Optimizing a photoacoustic Soot Sensor for the Measurement of ultra-low Soot Concentrations in real-world Exhaust

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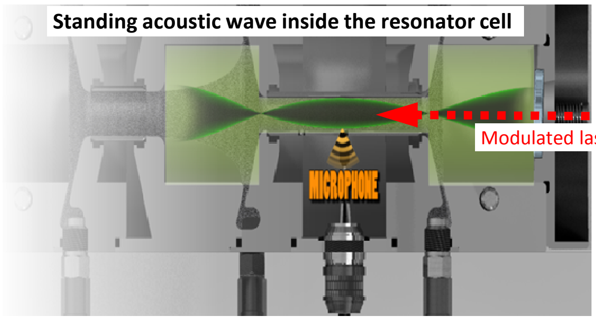
Introduction:

Photoacoustic soot sensors are capable of measuring very low concentrations of black carbon, similar to those found in ambient air. In exhaust gas other chemical components can induce disturbances to the signal. By proper dilution of the sample disturbances can be eliminated, but this may not be desirable in certain application. Cross-sensitivities to water vapor, which are normally negligible, can become a problem at low dilution. Diluents different from air (e.g. N2) can induce disturbances by changing the acoustic properties of the gas mixture.

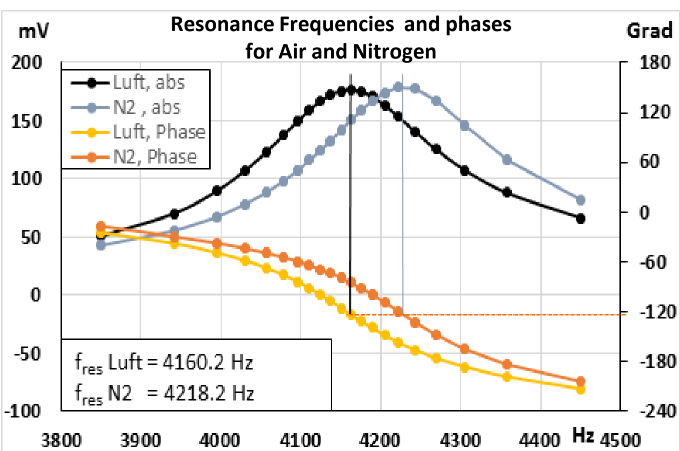
Photoacoustic Resonator:



A standing acoustic wave in the resonator is generated by stimulating the particles with a modulated light source.

The Problem:

The System shifts the resonance frequency and the phase angle, when the acoustic properties of the gas change. This causes a change in the zero signal vector (see plot).



Current Solution:

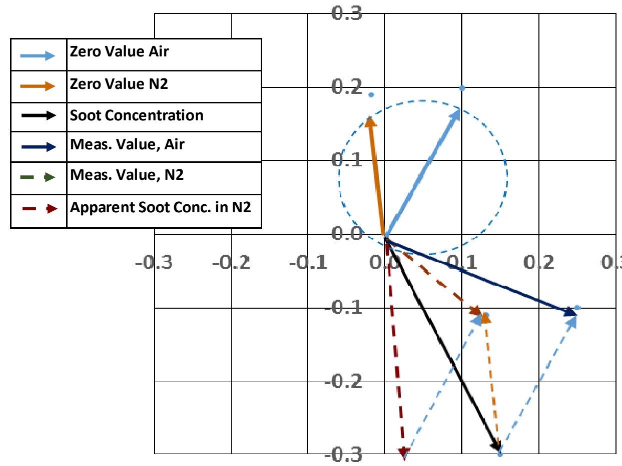
Zeroing with filtered Exhaust prior to Measurement

By performing a zeroing with filtered exhaust and determining the resonance frequency at the same time, the disturbing effects get eliminated.

The Disadvantage:

The Approach works for many applications, but adds complexity. In the case of engine tests the engine has to be running during the zeroing. If the humidity or the acoustic properties of the gas change during the test, the compensation is less efficient.

Vector Plot of Measurement Signal and Zero Signal in Air and Nitrogen



New Approach:

Real-time Adjustment of the Modulation Frequency

<u>Water vapor cross sensitivity is compensated</u> by measuring absH% with a humidity sensor, speed up its signal by a slope extrapolation algorithm and subtracting this fast humidity signal from the main photoacoustic signal in real-time. The cross-sensitivity coefficient ("ppm eBC/ absH%) is a constant quantity verified during the calibration process

<u>Signal phase and amplitude are continuously determined</u> by synchronous demodulation

If the acoustic properties of the gas change, the geometric path of the standing wave changes as well. *<u>At resonance, the phase angle and the damping remain constant!</u>*

By continuously adjusting the modulation frequency of the light source, *<u>the system is kept in resonance</u>*.

At very low concentrations, the phase angle determination of the main signal gets unstable. In this case *<u>an artificial signal is used for the resonance shift detection</u>*.

<u>The artificial signal is induced by a loudspeaker at a different frequency</u> (overtone). This signal is also processed by synchronous demodulation. It does not interfere with the main signal (as long as the signal is small), but reacts the same way to changes in the acoustic properties

Conclusion:

The new methodology has been implemented in the AVL Micro Soot Sensor plus signal evaluation Firmware. Cross-sensitivity to water is greatly reduced for measurements of gasoline exhaust. Acoustic disturbances caused by dilution with N2 could be removed in laboratory and first test bed experiments. Investigations with more complex gas mixtures are ongoing.