AVL List GmbH (Headquarters)

AVL Technical Expertise on Black Carbon Measurement

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CONTENT

The Calibration of eBC Measuring Instruments

Calibration (acc. to DIN 1319-1) means to use a traceable standard to determine the measurement deviation on the measuring device without any technical interventions (no changing of settings) on the device.

Adjustment (acc. to DIN 1319-1) means to minimize the measurement deviation by means of technical intervention (setting or adjusting) on the measuring device.

The term **equivalent Black Carbon** (eBC) – is the term for Black Carbon mass concentration (mg/m^3) derived from optical absorption methods (e.g PAS, FSN).

Calibration of AVL Micro Soot Sensor (MSS)

For the AVL Micro Soot Sensor (MSS) an empirical calibration procedure is employed.

The MSS is calibrated by establishing a mass correlation for a well reproducible aerosol, which has absorption properties of soot produced by internal combustion engine.

The calibration aerosol is produced by a CAST propane burner (Combustion Aerosol Standard) and has been analyzed[1] for absorption properties.

The MSS calibration procedure has shown good applicability on Black Carbon from a big variety of combustion engines.

The MSS performance has been demonstrated and accepted also for aircraft engines.

- MSS is a standard reference instrument for certification of aircraft engines [Ref. SAE E-31 AIR 6241].

[1] Brem, B., et al., The optics-chemistry link of dark matter; investigating mass absorption cross sections of soot particles from two combustion sources", ETH Conference, 2018

Calibration Set-up for AVL Micro Soot Sensor

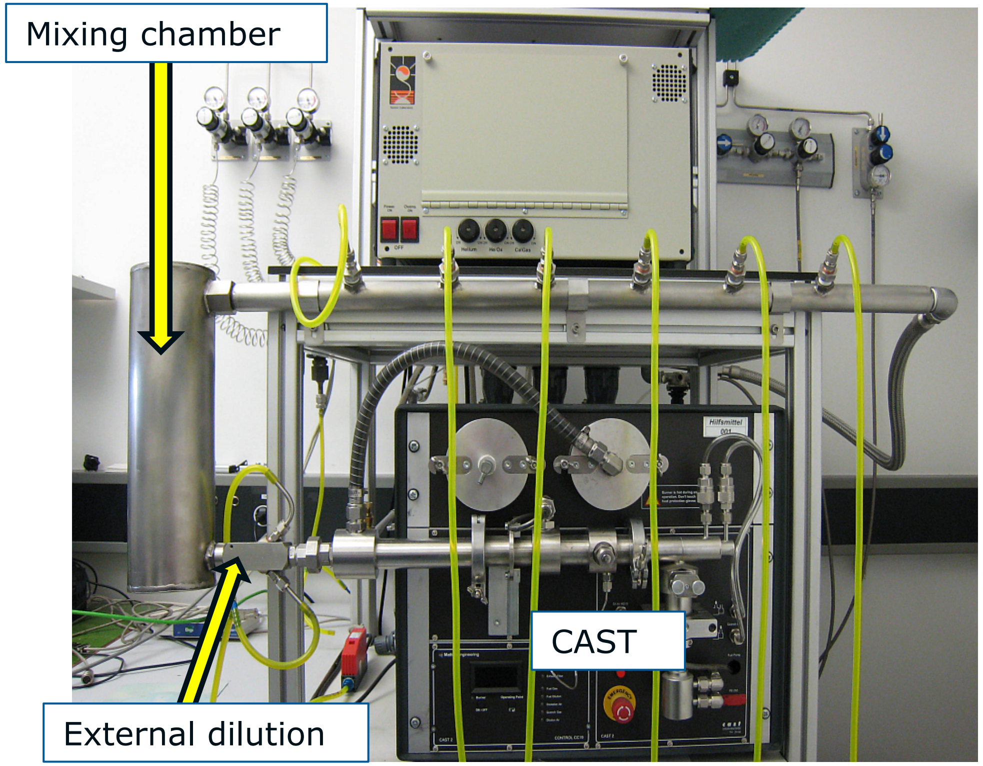
MSS is calibrated using a CAST aerosol vs. EC as reference.

For measurement of EC we use a commercially available “semi-continuous” OC/EC analyzer.

A modified thermal protocol derived from NIOSH5040 is used for OC/EC analysis.

A gravimetric determination (TX40 filter + microbalance) is used to cross-check the results.

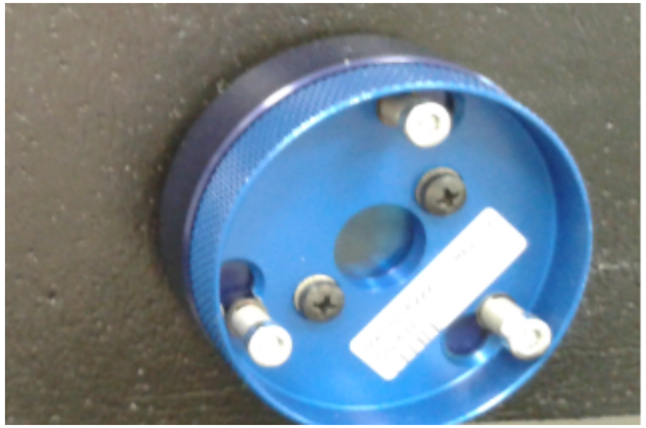
Industrialized calibration line used for calibrating 400-500 instruments/year.

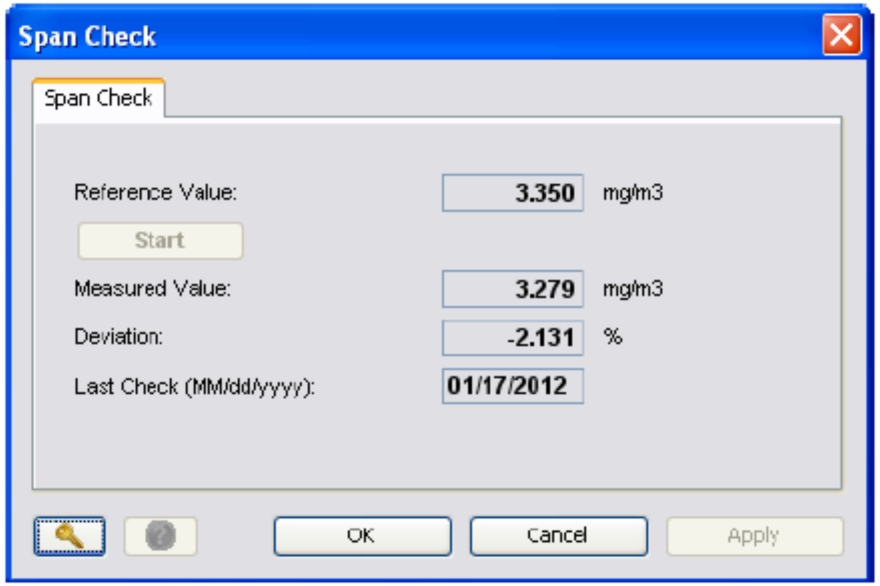


Example Calibration Setup for Micro Soot Sensor

MSS Calibration Check with Absorber Window

Unique calibration check procedure with an absorber window.



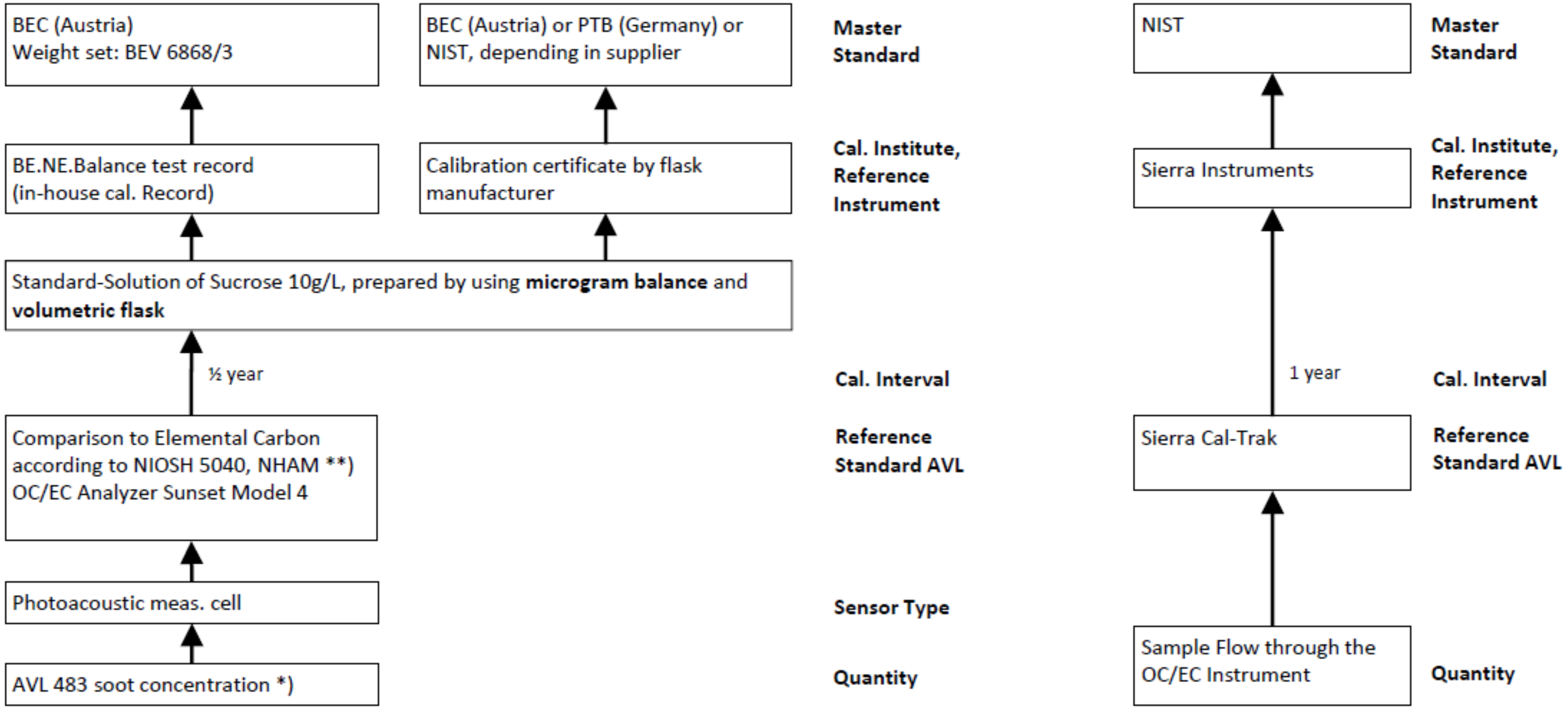


If a systematic deviation is detected a recalibration of the instrument is needed.

Traceability Chart - AVL MSS (1)

Traceability chart according to ISO 9001 – page 1

Product: Micro Soot Sensor 483 MSS Plus
Page 1: calibration equipment for the gravimetric reference calibration (primary soot sensor)



*) soot particles (90-120 nm mean diameter) generated by CAST

**) NHAM: NIOSH Handbook of Analytical Methods

Traceability Chart - AVL MSS (2)

Traceability chart according to ISO 9001 – page 2

Product: Micro Soot Sensor 483 MSS Plus

Page 2: calibration equipment for the internal sensor calibration (except primary soot sensor)

ÖKD at BEV (Austria) + UKAS National Standards for Temperature	DKD at PTB (Germany)	ÖKD at BEV (Austria) Primary absolute pressure standards	METAS (Swizerland) Certificates 25116 25096 25095	ÖKD at BEV (Austria) National Standards for AC / DC Voltages	**Master Standard**
ISOCAL (ÖKD accr.) Datron 1281 Multim. + Platinum resist. Ther-mometer 909/100/480	WIKA (DKD accr. Regi. No. DKD-K-03701) Pressure calibrator A5519 DKD07-01	ISOCAL Datron 4808 (accr. ISO/IEC 17025 reg.No. ÖKD 14)	Vögtlin / MOLBLOC 1847/401638 1848/401080 1822 / 401198	ISOCAL Datron 4808 (accr. ISO/IEC 17025 reg.No. ÖKD 14)	**Cal. institute, Reference Instrument**
1 year	1 year	1 year	1 year	1 year	**Re-Cal. interval**
Testo 925+ Sensor PM 336 and PM417 + PM 417B	Thommen HM 22 PM 420	Fluke 717 30G PM335 or PM388	Red-Y Type GSM-(GSC)-B	Agilent 34401a PM 410 or PM 419	**Reference Standard AVL**
Temperature NTC: T_meas.cell	Pressure p_diff, p_rel Honeywell	Pressure p_abs, Honeywell	Red-Y Type GSM-(GSC)-B	Voltages (DAC)	**Quantity, Sensor type**

Micro Soot Sensor AVL 483 Calibration during end test

PM numbers; AVL internal Ref. No. of calibration equipments. Calibration certificates for calibration equipment may be requested from the AVL List GmbH, Graz, Quality department

Verified: W. Schindler 2015

Calibration of the AVL 415SE

Calibration of the optical reflectometer head

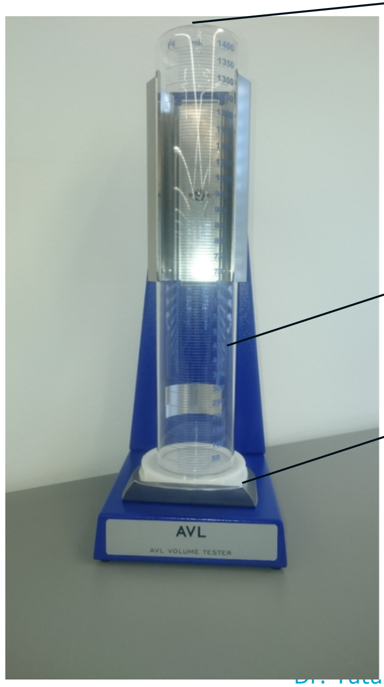
Performed with reference reflectance standards:

- one white diffuse reflectance standard SRS-99-010 (reflectance ~ 99 %) with calibration certificate
- one grey diffuse reflectance standard SRS-50-010 (reflectance ~ 50 %) with calibration certificate

The calibration certificates specify 2 x standard deviation (expanded uncertainty) of the standard instrument used for calibrating the reflectance standards.

Calibration of the sampling volume

Performed with a standard glass cylinder



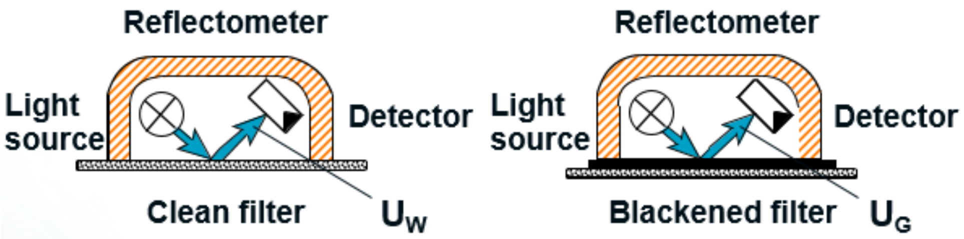
Optical Reflectometer Head Calibration

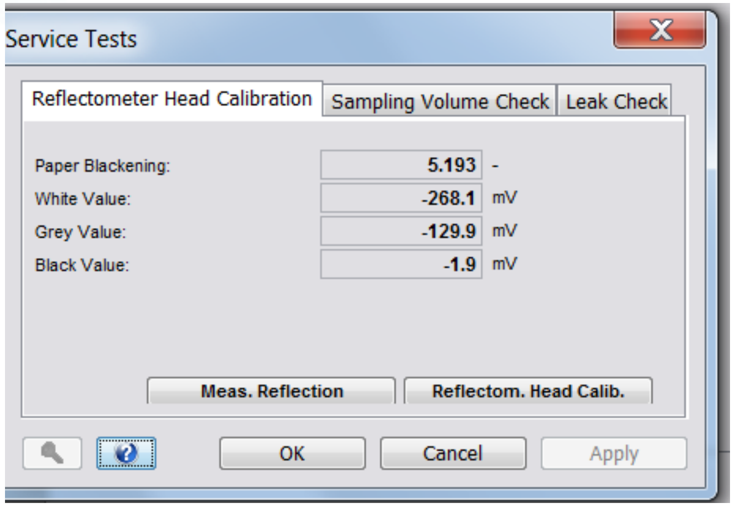
The AVL Smoke Meter 415SE is conform with ISO 10054. The characteristics of the optical measuring head are defined in the ISO norm.

Calibration is performed to check the linearity of the measuring head.

During calibration, when the white standard is placed on the measuring head, the system switches off the bulb and performs a recording of the black value (UB) then switches on the bulb for 1s and records the white value (Uw). When, the grey standard is placed on the measuring head, the grey value is recorded and PB calculated according to the formula.

During the measurement, the device is performing a new recording of the white and of the black values and checks these values between them. If there is a deviation higher than the allowed limit implemented in the FW, it makes a paper feed and takes a new white and a new black. If the error is exceeded, the error is displayed.





$$P_B = 10 \times \left(1 - \frac{U_G - U_B}{U_W - U_B}\right)$$

P_B .... paper blackening
U_B .... output voltage of reflectometer when filter paper is completely blackened (i.e. no reflected light, black value)
U_W ....output voltage of reflectometer when filter paper is unblackened and clean (i.e. white value)
U_G ....output voltage of reflectometer when filter paper is blackened i.e. grey value)

Calibration of the Sampling Volume

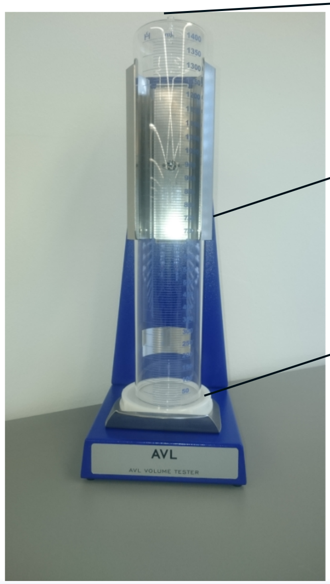
This function is used to compare the amount of the sampled volume with an external reference measurement system (a glass cylinder).

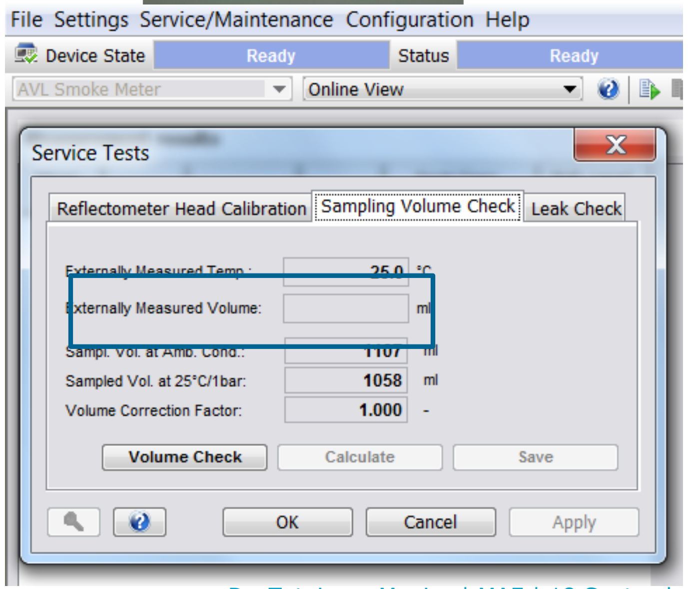
Simple calibration procedure:

- Enter the ambient temp. and the vol. that is measured by the external devices.
- Press calculate to determine the new volume correction factor.
- Compare the externally measured volume with volume sampled at amb. cond.

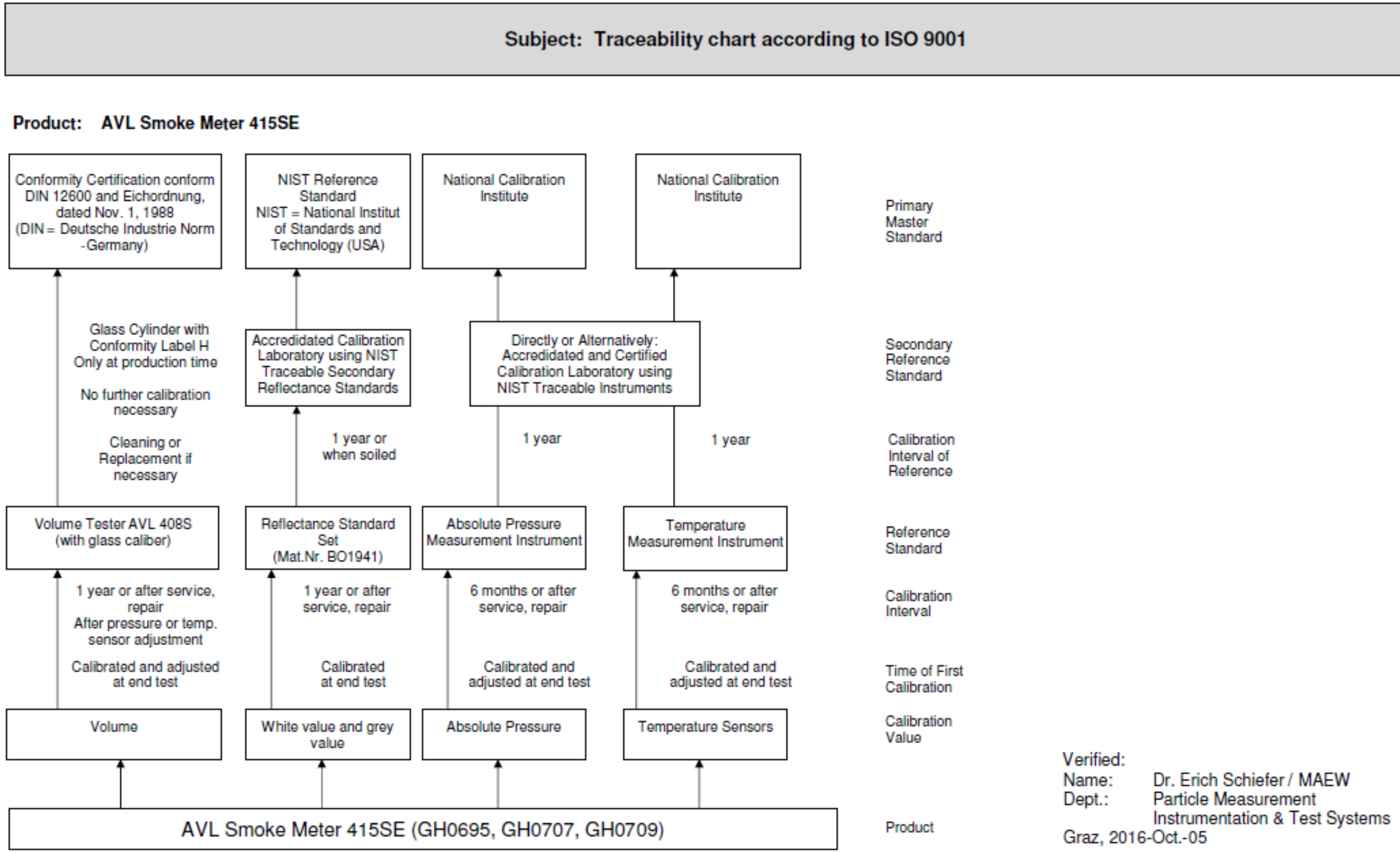
If necessary, an adjustment may be applied.

- Save the correction factor by clicking APPLY.





Traceability Chart – AVL 415SE



FSN Correlation to eBC Mass Concentration

Calculation of Black Carbon concentration [mg/m^3] from Filter Smoke Number by means of an AVL correlation formula.

Correlation formula is part of ISO 8178-3.

For measurements performed with instruments operated in heated conditions (heated instrument and heated sampling lines):

$$\mathrm{BC}\left({}^{mg}/_{m^3}\right) = \frac{1}{0.405} \times FSN \times 5.32 \times exp^{(0.3062\ x\ FSN)}$$

The correlation function was established empirically (laboratory and engine test bed measurements) and it is was based on comparing the smoke meter reading with gravimetric filter measurements (the insoluble fraction/part of the particles deposited on TX40HI20 filters after extraction of the soluble parts with dichloromethane).

Recommendations Towards a Standardized Sampling, Conditioning and BC Measurement

Correct sampling of the exhaust gas is essential for reproducible measurements.

The test set-up and particle losses due to transfer conditions from the probe to the measuring instrument can contribute to sampling artefacts.

Sampling artefacts have been intensively investigated within AVL, have been quantified and considered when developing the AVL instruments, the sampling lines, the probes and when performing particle measurements.

Location and design of the sampling probe are essential in order to obtain consistent test results.

- Probe location:
  - in an exhaust duct where the soot concentration distribution is homogeneous (preferably on the exhaust pipe centreline, in a straight section of the exhaust pipe)
  - at a point without pressure fluctuations
- Probe design (e.g. single hole, multihole, 45° beveled)
  - a 45° beveled probe

Recommendations Towards a Standardized Sampling, Conditioning and BC Measurement

Sampling probe direction (facing the flow or against the flow):

- a 45° bevelled probe with the opening facing the flow of the exhaust stream may sample more or less particulates than a probe looking away from the exhaust stream. The difference depends on the sample flow and on the particle size.

Stainless steel sampling probe.

The sampling line should be mounted as straight as possible from the sampling point to the device (avoid bend to prevent large deposits), have an ascending layout from the exhaust duct towards the device.

Sampling lines up to a length of 3 m (unless longer ones are absolutely necessary).

Roughness of the sampling lines (very smooth inner surface to lower the contamination effect).

Recommendations Towards a Standardized Sampling, Conditioning and BC Measurement

Particulate deposition is an unavoidable effect in any sampling situation.

There are several mechanisms which contribute to depositions:

- **Turbulent deposition** - occur whenever the aerosol passes bends or edges.
- **Thermophorectic deposition** - always occur when there is a temperature gradient.
  - Can only be eliminated by sudden cooling of the hot exhaust via dilution (like in a CVS). All other sampling and dilution methods suffer from thermophoretic losses.
  - Can be calculated with an empirical formula by Kittelson (ISO 8178-1 Annex C.1).

$$\frac{c_{out}}{c_{in}} = \left(\frac{T_{out}}{T_{in}}\right)^{0,38}$$

  - AVL MSS probe includes a thermocouple to measure the raw exhaust temperature (T_{in})
- **Condensation**
  - Heated instrument and sampling line - prevents condensation during measurements and improves measurement reproducibility.
  - To minimize the contamination effects, the sampling line and the probe should be purged with compressed air on a regular basis
    - purging of the sampling lines with pressurized air at the beginning and at the end of the test procedure (or at the beginning and the end of the day).
    - additional purging of the device as often as possible.
    - we recommend to replace regularly the sampling line with new lines.

Summary

AVL Instruments calibration and check procedures are simple and traceable to national standards.

Technical expertise on BC sampling and measurement ***is available!***

Appropriate BC measuring instruments ***are available!***

A test procedure for measurement of BC emissions from marine engines (on test-bed as well as on-board) ***is possible!***

Thank You

AVL

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