Smoke Particulate Sensors for OBD and high Precision Measuring

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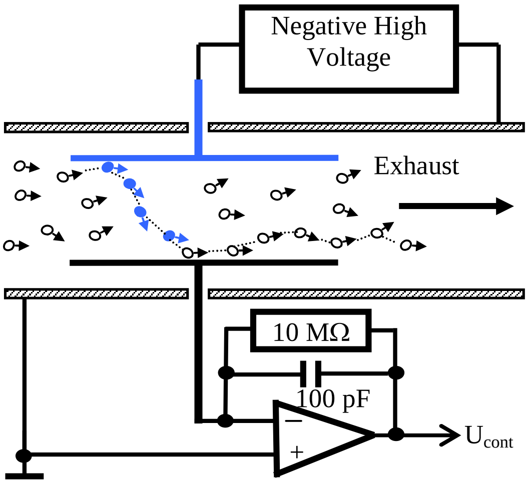
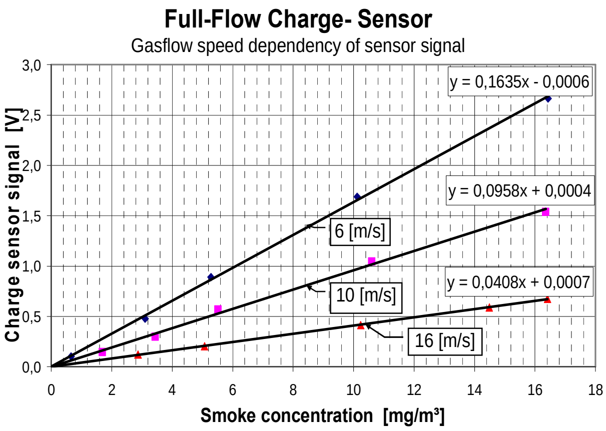
1. Methodology of Operation

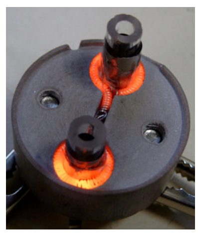


Soot particles produced during combustion are in principle charged but their net charge is essentially zero. Thus soot particles can be deviated by a transverse electrical field and can discharge on an electrode on impact. This property of the particles is used for transportation of electrical charge. Therefore capacitor blades are implemented inside the exhaust gas tube with a distance of 3 [mm]. The high voltage of 1500 [V] stays approx. 50 % beyond a spark event happens and produce the max. possible strength of an electrical field. Whilst the particulates pass this capacitor they are attracted by Coulomb forces on to the high voltage blades and, during statistically touching them, they will be charged. As they have then the same polarity as the electrode itself they are repelled and move on to the measuring electrode and are discharged there. The negative charge of the particles results in a positive output voltage of the DC-coupled charge amplifier. The RMS value of this voltage U_{cont} represents the particle mass with a correlation of R^2 = 97 % comparing to gravimetric measurements. At constant gas-flow speed the signal of the sensor shows a linear dependency on the particle concentration. At low gas-flow speed the quantity of charge transport is much higher than at a high gas flow. Therefore the speed of the gas flow must be known in order to calculate the smoke concentration [mg/m³] of the Exhaust gas. As the speed vary very much in OBD-applications the speed profile through the capacitor blades must stay constant as shown at the last poster session in 2005.

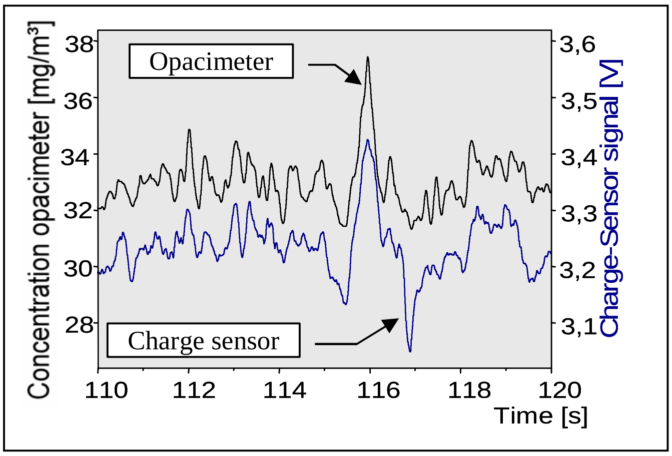


2. Charge sensor for OBD application

The most important part of the sensor construction consists of the electrode shaft heating. It is necessary to keep the isolation resistance within the range of 50 [MΩ]. It was found out, that a temperature of 350 [°C] is sufficient to keep the insulators clean of smoke particulates. The photo aside shows the heating at much higher temperatures for demonstration only.

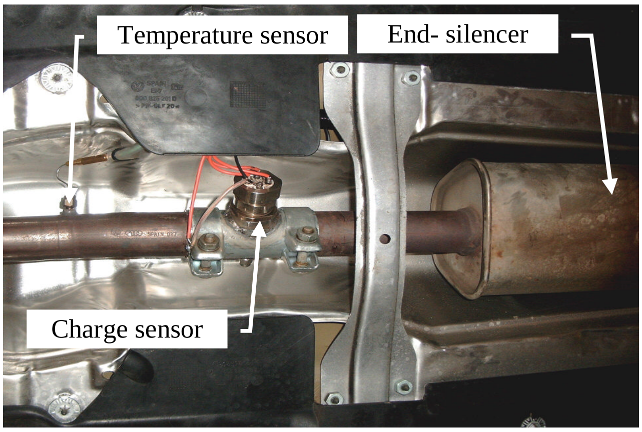


The next graph shows a time cut-out of a constant particulate emission. The dynamic behaviour was compared with the analogue output of the opacimeter. It can be determined that both



curves have nearly the same structure though they result from completely different methodologies. The curves of the plot aside are presented with a different zero offset for better view only. At higher smoke concentrations like in the diagram aside the charge sensor signal corresponds to the opacity with a correlation of R^2 = 95 %.

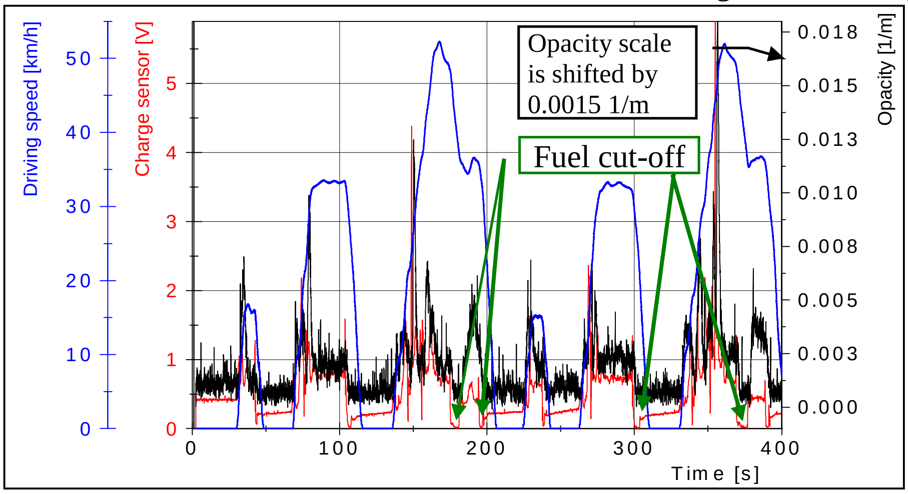
3. On-board measurement in an EURO IV vehicle



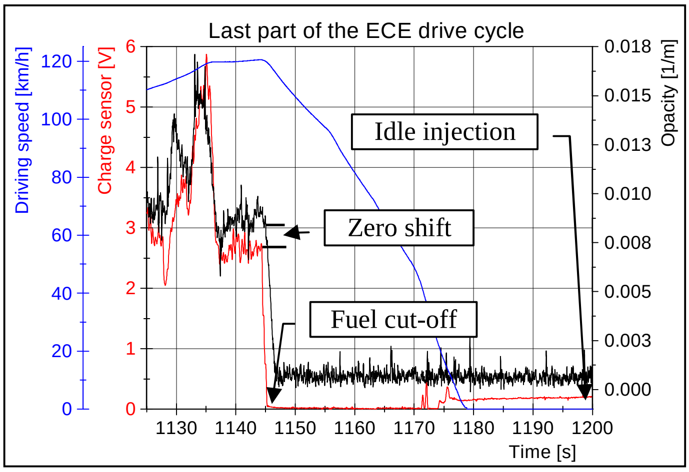
The OBD charge sensor mounted on the exhaust tube of a small vehicle with EURO IV certification was examined on roller type dynamometer and on the road.

With this OBD installation a distance in total of 1100 km was driven. The sensitivity and reaction of the sensor is shown on parts of an European drive cycle.

In the graph the fuel cut-off occurs when the gears are changed and this results in an immediate zero emission of smoke.

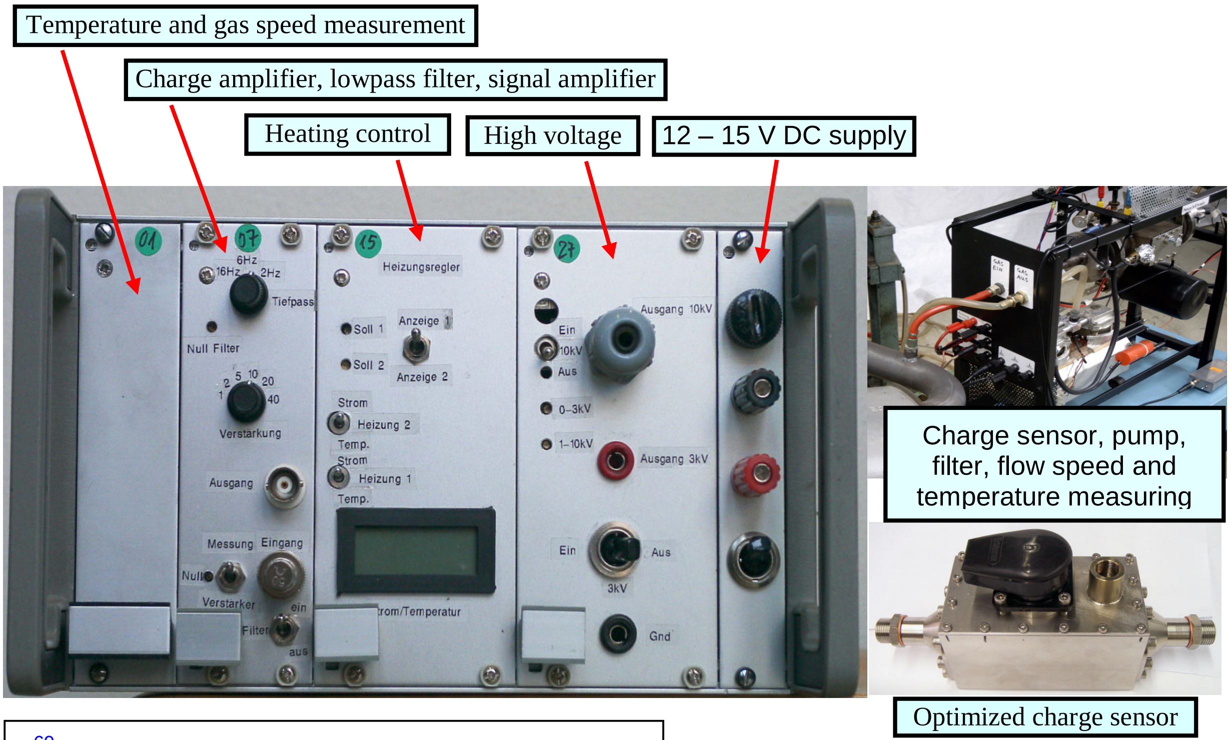


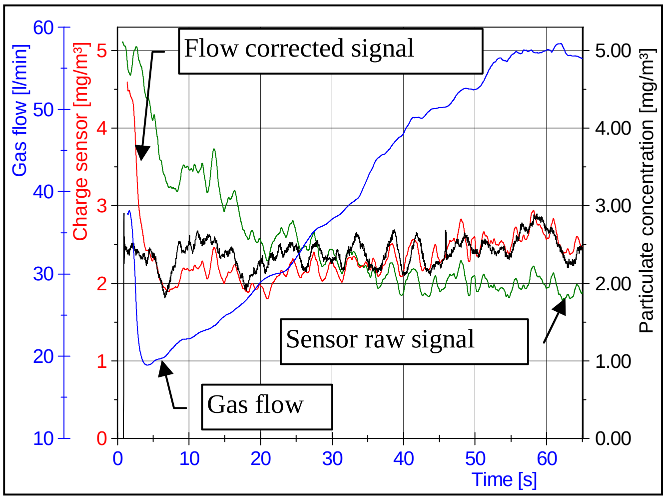
In the last part of the ECE drive cycle it can be seen that during the coast down operation of the vehicle the fuel cut-off results in a zero particle emission and at very low driving speed the idle injection begins and supplies a small amount of particles. The opacimeter of course cannot show any reaction because of the very low smoke emission. It should be mentioned that the zero point of the scale of the opacimeter is shifted by 0.0015 [1/m] to make the curve of the charge sensor visible.



4. Bypass measurement for garages and authorities

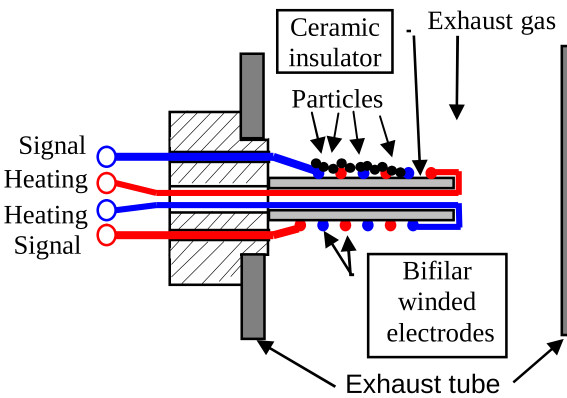
The investigation of particle traps in Diesel vehicles needs an independent measuring system with high sensitivity and easy handling. At low gas-flow speed the sensitivity rises following an exponent curve. Measurements were made at a gas-flow of 30 [l/min] and a signal amplification by 40 times. At a smoke concentration of 50 [µg/m³] the signal output supplies 1 [V] while the noise level at this amplification stays at 5 [mV] according to 0.25 [µg/m³].



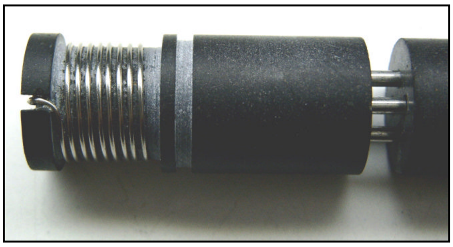


The first design of this measuring equipment consists of a flow optimized charge sensor, a piston pump followed by a particle trap to avoid particles reaching the flow meter and the pump. In principle the gas flow stays constant but small deviations happen by different exhaust gas pressures inside the tail pipe at different engine speeds and loads. The affect of the gas-flow corrections are shown in the diagram aside. The mathematical procedure covers gas-flow changes of factor 2.5.

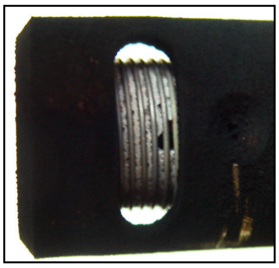
5. Progress of measuring the resistance of smoke particles



Carbon particles produce electrical resistor bridges across the electrodes and gradually reduce the isolation resistance. This principle is used as measuring device by plotting also the gradient of the resistor changes as a measure of the dynamic particle concentration. The bifilar coil is manufactured of resistance material and by simply shorten the ends of the coils the measuring device is used as well for burning the particles. The problems during this burning procedure are solved by designing a temperature control unit that keeps the temperature constant at 650 [°C]. The mostly cooler exhaust gas cannot stop this process now. Controlling the temperature is established by using the positive temperature coefficient of the resistance material by keeping the resistor at a constant value representing the specified temperature. According to the exhaust gas temperature and the gas speed the electrical power consumption during the cleaning period can reach 150 [W].

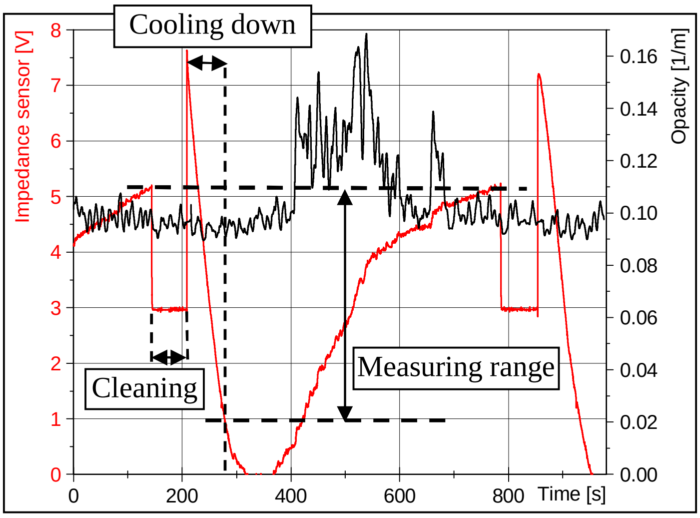


The bifilar sensor in use has the size of a spark plug. The ceramic part of the sensor is protected by an enclosure which reduces the intensity of the cooling exhaust gas flow and furthermore supplies a labyrinth sealing along the ceramic body to avoid particles reaching the four electrode shafts. The right lower photo shows the sensor operating for several days after a cleaning process.



The typical measuring behaviour will be discussed next diagram.

When the upper measuring threshold of 5,2 [V] is reached the cleaning process begins lasting for 60 [s] followed by the cooling-down time of the ceramic of approx 70 [s] finished when the signal goes below the lower threshold of 1 [V]. The measuring starts again when the electrodes are bridged by the particles after 145 [s] counted from end of the cooling-down time. This time gap vary according to the smoke intensity. In the example aside the smoke opaqueness has a value of 0.14 [1/m]. At lower concentrations this time delay can move up to approx 10 minutes.



There are different possibilities of interpretation of the measuring result. For long-time averaging the length of the time interval between the cleaning actions is registered. For on-line measuring the gradient of the signal curve is correlated to the momentary smoke concentration. In the first part of the measuring range form 1 to 4 [V] the opaqueness was 0.14 [1/m] than it goes down to 0.1 [1/m] and the curve gradient changes to lower values within the range from 4 to 5 [V]. Then the cleaning process starts again. In order to measure continuously three sensors have to be installed so that the processes are overlapping.

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