Product Specification

Truckflow PEMS

Portable Emission Measurement System

Exhaust Gas Mass Flow Meter

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2 Description

2.1 Measurement principle

systec PEMS is based on the differential pressure method and is individually designed to the flow range and needs of the customer application.

systec designs the optimum primary element (pitot tubes, venturis, nozzles or others) for the application. Important parameters for the selection and design is the robustness against soot, the limitation of the maximum backpressure, inlet optimization, easiness to clean the primary element and dimensions and weight.

The differential pressure-, absolute pressure- and temperature-sensors used for systec PEMS (TFI4BG-HP and TFI4PT1000) are CAN-based sensors. They are easy to integrate into drive emission loggers. The sensing elements are robust, accurate and lightweight. The sensors integrate beside the accurate measurements, patented filtering methods to cope with the high pulsations of combustion engine exhaust. The integrated massflow calculation is therefore highly dynamic, accurate and perfectly filtered for best readability.

2.2 Use

systec PEMS can be used for all types of combustion Engines (and sure also for other Gas Mass Flow applications). The system is designed to fit to on-road and off-road vehicles.

systec PEMS is designed to cover flow spans of 1:7 with <1% accuracy and 1:10 with <2% accuracy. (ex factory calibration)

The maximum flowrate is depending on the selection and design of the primary element. The primary elements can be designed for maximum flow as low as 10kg/h (3/4in venturi type). For high flow applications there is practical no limitation. systec supplied exhaust gas meters for applications with >40.000 kg/h (ship diesel engines).

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3 Primary Elements

The primary elements are selected carefully on the application of the customer. The main selection criteria are:

- Flow span and Temperature range
- Acceptable back pressure (pressure loss)
- Robustness against condensates and soot
- Easy detachability for cleaning
- Packaging / total length
- Weight

3.1 Venturis / Nozzles (ISO 5167)

Venturis or nozzels are mostly used for systec PEMS. They have a low back-pressure (pressure loss), are robust of soot and condensates, easy to clean, and they are insensitive on short inlets. Venturis can be manufactured from 1/2 in (DN15) up to 8 in (DN200).

Bigger venturis are possible but they may get heavy and expensive. Venturis are unable to measure backflow. So for applications where backflow is expected, pitot tubes are preferably used.

3.2 Pitot Tubes (systec deltaflow)

The systec deltaflow has a high accuracy and low pressure drop. Due to its symmetric structure, backflow can be measured (bi directional flow). For pipe diameters from DN100 up DN1000, the type DF25 may be used, which is highly resistant against condensates and soot.

For smaller diameters (DN20..DN80), type DF12 is used. DF12 is also bidirectional, accurate and with low pressure drop. Tappings and internal piping are 3mm only. So the DF12 is more sensitive on condensates and soot which has been taken into account.

3.3 Inlet/Outlet

To ensure perfect accuracy, flowmeters need defined in- and outlet pipes. Systec primary elements are usually supplied including the necessary in- and outlet piping:

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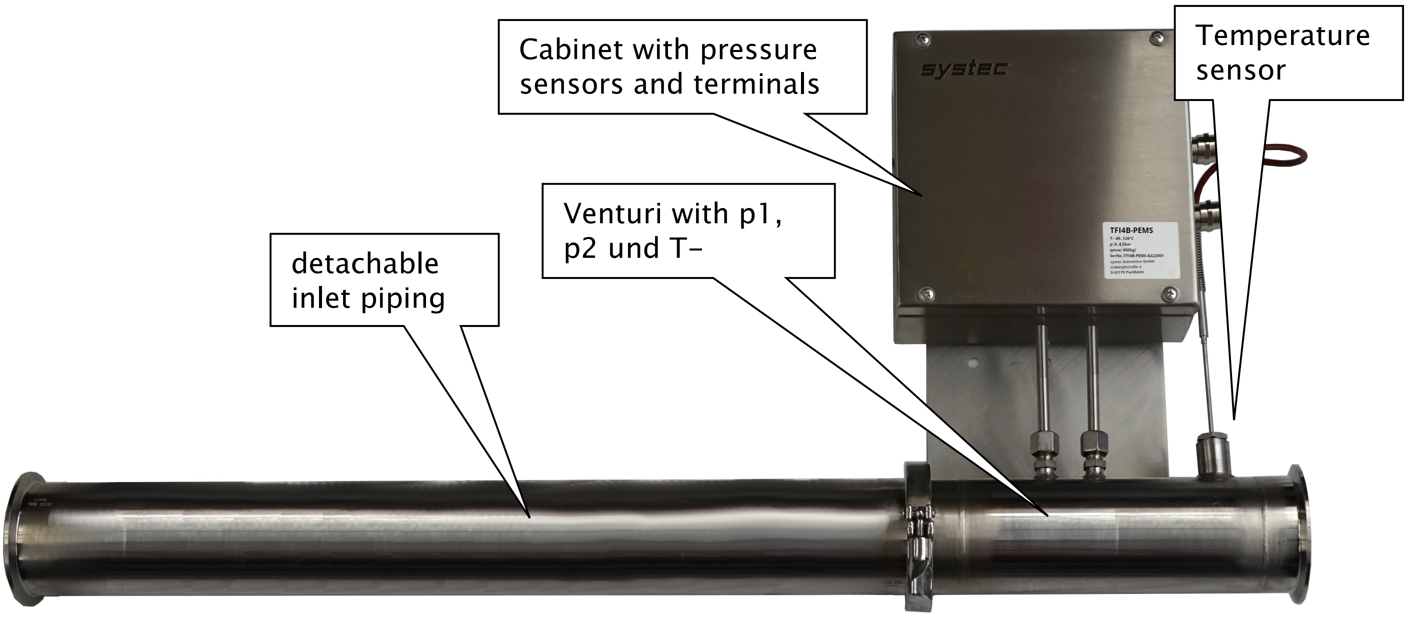


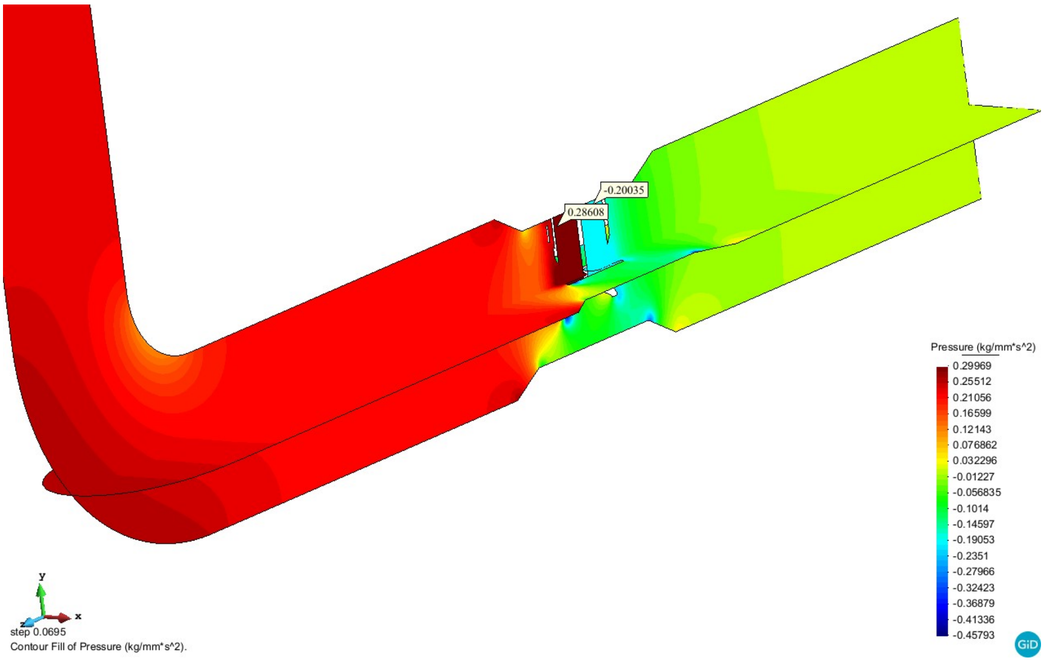
A complete systec PEMS spool usually consist of:

- Inlet-piping (optional)
- Primary Element (venturi/ nozzle/ pitot tube) including
  - SS-Cabinet with
  - dp-Sensor,
  - pabs-Sensor
  - T-Sensor
  - massflow computing unit
  - Terminals for connecting CAN Bus to ECU
- Outlet-piping (optional)

The three parts of the spool are usually combined with Tri Clamp flanges (DIN 32676 / ISO 1127) so that they can be easily be mounted and cleaned if necessary.

3.3.1 Inlet piping:

The inlet piping ensures stable flow profiles at the primary element and is therefore essential for the accuracy. The inlet is therefore scope of delivery of systec and will be part of the meter factory calibration.
Ideal inlet conditions for primary elements are 7-20 D (D=pipe diameters). In particular, for bigger dimensions, long straight inlets may become inconvenient to be mounted on the vehicle. For these applications, elbows will be included in the inlet and will be part of the calibration.



Systec is able to ensure high accuracies also with 90 or 180 deg bended inlets, as long they are part of the calibration. This opens the possibility to create compact spools.

For inquiries, please define the available space and the intended mounting position on the vehicle so that systec can propose an appropriate spool.

3.3.2 *Primary Element with SS Cabinet*

The primary element (venturi spool or pitot tube spool) is manufactured from stainless steel, typically SS316Ti (others are available on request). The length is typically 4D (D=Inlet Diameter). Is includes hose connectors for p1 and p2 and a male ¼" R connector for the PT1000 temperature sensor. The SS-Cabinet is ready connected with the Venturi and holds the multivariable sensor (dp, pabs and T) which calculates massflow. Inside of the cabinet is a terminal for the CAN-Bus: GND, 5 VDC, CAN hi and CABN lo.

The cabinet can be easily detached from the primary spool for cleaning, service or calibration.

3.3.3 *Outlet Piping (optional)*

systec can also provide outlet piping. The influence on the calibration is usually negligible, but it shall be also included in the factory calibration. The outlet piping can be used, to carry additional sensors (not scope of systec delivery), e.g. NOx or O2-Sensors. The outlet can also be bend, if this is necessary for packaging reasons.

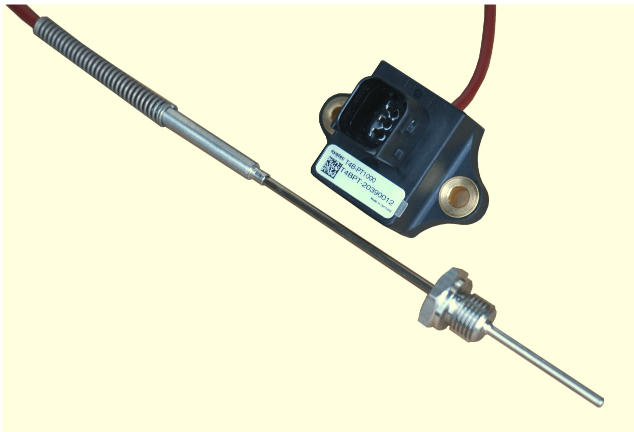
Additional sensors can also be placed in the inlet piping. In this case, they will have an influence on the calibration of the primary element and shall then be part of the factory calibration and need to be supplied to systec.

4 Sensors

For a massflow measurement three sensor are needed: Differential pressure (dp), absolute pressure (pabs) and temperature.

Since Exhaust gas has high temperatures, for the PEMS systems TFI4BG-2P and TFI4PT1000 are used. TFI4BG-2P is a multivaraible sensor which is connected via hoses to the hot exhaust gas pipe. TFI4PT1000 is a high temperature sensing element with CAN-based, digital protocol. The PT1000 element is connected via ¼" thread to the exhaust pipe.

TFI4BG-2P Multivariable dp and pabs Sensor including



TFI4PT1000 Can-based digital Temperature Sensor

Both sensors communicate on the bus of the connected PEMS-ECU and calculate accurately the mass flow of the exhaust gas.

There are separate product manuals available for both, TFI4G-2P and TFI4BPT1000.

4.1 flow calculation.

The mass flow through a tube with a cross section A_q is calculated based on the differential pressure signal dp at the sensor element and the density ρ of the medium. (eq. 4.1)

eq. 4.1:

$$\dot{m}\left[\frac{kg}{s}\right] = \underbrace{K_S \cdot K_M \cdot A_q\left[m^2\right]}_{ECU\ -Factor} \cdot \underbrace{M_i\left[\frac{kg}{m^2 \cdot s}\right]}_{SensorSignal}$$

$$M_i = \varepsilon\sqrt{2 \cdot dp \cdot \rho}$$

K_S represents a flow constant, which is applicable for steady flows with fully developed flow profile. It represents the calibration constant of the primary Element. K_M is determined on the systec flow

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calibration bench and compensated the influence of inlet elbows and outlet sensors on the primary element.

For a venturis, nozzle or orifice type primary elements, A_q is the cross-section of the core (throat) diameter.

After calibration os the systec Test bench, systec provides a complete ECU-factor for scaling the digital CAN based PEMS mass flow output.

At a venturi or nozzle, the absolute pressure at the inlet and the outlet differs by the differential pressure. Thus, at the inlet and outlet the density of the medium is different. The gas expansion factor ε compensates the influence of the density change across the primary element on the mass flow measurement (see also DIN EN ISO 5167). It is defined in eq. 4.2 using the dp and p_{abs} values of the instant sensor readings during the mass flow measurement:

eq. 4.2: $$\varepsilon = 1 - \left(\frac{dp[mbar]}{p_{abs}[bar]} \cdot \frac{K_{eps}}{4095} \right)$$

The K_{eps} parameter, which is scaled by a factor of 4095, is defined in eq. 4.3:

eq. 4.3: $$K_{eps} = \frac{p_{abs,Design}[bar] \cdot 910}{dp_{Design}[mbar]} \cdot (1 - \varepsilon_{Design}) \cdot 4095$$

The factory setting for K_{eps} = 0 results in an epsilon value of ε= 1. That means no expansion factor correction is being made and typically leads to too high readings at high flow rates. Typical values for ε_{Design} range between 0.9 and 1 and are defined at a specific absolute pressure $p_{abs,Design}$ and differential pressure dp_{Design}.

TH Keps-Factor has to be transmitted via CAN to the PEMS-sensor once.

The calibration constant Ks and the Keps values are also determined on the test bench at systec Controls.

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5 Specifications

5.1 Operating conditions

Parameter	Symbol		Value		Unit
		min.	typical	max.	
Supply voltage stabilized; provided by ECU (*)	U_S	4.9	5.00	5.1	V
Supply current at U_s=5.0V	I_S		25	80	mA
Max Inrush current	I_I	300mA for 120 nsec			
Pressure of medium	p_{abs}	0		4.5	bar,abs
Temperature of medium	T_{medium}	-40		500	°C
Ambient temperature	$T_{ambient}$	-40		125	°C
Temperature at electronic board	$T_{internal}$	-40		80	°C
Differential pressure	dp	-30		250	mbar

(*) Note: The sensor is protected up to a supply voltage of +36V on short term (<1min). To avoid overheating of the sensor electronics the sensor must be operated in the operating supply voltage range given in the table.
The sensor is also protected against reverse current up to -36V.

5.2 Media compatibility

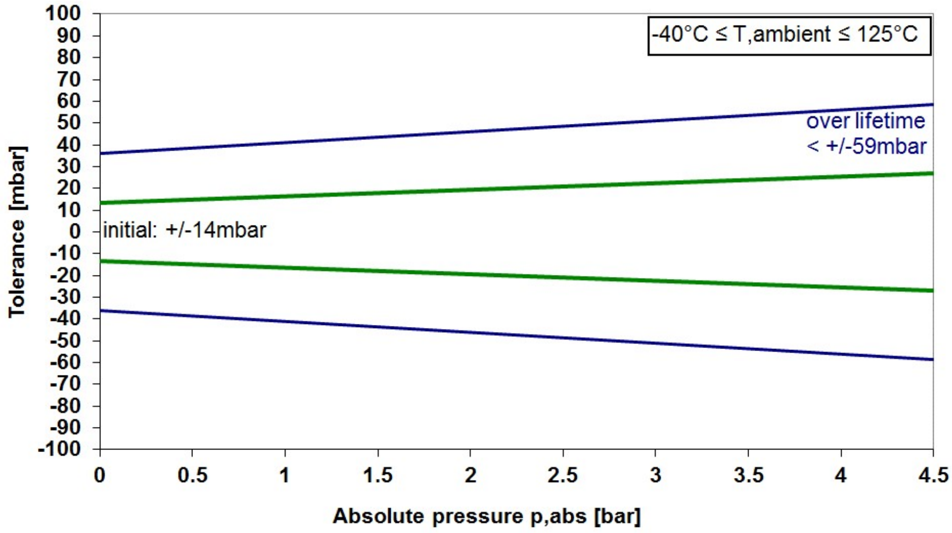
TFI4BG is compatible with many gaseous and condensing agents and therefore compatible with fresh and typically contaminated air and with typical exhaust gases from diesel engines. The tested agents can be reviewed in the environmental report. The compatibility with the individual application, needs to be tested and ensured by the customer. Please ensure condensate drainage, since condensate may lead to blocked pulse pipes in case of frost and may have capillary and water column effects on the dp signal.

5.3 Environmental tests

Please review the environmental test report of TFI4-Specification

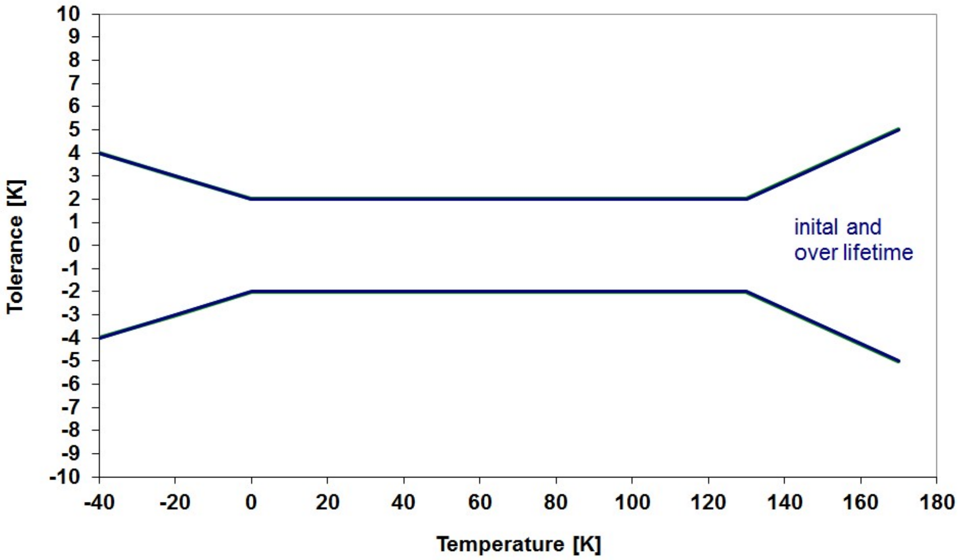
5.4 Accuracy of Pressure Sensor

The implemented absolute pressure sensor is by factory calibrated over the full measurement range at the temperature levels between -40°C and 125°C.



5.5 Accuracy of Temperature Sensor

The sensor's tip which faces the flow is a glass encapsulated NTC temperature sensor.
The figure below shows the sensor's measuring tolerance between -40 to 170°C.

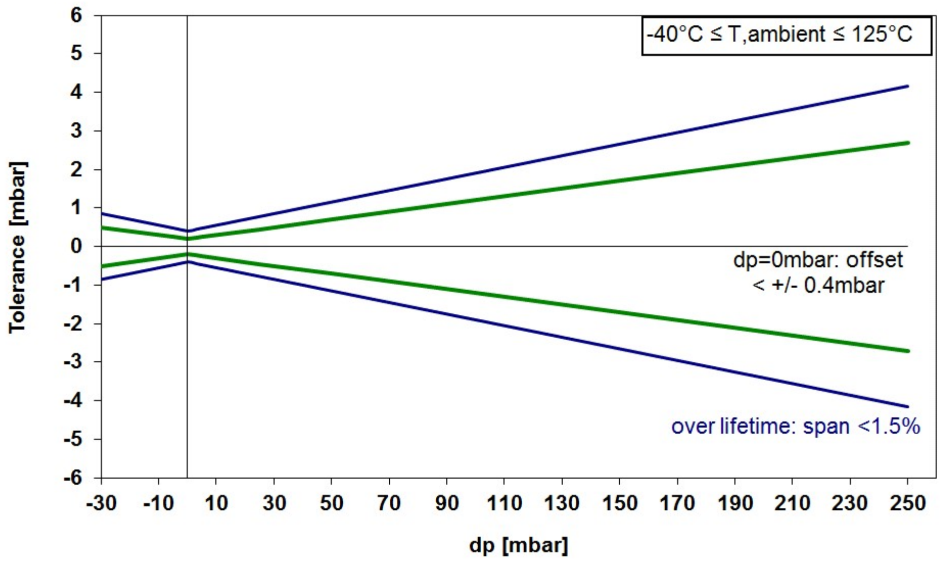


5.6 Accuracy of Differential Pressure Sensor

The accuracy of the resistive differential pressure sensors strongly depends on the offset drift due to temperature. Each sensor is individually calibrated over the complete dp pressure range.

Long term drift should be compensated by taking the actual sensor offset at “no flow condition”: sensor is powered, but engine is not running yet. The ECU should then send command 1 to measure and store the current offset in the sensor’s flash memory (see chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**).

To assure accuracy on the long term the sensor’s offset should be periodically tested and re-adjusted if needed. Without offset calibration over lifetime the offset drift could be higher. Detailed information requires durability runs.



5.7 Accuracy of Mass flow

The mass flow equation reads:

eq. 5.1:

$$\dot{m} = K_s \cdot A_q \cdot \varepsilon \sqrt{2 \cdot dp \cdot \rho} = \underbrace{K_s \cdot A_q \cdot \varepsilon}_{calibrated} \underbrace{\sqrt{2 \cdot dp \cdot \frac{p_{abs}}{R \cdot T_K}}}_{measured} \left[\frac{kg}{s}\right]$$

The accuracy of the mass flow depends on a set of calibrated and measured values. In the following only the sensor accuracy is regarded:

The measurement error for the measured parameters dp, p_{abs} and T_K is estimated according to the norm DIN EN ISO 5167 using the Gaussian error function eq. 5.2:

eq. 5.2:

$$\Delta\dot{m}(dp, p_{abs}, T_K) = \sqrt{\left(\frac{\partial \dot{m}}{\partial dp}\Delta dp\right)^2 + \left(\frac{\partial \dot{m}}{\partial p_{abs}}\Delta p_{abs}\right)^2 + \left(\frac{\partial \dot{m}}{\partial T_K}\Delta T_K\right)^2}$$

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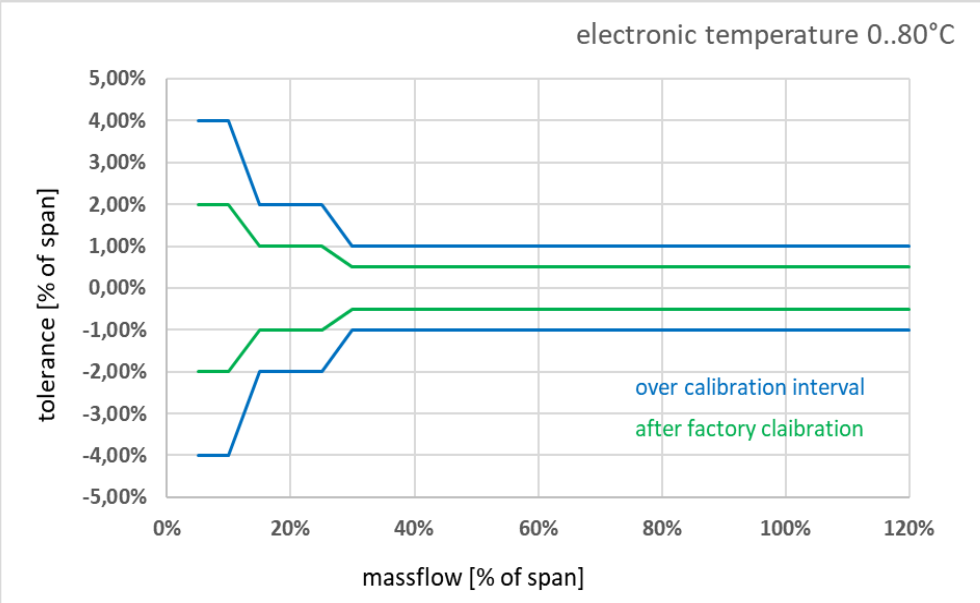
Applying the mass flow equation yields eq. 5.3:

eq. 5.3: $$\frac{\Delta \dot{m}}{\dot{m}} = \sqrt{\left(\frac{\Delta dp}{2dp}\right)^2 + \left(\frac{\Delta p_{abs}}{2p_{abs}}\right)^2 + \left(\frac{\Delta T_K}{-2T_K}\right)^2}$$

The error caused by the mathematical data processing in the electronic sensor unit is lower than 0.1%.

The graph shows a typical total accuracy after factory calibration and within the calibration interval.



Calibrations interval for normal use is 24 months.

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6 CAN-Bus Communication

The Truckflow sensor communicates with the ECU of the engine according to CAN 2.0B definition at a data rate of 500kbit/s (250kbit/s are also available). The CAN objects used have a 29bit identifier.

The sensor transmits the measurement parameters mass flow, absolute pressure, temperature and the parameter status and error codes. The sensor can receive a CAN message from the ECU in order to allow external control of the sensor's internal parameters or functionality.

The detailed CAN-protocoll description can be found in the TFI4B-manual

7 On Board Diagnosis (OBD)

The systec PEMS has a comprehensive OBD (On Board Diagnostics) protocol. On Board Diagnostics (OBD) communication for the PEMS-sensor is according to SAE J1979 standard protocol. The diagnosis offers certain functions which allow the ECU to read or write data from or to TFI4-sensor.

Available diagnosis functions:

- Read Sensor serial number
- Read Hardware and Software version
- Write K-Epsilon value
- Read K-Epsilon value
- Read Temperature scale factor
- Read Data: Mass flow, absolute pressure and medium temperature
- Further Diagnostic from Error Log

The OBD-protocoll is described in detail in the TFI4B-manual

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8 Nomenclature

Symbol	Parameter	Unit
A_q	Primary element cross section	$[m^2]$
dp	Differential pressure	$[Pa]$
I_S	Supply Current	$[A]$
K_{eps}	Expansion factor compensation constant	$[-]$
K_S	Flow constant	$[-]$
$\dot{m}$	Mass flow	$\left[\frac{kg}{h}\right]$
$\dot{m}_{corr}$	Corrected Mass flow	$\left[\frac{kg}{h}\right]$
M	Area mass flow signal from sensor	$\left[\frac{kg}{h \cdot m^2}\right]$
p_{abs}	Fluid absolute pressure	$[bar]$
p_{ECU}	Fluid absolute pressure from ECU	$[bar]$
R	Gas constant	$\left[\frac{J}{kg \cdot K}\right]$
R_{air}	Air constant	$\left[\frac{J}{kg \cdot K}\right]$
T_K	Fluid absolute temperature (in Kelvin!)	$[K]$
T	Fluid temperature	$[°C]$
$T_{housing}$	Housing temperature	$[°C]$
$T_{ambient}$	Ambient temperature	$[°C]$
$T_{internal}$	Electronic temperature	$[°C]$
T_{medium}	Medium temperature	$[°C]$
T_{air}	Air temperature	$[°C]$
T_{ECU}	Medium temperature from ECU	$[°C]$
T_{uC}	Microcontroller temperature	$[°C]$
T_{dp}	Differential pressure temperature	$[°C]$
U_S	Supply Voltage	$[V]$

Greek symbols:

ε	Gas expansion factor	$[-]$
ρ	Fluid density	$\left[\frac{kg}{m^3}\right]$

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