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Development and Experimental Proof of a Soot- and Particle Sensor

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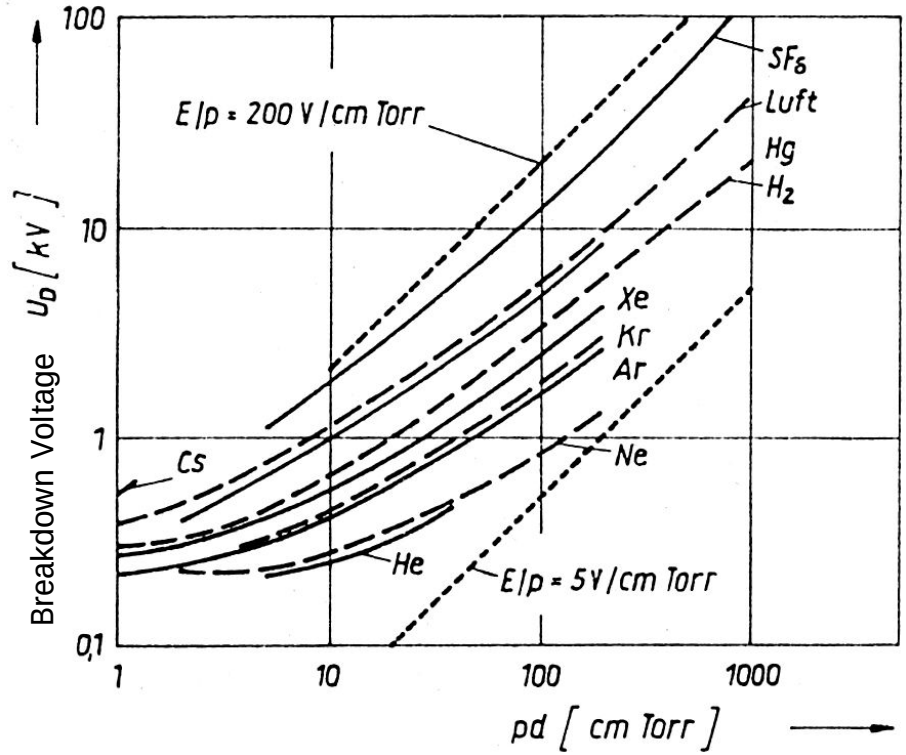
FUNCTIONAL PRINCIPLE

- The breakdown voltage in gasses is carried out theoretically after the known Townsend's mechanism.
- The static breakdown voltage can be found out experimentally and graphical represented (s. figure) usual in form of the Paschen's curves.



Product of pressure (p) and electrode clearance (d)

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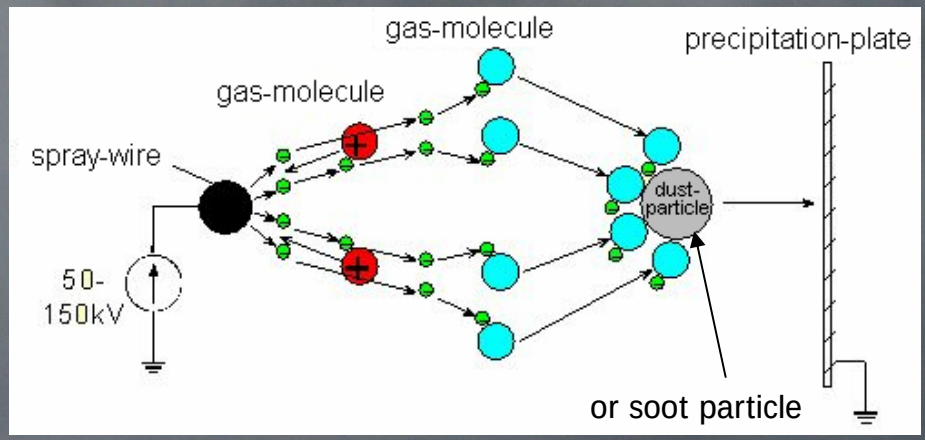
FUNCTIONAL PRINCIPLE

- However, the breakdown voltage also depends on the following factors besides gas pressure and electrodes clearance:
  - form, material and temperature of the electrode
  - temperature, speed and composition of the gas
  - presence of soot particles in the gas

- The electrostatic-filter-effect also can have a certain but however very lower influence (s. figure):
  - because of the short time intervals with laid out voltage between the electrodes and
  - because of the wire-shape anode (no precipitation plate)



FUNCTIONAL PRINCIPLE

- Experimentally were proved that the presence of soot particles in the electrodes clearance and/or their deposits on the cathode favors the electrons release and consequently diminishes the necessary voltage for an electrical breakdown by ca 70%.
- In addition, an influence on the stability of the necessary voltage for an electrical breakdown was found. The spread of this voltage lies e.g. in pure air at ± 22% and in presence of soot in the air it was reduced to ± 4%. This happened also in the case of very small soot concentrations.

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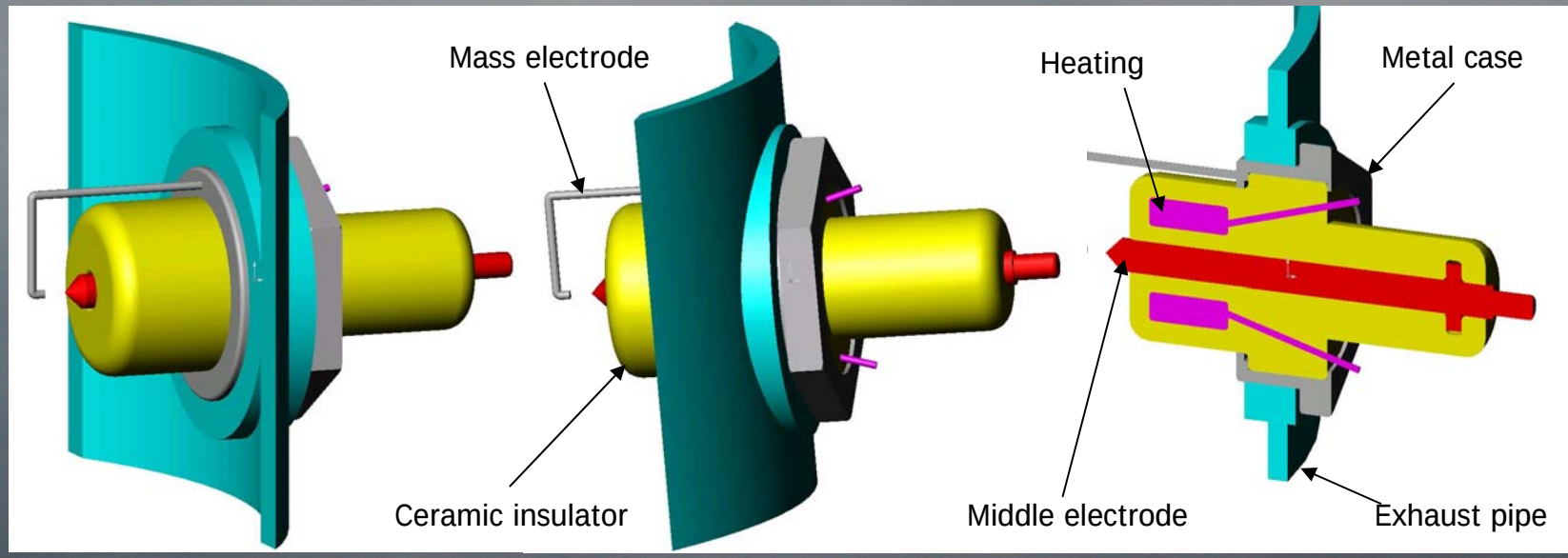
DEVELOPMENT STAND

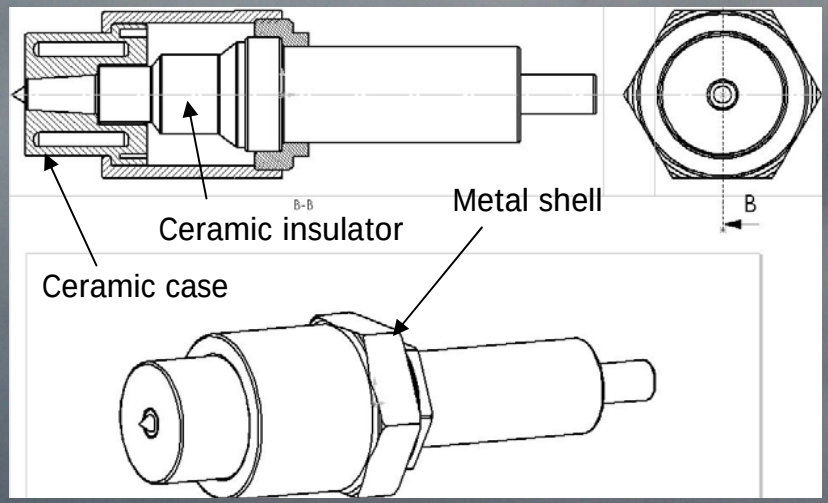
- In principle the soot sensor is built as a combination of usual spark and glow plugs.
- The mass electrode can be positioned referred to the exhaust gas flow direction and in addition the middle one can be heated.
- The best solution for the manufacturing of the heated soot sensor is to integrate its heating directly into the ceramic insulator (s. figure).

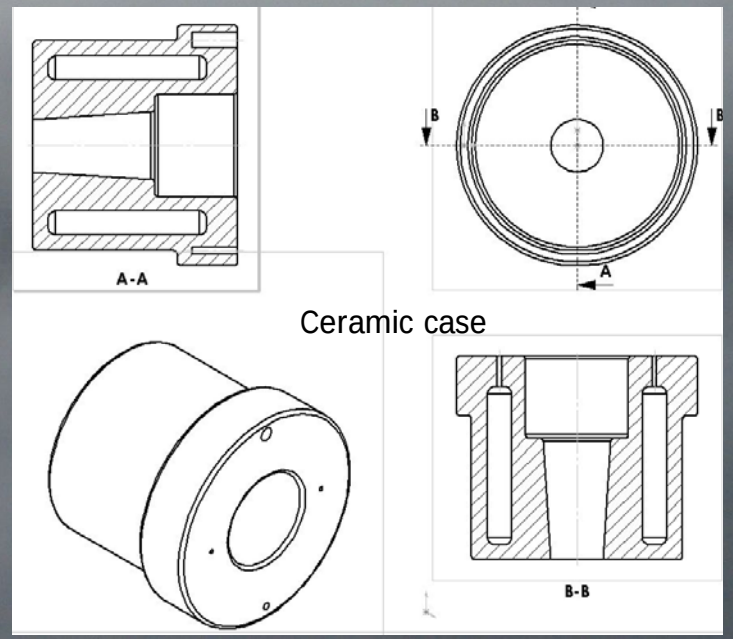


DEVELOPMENT STAND

- However, the ceramic insulator of a heated soot sensor can be produced (s. figure) also from two or more ceramic parts.

  – The advantage of this solution is that the ceramic insulator of the middle electrode can be take over from a usual spark plug.
  – The ceramic case with an integrated heating is therefore a separated part which can be put together with the ceramic insulator e.g. by means of a metal shell.





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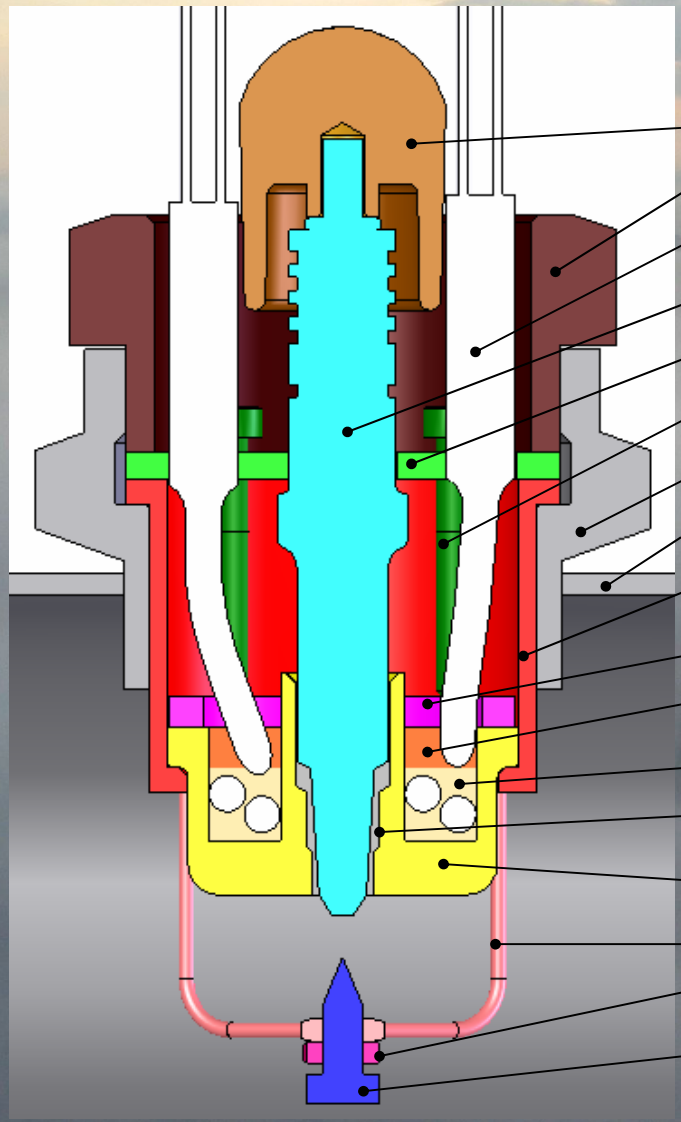
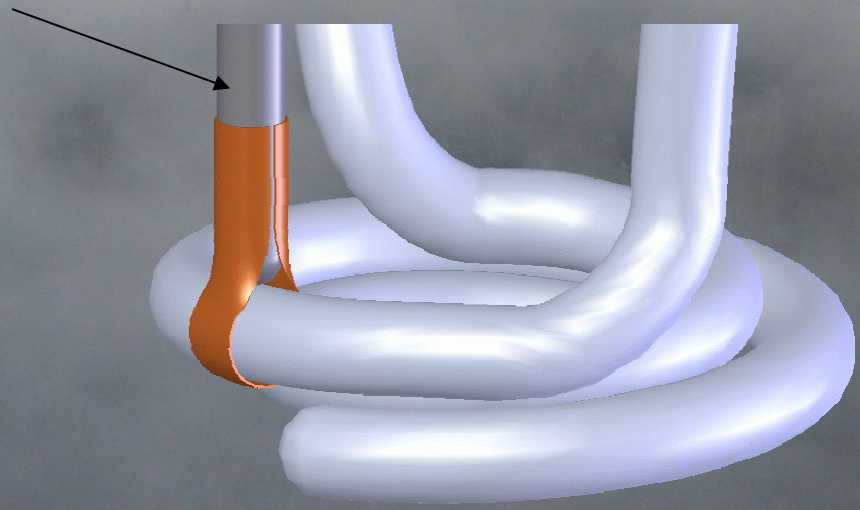
DEVELOPMENT STAND

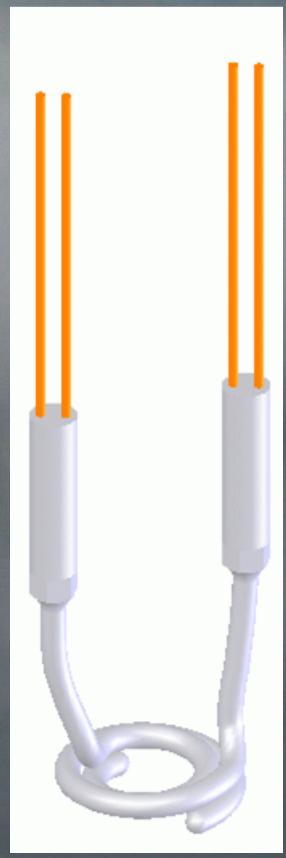


- Soot sensor prototype built form many parts

DEVELOPMENT STAND

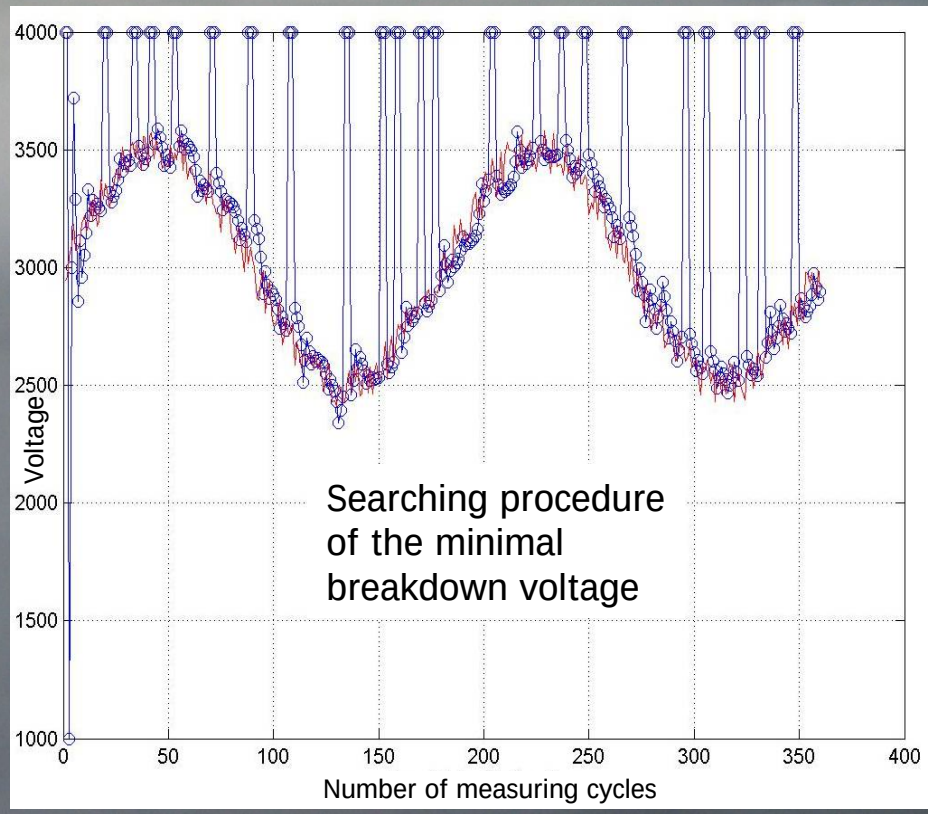
- The previous presented prototype use two 20 W custom-made heating elements.
- Their temperature is controlled by means of a thermoelement.





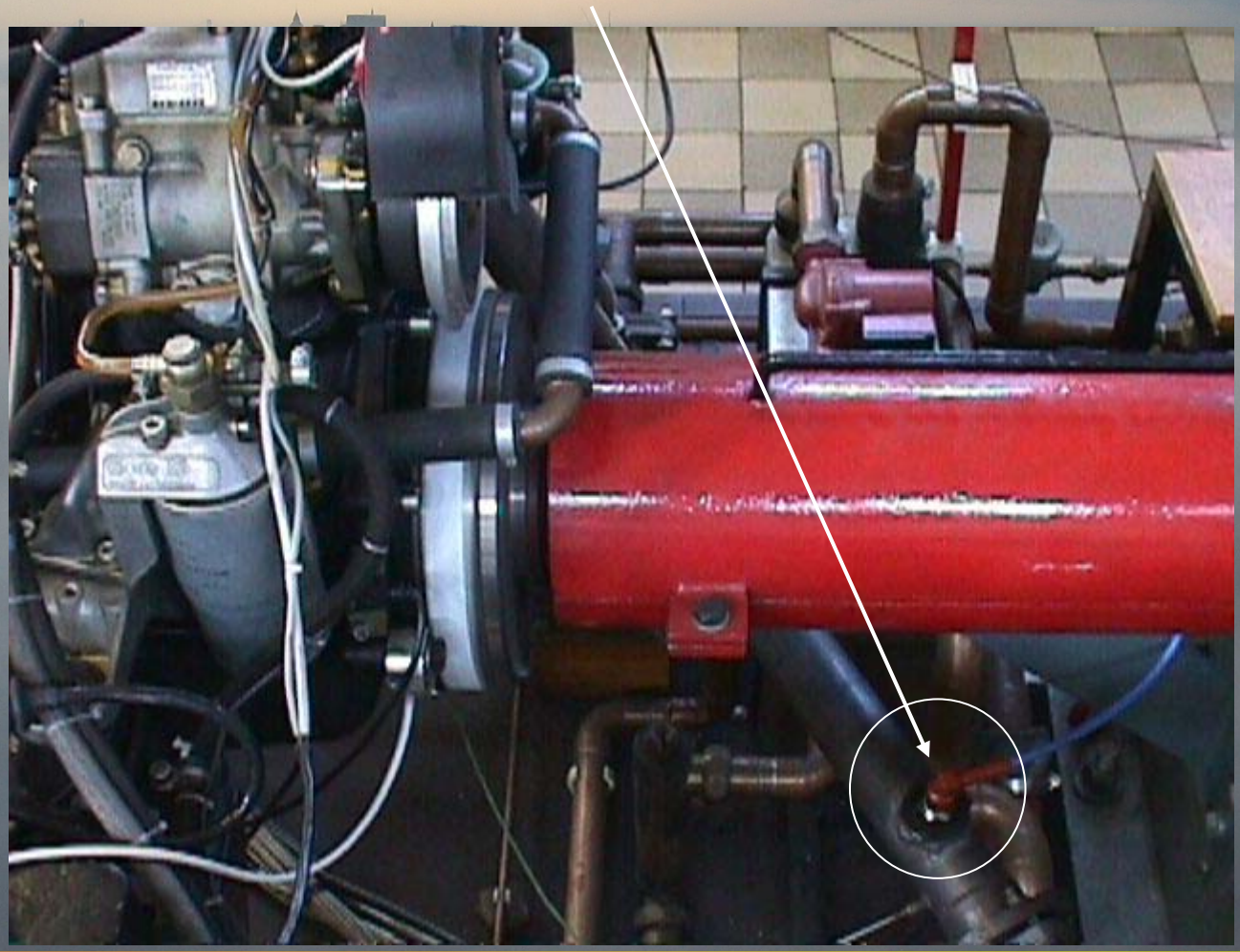
MEASUREMENT PROCEDURE

- The measurement procedure consists in searching and finding of the minimal breakdown voltage applying between the electrodes at which e.g. sparks still permanently appear.
- This voltage level is considered as measure of the soot and particle concentration.



MEASUREMENT PROCEDURE

- The soot sensor can be installed directly on the engine exhaust pipe, i.e. no bypass is needed.



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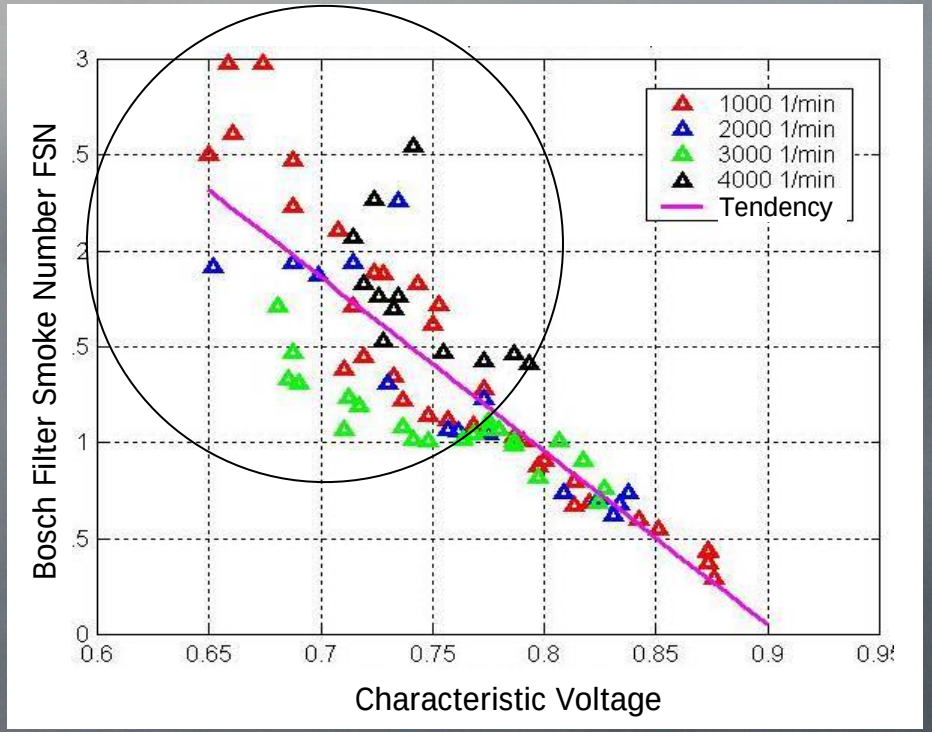
PROBLEMS

- The **unheated** soot sensor tends to build soot deposits on the ceramic insulator at large FSN.
- As consequence the electrical discharges cannot be carried out only between the electrodes but also between the middle electrode and exhaust gas pipe along the ceramic insulator via the soot deposit.
- In this case inaccurate and with a great spread width soot values are measured (s. area with FSN > 1).



PROBLEMS

- Unfortunately, the minimal voltage at which sparks still appear also depends on other running (cross) parameter, such as: temperature, pressure, mass flow rate and AFR of the exhaust gases, engine speed and load, battery voltage etc.
- The measurement procedure needs a sensor ECU which must take care of the following functions:
  - Searching of the minimal voltage at which sparks still appear ⇨ **measurement recording**
  - Getting the other running parameters e.g. via CAN bus from the engine ECU ⇨ **cross influence parameter recording**
  - Correction of the measurement in dependence of the cross influence parameters ⇨ **measurement determination**
  - Sending the final result e.g. via CAN bus to the engine ECU ⇨ **measurement communication**

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ADVANTAGES

- The developed soot sensor needs a little amount of electrical energy during the whole measurement procedure (unheated ca 30 W, heated ca 70 W).
- The manufacturing process of the heated soot sensor should not cause big or unknown manufacturing problems.
- The price of a soot sensor (without sensor ECU) should lie between their of spark and glow plugs.
- The sensor ECU is quite simple (and therefore cheap) and can:
  - either be realized as a separate unity (today's development stand),
  - or form a unity together with the ignition coil and eventual with the soot sensor,
  - or still be integrated e.g. in the engine ECU.

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ADVANTAGES

- The soot sensor and its ECU originates a so-called intelligent sensor, which can deliver the measured soot concentration to the engine ECU by means of a bus system (e.g. CAN).
- The soot sensor can be used in the exhaust everywhere i.e. engine near, in front of and behind the soot filter.
- The soot sensor is suitable to be used as a simple sensor for the detection of a certain soot concentration threshold. In this case it can be used e.g. after the soot filter to determine the regeneration phase start (and eventually end) time and can also be integrated in OBD I procedure.
- Alternatively it can be used for continuous measurements of the soot concentration. In this case the soot sensor can in addition to be integrated in the engine closed loop soot control. It also can be integrated in OBD II and OBM procedures.

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FURTHER STEPS

- New prototypes of the heated soot sensor in the version spark plug + ceramic pot will be manufactured.
- Prototypes of the heated soot sensor in the version with integrated heating element will be also manufactured.
- Both new prototype versions will be tested and evaluated on different engine test beds (Hamburg, Dresden, Darmstadt) and different diesel engines.
- The corrections for the cross influence parameters will be determined and compensated.
- Industry partners for a closed cooperation are looked for.

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