High speed OBD sensor tests at Wärtsilä engine laboratory

In order to be able to measure the rapid particle concentration changes in exhaust line during transient driving conditions, the time response of the measurement instrumentation needs to be fast enough. The typical time scale in the changes is well below one second and currently there are some sensor type instruments available for this time scale. But if the instrumentation could be fast enough, it would be possible to monitor the differences between different working cycles of the engine. This could provide information about the differences between different cylinders in a multi cylinder engine. The information could be used in engine development to track down the differences and to optimize the operation of each individual cylinder.

Previously, a high speed particle sensor made from modified OBD sensor by Pegasor Oy, was tested in engine dynamometer measurements in March 2012. During the tests it was found out, that the space charge of the charged exhaust aerosol was causing some interference to the measurement. Additionally, the 100 Hz sample frequency of the sensor was found to be just about enough for the measurement. For the second tests at November 2012 there was some improvements made to the prototype sensor. The sample frequency was increased to 200 Hz in order to improve the temporal resolution of the measurement and a static shield was constructed around the sensor head to prevent the space charge interference of the charged particles. A short set of measurements were carried out at the Wärtsilä engine laboratory in Vaasa to test the feasibility of the improvements.

Measurement setup

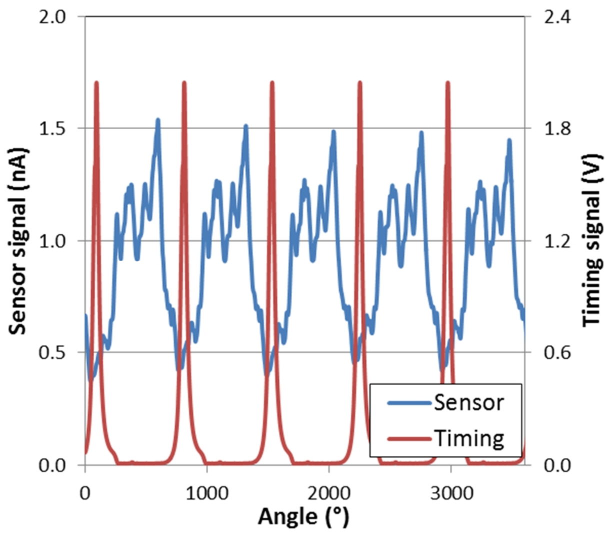
The OBD sensor was fitted directly in the exhaust manifold in the EGR return line after the EGR valve. This location was chosen because of an existing sampling point readily available in the manifold. The EGR return line is situated before the turbo charger, which made it possible to measure the individual working cycles of different cylinders. The chosen sampling location also provided the possibility to change the flow rate of the exhaust gas by changing the EGR valve position.

The measurements were started with idling conditions after which the engine speed of rotation and load was gradually increased. Additionally the EGR valve position was varied in different points to test the effect of exhaust gas flow velocity to the sensor signal. With the test engine it was possible to control the fuel injection of each cylinder separately. In the last measurement point, the fuel injection of one cylinder was gradually delayed to increase the particle emission from one cylinder. This simulated a fuel injection malfunction in one cylinder.

Results

The measurement results from two different engine load points are shown in figures 2 and 3 together with a pressure signal from one cylinder used as timing signal. In all plots an average of 20 repeated signals is shown as a function of the engine rotation angle. For both load points two different results are shown: on the left the sensor operated in normal conditions and on the right the sensor had particle charger switched off. The plots on the left hand side of the figures show the temporal behavior of the particle concentration measured by the sensor. The results measured without charging the particles gives information on the unwanted noise level coming from the flow of charged particles around the sensor head. As seen on the plots on the right hand side, the noise level is negligible compared to the measured signal level.

By comparing the right hand sides of figures 1 and 2 it can be seen that the temporal behavior of the concentration measured by the sensor is somewhat different. However in both cases the signal shape is very well repeating in consecutive working cycles of the engine. There is also difference in the average value of sensor signal, but it must be kept in mind, that the sensor was fitted in the EGR return line and the EGR valve position affected to the measured signal level.



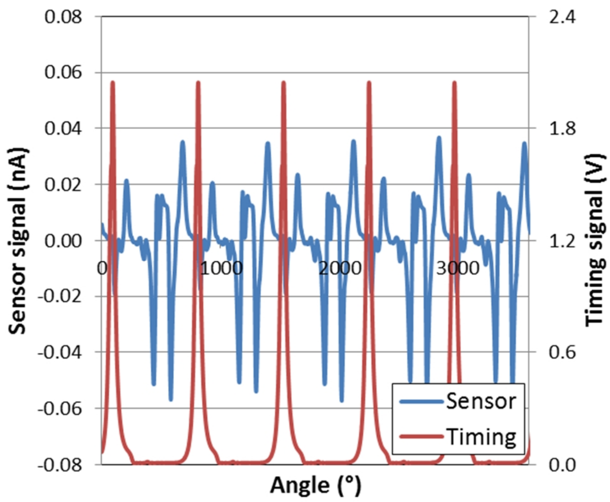


Figure 1. Measurement results at 350 rpm and 62 kW load. On the left the sensor output in normal operation and on theright the sensor output with the charger switched off.

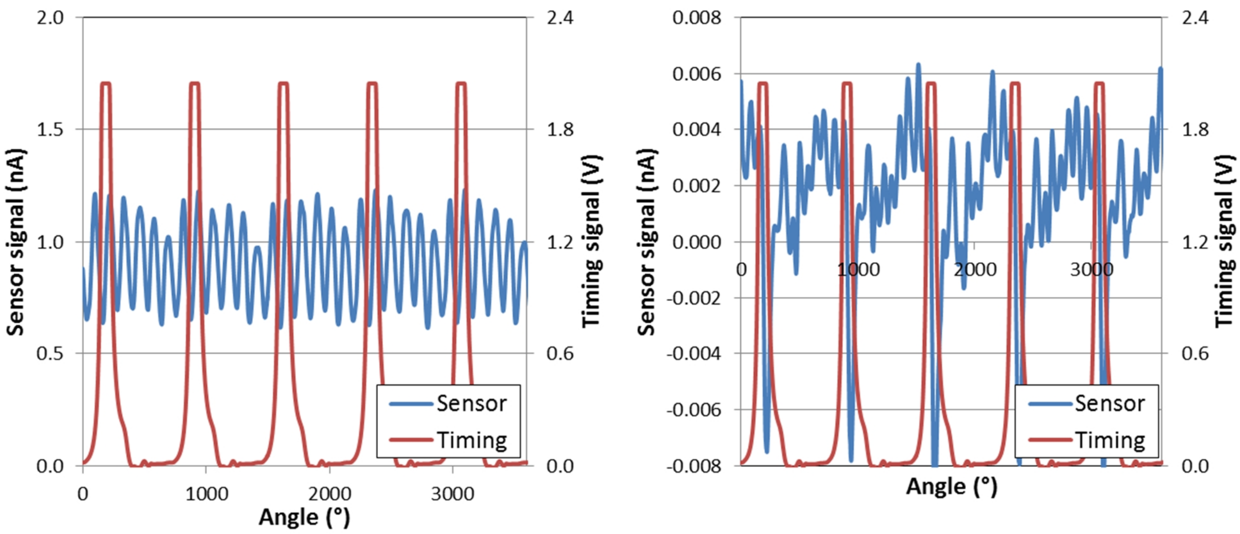


Figure 2. Measurement results at 750 rpm and 513 kW load. On the left the sensor output in normal operation and on the right the sensor output with the charger switched off.

In order to test the sensor feasibility to monitor the emission from individual cylinders, an injection malfunction in one cylinder was simulated. The high level of fuel injection control in the test engine made this possible by delaying the fuel injection in one cylinder. The measurement results of this test are shown in figure 3, where the sensor output signal from normal conditions and simulated injection malfunction conditions are plotted together with the timing signal. At the time of the measurement the engine was run with 350 RPM and 62 kW load. A clear difference can be seen between the two conditions. In normal conditions the sensor signal is relatively stable, but with the simulated malfunction conditions a distinctive repeating peak can be seen in the results. The peak indicates higher particle emission from the cylinder, where the fuel combustion is impaired by the delayed injection.

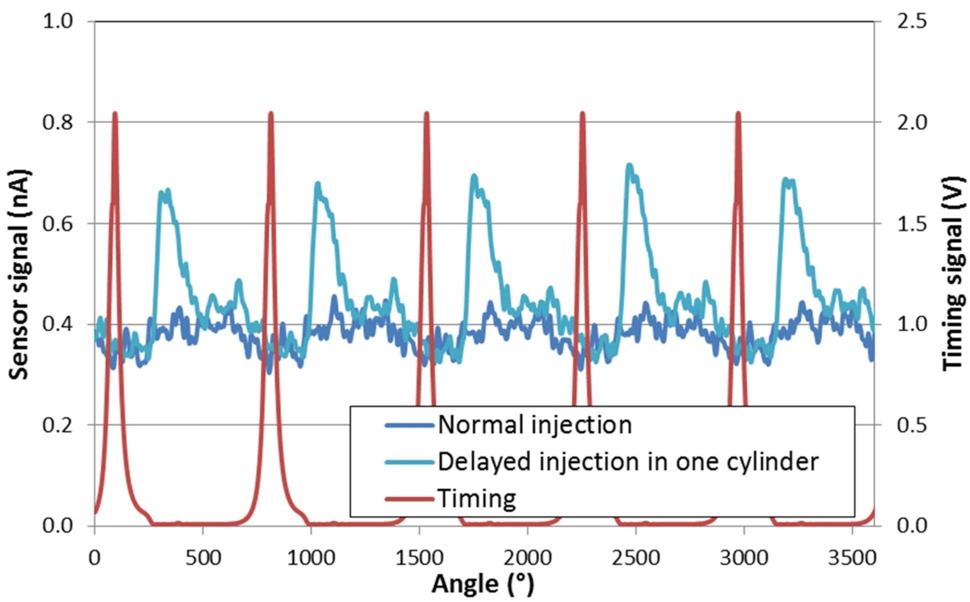


Figure 3. Sensor signal in two different engine conditions with 350 RPM and 62 kW load. Normal engine operation compared to simulated injection malfunction in one cylinder.

Summary and discussion

The improved version of the high speed particle sensor was tested by engine measurements at Wärtsilä engine laboratory in Vaasa. Despite the high temperatures, pressures and particle concentrations at the sampling point, the sensor operated well during the measurements. The measurement results show clearly repeating temporal changes in the particle concentrations at various engine speeds and loads. Additionally the simulated injection malfunction in one cylinder was clearly seen in the sensor signal, confirming the feasibility to measure particle emission of individual cylinders in multi cylinder engine. The sensor signal quality was improved by the improvements made. The higher sampling frequency increased the temporal resolution of the sensor, while the static shield around the sensor head reduced the interference from the flow of charged particles to a negligible level.

Although the prototype sensor operated well in these feasibility tests, there is still some room for improvements. As seen from the results, the sampling frequency of the sensor could be higher for the higher RPM load points measured. This would be possible by redesigning the sensor electronics to further improve the temporal resolution of the measurement. Increased sampling frequency would increase the signal quality and give the possibility to have good time response also with higher RPM. The sensor was only operated a limited time during the measurements. To minimize the sensor fouling and to minimize the need for sensor service accordingly, the sheath and cooling air flows needs to be improved. For this some changes in the mechanical design of the sensor is needed. For the sensor calibration and comparison measurements planned a set of fast enough reference instruments is needed. The time scale of the measurement is really challenging for the particle measurement instruments, since most of the instruments require sampling and dilution of the sample, which limits the time resolution of the measurement.