIMM Fast Automotive Particle Emission Spectrometer (FAPES) measures number size distributions in engine exhaust gas in the size range of 6.3 nm to 484 nm with a sampling rate of 0.1s in a wide range of concentrations (~500 to $4x10^9$ particles/cm^3), as shown in Fig.1.

The FAPES system includes: (i) fully integrated sampling and dilution system which is illustrated in Fig.2, suitable for temperatures of 5 - 500℃ and for a pressure range of 100 – 1300 hPa, (ii) a bipolar diffusion charger (18.5 MBq Am-241), (iii) 10 Vienna-type Differential Mobility Analysers (DMAs), (iv) 10 fast and low noise Faraday Cup Electrometers (FCEs), each directly attached to a DMA. The bipolar charging guarantees a well defined charge distribution and thus a reliable reconstruction of the PSD, and unlike for unipolar chargers no calibration is necessary.

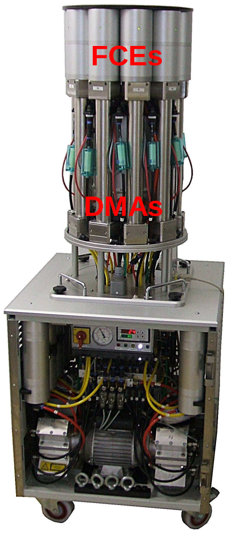

Fig.1 FAPES Components.

The sampling probe is connected to the bottom of the FAPES by a flexible metal tube, and contains a heater for the dilution air, the diluter, and a cooler for the diluted sample air. The sample air is diluted with particle free, heated and dried air. This dilution air is generated from recirculated sample air without need for external air supply. The dilution process occurs without condensation of volatile components and it does not change the PSD. The equilibrated pressure of the dilution system and the exhaust gas tunnel avoids the evaporation of volatile components.

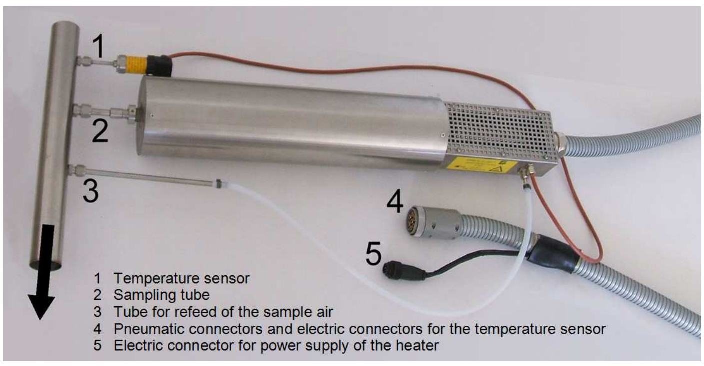

Fig.2 The sampling probe connected to an exhaust gas tunnel.

Aerosols from the dilution system pass through the bipolar diffusion charger. The charged particles are classified with 10 DMAs operated in parallel. The DMA voltage is kept constant for each of the individual 10 DMAs. Each DMA is operated with a constant sample air and sheath air volume flow.

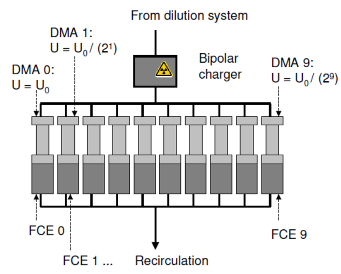

Fig.3 Measurement principle.

The detection of particles is accomplished with 10 FCEs, one FCE for each DMA. The FCE signals are insensitive to mechanical shocks and vibration.

3. Typical Results

With GRIMM FAPES system, each signal originates from an individual DMA and corresponds to a well defined and narrow size range; therefore we achieve an excellent size resolution over the full size range. Moreover, the spacing of voltages facilitates a proper correction of multiple charged particles in the inversion algorithm. It enables simultaneous concentration measurements for 10 particle diameters in excellent accuracy and precision, and these data are used to reconstruct the number size distribution in 21 channels. Figure 4 shows a group of continuous measurement results for diesel engine 1.9l and gasoline fuelled engine 3.5l.

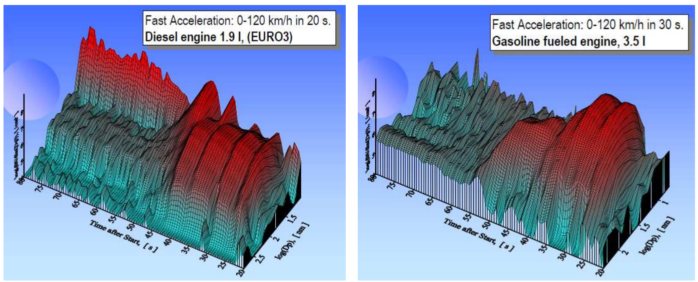

Fig.4 Results measured with GRIMM FAPES.

Parallel measurements were done with a PMP system and the FAPES, seen in Fig.5. The sample gas was drawn from a raw gas tunnel with a heavy duty EURO2 engine operated with the European Stationary Cycle (ESC) at the Korean Automotive Testing and Research Institute (KATRI). For the comparison of the two systems, we have calculated total number concentrations for particle sizes larger than 23 nm from the measured size distributions. These calculated number concentrations agree very well with number concentrations measured with the PMP system.

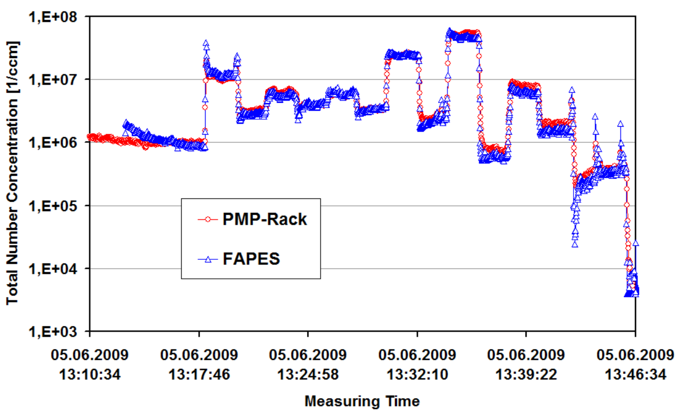

Fig.5 Comparison between FAPES and PMP-Rack.

4. Applications

The FAPES finds a wide range of applications, from standard test measurements to fundamental research, from high concentrations in engine exhaust gas to normal environmental conditions, from dynamic behaviour in combustion processes to dynamic processes during nucleation events even at different temperatures, pressure levels or altitudes.