

Application Note

Thermal Mass Flow Sensor

FS7



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1. FS7

1.1 About the Sensor

The Innovative Sensor Technology IST AG thin film mass flow sensors were developed to offer solutions for a wide variety of flow applications with considerable advantages. Thermal mass flow modules and measuring systems are well-known devices that are offered in a wide range of applications by a handful of suppliers in the marketplace. Most of these designs are compact, ready to use systems with a channel and a passive or active output. These modules are sufficient for many general purpose applications where component price and size are less significant, but they are not well-suited for price-sensitive and space limited flow control solutions.

The FS7 flow sensors are based on a function of the flow speed and utilize heat transfer principles to determine the flow velocity. As flow passes across the sensor, heat is carried from the sensor to the medium. As flow increases, so does the amount of heat that is transferred. By knowing the heat transfer, the flow rate can be determined from the amount of voltage compensation needed to maintain a constant temperature differential.

The FS7 flow sensor with symmetric heater design and improved sensitivity is the successor product of the former FS5 flow sensor. The sensors can be applied in various gases. They have a wide operating temperature range and flow measuring rate. Flow channels guarantee the best possible adaptation of our sensors to the requirements of your application, whether in terms of dynamic range, response time or ambient conditions. The FS7 flow sensors are optimal for limited space system integration and can be upgraded into finish developed systems simply. Furthermore, customer specific designs of the chip and housing/channels are possible as well as implementation in customer defined and supplied housings.

1.2 Benefits and Characteristics

The following list outlines the advantages of the FS7 sensor. It is not a list of the sensor's full range of capabilities and should not be seen as such.

- No moving mechanical parts
- Simple signal processing
- Simple calibration
- Easy adaptation in various applications and housings
- FS7.4W sensor is applicable up to ambient temperatures of +400 °C
- Excellent long-term stability
- Stable platinum technology
- Excellent reproducibility
- Customer-specific sensor available upon request

1.3 Application Areas

Amongst others, the FS7 flow sensor is suitable for, but not limited to, the following application areas:

- Compressed air billing
- HVAC - building automation
- Automotive
- Medical applications
- Device monitoring
- Coolant monitoring



1.4 Sensor Structure

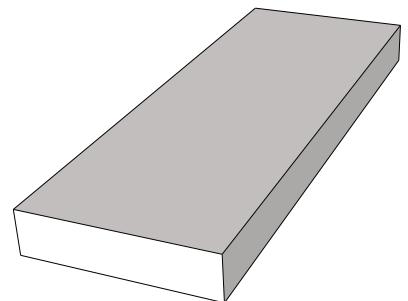
The following paragraphs describe and elaborate the multiple steps of the sensor structure.

Substrate

The base of the FS7 flow sensor chip is a special ceramic with low thermal conductivity.

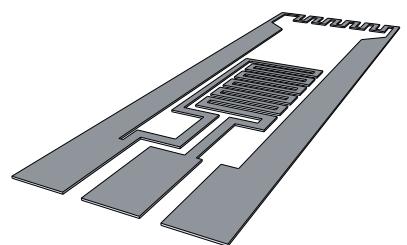
The production of the FS7 flow sensor starts by deposition of high purity platinum thin film layers onto the ceramic substrate.

To ensure high quality sensors, wet chemical processes are performed on automated systems for chemical cleaning and etching processes.



Resistive structure

The resistive structure on the sensor consists of two platinum resistors on one chip. The small resistor is used as heater and the high resistor as temperature sensor. They are fabricated by multiple steps, hereunder spin coating of a photo-sensitive resist, illumination of the photo sensitive resist through a mask, developing the photo resist and etching the platinum, leaving only the sensor structure on the chip.

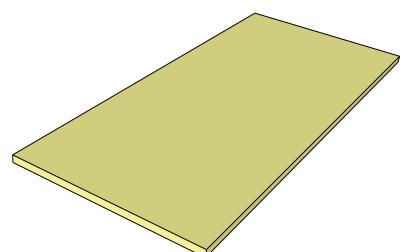


The sensor is individually laser trimmed to the customer specific resistance.

Passivation

The resistive structure is covered with a glass passivation using screen printing, which furthermore increases the robustness and strength.

Afterwards each substrate is diced on fully automated dicing machines and ready for wiring.





Wire connections



The FS7 sensor is equipped with wire connections welded on the chip on automated welding machines. For easy to use design-in the sensor can be ordered with various customer specific lengths, requirements and specifications.



The standard FS7 sensor is delivered with 195 mm black PTFE-insulated AWG 30/7 stranded wires suitable for crimping and attaching connectors.

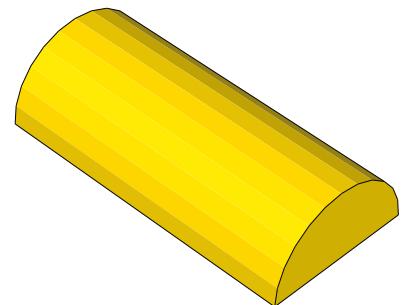


The wires are stripped 5 mm.



Wire fixation

The welding area is additionally covered by a polyimide to increase robustness, resulting in a pull strength of 10N.



1.5 Measurement Principle

The Innovative Sensor Technology IST AG FS7 thermal mass flow sensors are based on a variation of the heat transfer coefficient, which is a function of the flow speed. Thermal mass flow sensors utilize heat transfer principles to determine the flow velocity of a medium.

Flow speed changes the thermal energy loss by the heater: As a medium passes across the sensor, heat is carried from the sensor to the medium. As flow increases, so does the amount of heat that is transferred, meaning an increase in flow speed results in a higher cooling. This effect leads to a heat transfer coefficient change. Hence, cooling is a function of the mass flow.

By adapting controllers, a constant temperature difference between the heater and the temperature sensor can be achieved. This measuring principle is called Constant Temperature Anemometer (CTA). The supplied electrical power, which controls the temperature difference, is a function of the flow speed. The power is converted into a voltage output signal with a bridge circuit and can be easily readout. Knowing the temperature of the medium, the flow rate can be determined from the amount of voltage compensation needed to maintain a constant temperature differential.

The range of flow measurements is very wide and can be adjusted to the specific application. Through an electronic circuit, it is possible to increase the temperature of the heater with respect to the temperature of the medium.



1.6 Dimensions and Housing

The following describes the dimensions of the two standard IST AG FS7 thermal mass flow sensors - the FS7.0 without housing and the FS7.A with housing.

1.6.1 FS7.0

The standard FS7.0 measures 6.9 mm x 2.4 mm x 0.2 mm

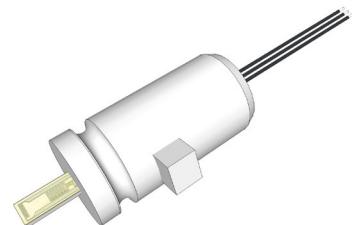
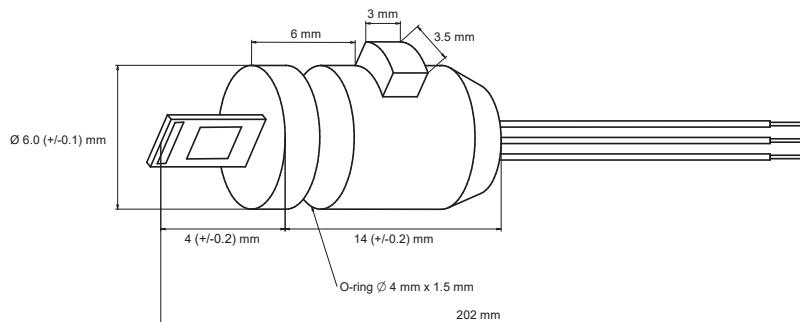


Tolerances: outer dimension (chip): ± 0.2 mm; thickness (chip): ± 0.1 mm, height ± 0.3 mm

Other dimensions, customer-specific housings and wire lengths available upon request.

1.6.2 FS7.A

For an easy mounting in a channel, the FS7.A is offered with a standard housing.



The standard FS7.A measures $\varnothing 6.0$ (± 0.1) mm, L = 14 (± 0.2) mm.
 PTFE wires measure 195 mm.

Other dimensions, customer-specific housings and wire lengths available upon request.

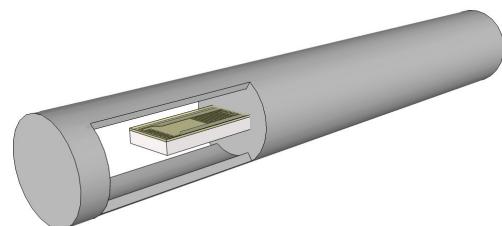


1.7 Mounting

The following mounting possibilities are only intended as examples. If you have any questions regarding specific mounting possibilities, please contact us to find the best possible solution for your application.

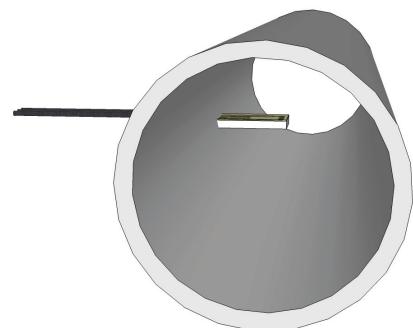
Duct mounting flow probe

Sensor mounted in a duct flow probe. The direction of the air flow must be across the sensor meaning an air flow flowing over the active sensor surface.



Customized channel/pipe with flow sensor

Sensor mounted in an air flow channel. The direction of the air flow must be across the sensor meaning an air flow flowing over the active sensor surface.



O-Ring

The size of the O-ring is 4 mm x 1.5 mm. The material is NBR with a shore hardness of 70.

Other materials and sizes upon request.

Connector

The standard FS7 sensor is not supplied with a connector, but the sensor can be purchased with e.g. a JST connector. Please contact Innovative Sensor Technology IST AG for more information regarding the various connector possibilities.

1.8 Delivery and Content

The standard delivery time of the Innovative Sensor Technology IST AG FS7 sensor is 4-6 weeks after orders received.

The FS7 sensor is delivered without electronic parts or modules. The FS7 test module must be purchased separately.



1.9 Handling

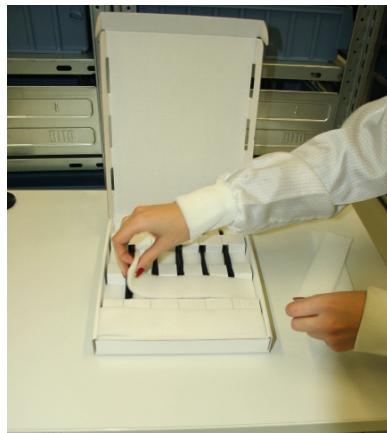
The FS7.0 sensor is delivered in a carton box and must be handled as follows:



The FS7.0 sensor is delivered in a box with label showing the exact sensor type and lot-number



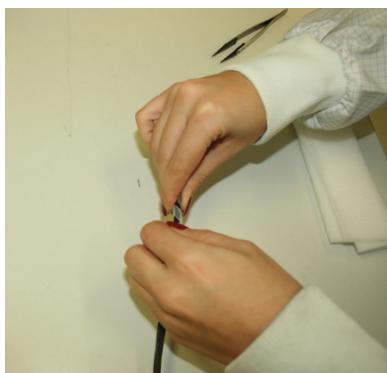
Open the box carefully with both hands



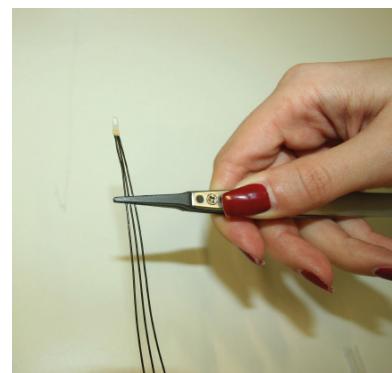
Remove the stripes of plastic covering the sensors



Open the carton flaps to release the sensors



Carefully remove the plastic spiral around the wires



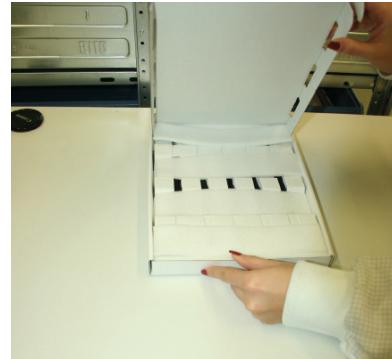
Handle the sensors with plastic tweezers only



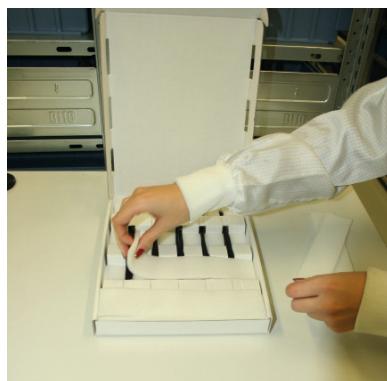
The FS7.A is delivered in a carton box and must be handled as follows:



The FS7.A sensor is delivered in a box with label showing the exact sensor type and lot-number



Open the box carefully with both hands



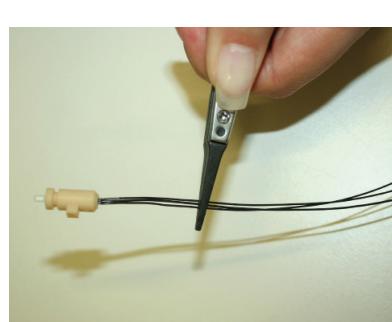
Remove the stripes of plastic covering the sensors



Open the carton flaps to release the sensors



Carefully remove the plastic spiral around the wires

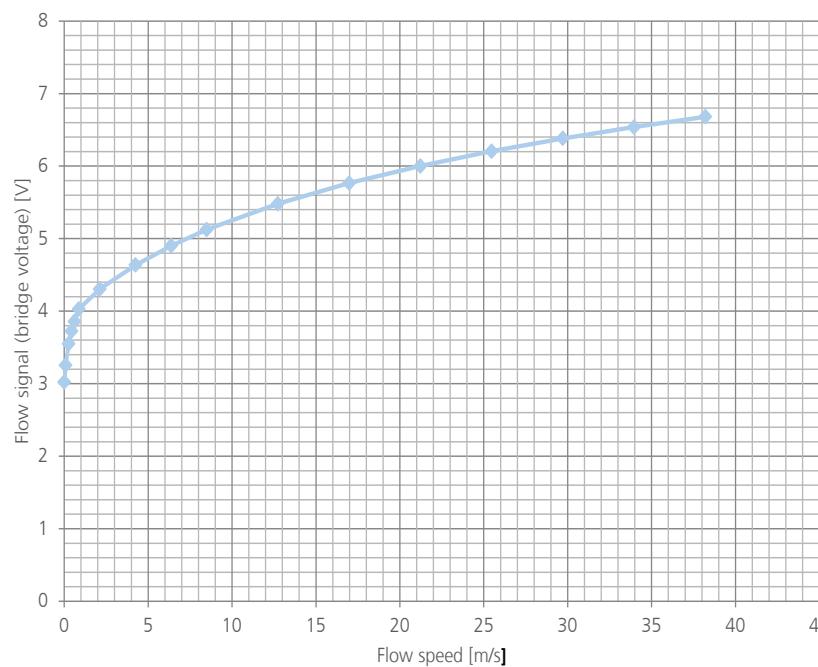


Handle the sensors with plastic tweezers only



1.10 Performance

The following graph showcases the performance of the IST AG FS7 sensor during application. Depending on the specific application and possible influences the measurements might vary.



The output signal is adjusted to 3.0 V at zero flow and corresponds to a temperature difference (heater temperature minus ambient) of approximately 30K. With the temperature difference an optimal overhead of the heating element is generated and hence a perfect performance exists. According to King's Law, which is declared in section 1.12, the sensor performance has the highest sensitivity at lower flow speeds.

The flow speed was measured with a CTA-circuit (see section 1.12) and with nitrogen at an ambient temperature of 25 °C. The sensor was mounted in a tube with an inner diameter of 5 mm.

1.11 Influences

The following list showcases possible influences, however is strongly dependent upon the application. If you have any questions regarding specific applications and its possible influences, please contact us to find the best possible solution for your requirements.

Contamination

The characteristics can be affected due to sensor contamination such as dust.

Alignment

The characteristics depend on sensor alignment/orientation. The sensor must be aligned so the flow passes over the active sensor surface. The IST AG FS7 is independent of the flow direction.



Temperature (medium)



The characteristics depend on the medium temperature; therefore temperature compensation is necessary in order to achieve an accurate measurement.



Temperature changes in the medium are already compensated by using the CTA electronics („first order“).



1.12 Electronic and Circuit Diagram

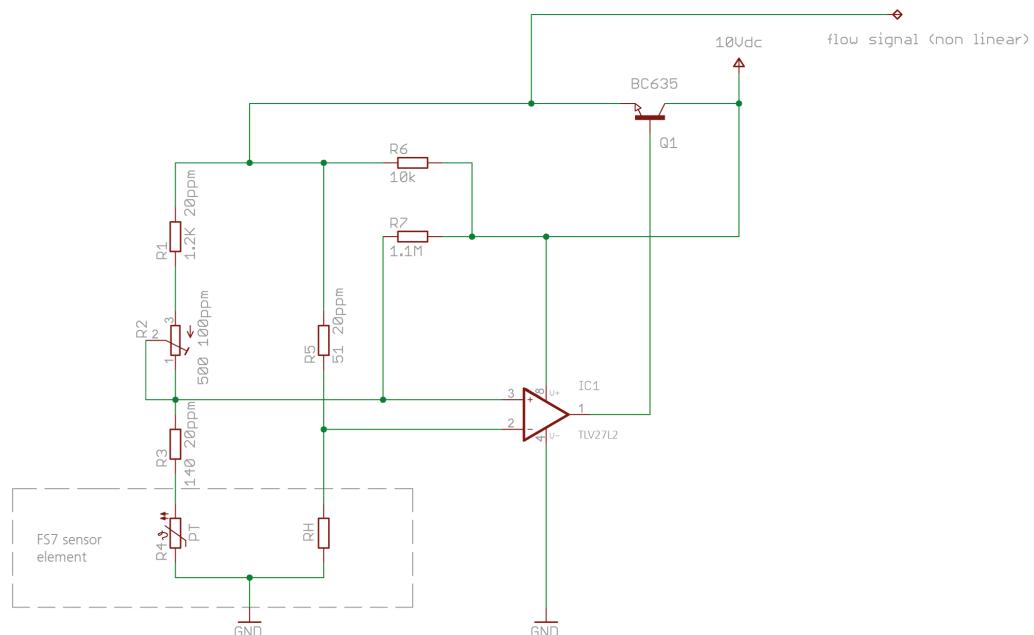


The CTA-mode (Constant Temperature Anemometer) consists of a simple feedback circuit for the temperature regulation of the heater on the flow sensor, as flow speed changes the thermal energy loss by the heater. When a medium passes across the sensor, heat is carried from the sensor to the medium. As flow increases, so does the amount of heat that is transferred, meaning an increase in flow speed results in a higher cooling. This effect leads to a heat transfer coefficient change. Hence, cooling is a function of the mass flow.

By adapting controllers, a constant temperature difference between the heater and the temperature sensor can be achieved. The supplied electrical power, which controls the temperature difference, is a function of the flow speed. The power is converted into a voltage output signal with a bridge circuit and can be easily readout. Knowing the temperature of the medium, the flow rate can be determined from the amount of voltage compensation needed to maintain a constant temperature differential.

The medium temperature variation is compensated by the temperature sensor on chip (Pt1200). The resistors R1 to R6 can be chosen as shown in the circuit below. The temperature difference (DT) between heater (RH) and medium (RS) is set by resistor R3, e.g. DT=30 K for air. The resistor R2 should be adjustable within $\pm 10\%$ for calibration. The R7 resistor is placed for stability of the anemometer circuit.

Depending on used operational amplifier, it should be valued from $1.1 \text{ M}\Omega$ to $3 \text{ M}\Omega$.



Electronic circuit and curve progression are examples. Each application linked to the accuracy level requires an individual calibration of the system.



The CTA is described by King's law:



$$P_H = I_H^2 \cdot R_H = (A + B \cdot \bar{v}^n) \cdot \Delta T \quad n = 0.3 \dots 0.5$$



By conversion and simplification, the equation can be obtained in the following form:



$$U = U_0 \cdot \sqrt{1 + k \cdot \bar{v}^n}$$

U = CTA-output

k = Fluidic dependent constant

U₀ = Free convection offset

v = Fluid velocity

U represents the flow depended output signal. U₀ represents the value of constant temperature difference (ΔT) between the heater and fluid at no flow speed, which results due to natural convection.

The controller of a CTA keeps the ΔT between heater and temperature sensor constant.



Maximum supply voltage

2 V to 5 V

Maximum heater voltage

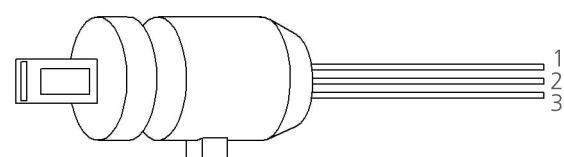
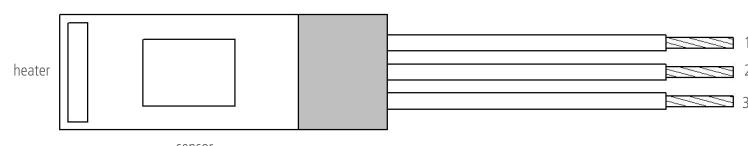
3 V (at 0 m/s)

Optimal resistance values (heater resistance)

RH (0 °C) = 45 Ohm ± 1 %

For gas applications, the temperature difference (resistor value) is recommended to 30 K.

Pin assignment



1	2	3
heater	temperature sensor	GND



1.13 Calibration and Linearization

1.13.1 Calibration

For linearization the reverse function of CTA- equation is used.

$$U = U_0 \cdot \sqrt{1 + k \cdot \bar{v}^n} \quad \text{CTA - equation}$$

$$\bar{v} = \frac{[(U - U_0) \cdot (U + U_0)]^{\frac{1}{n}}}{(k^{\frac{1}{n}}) \cdot U_0^{\frac{2}{n}}} \quad \text{Reverse function}$$

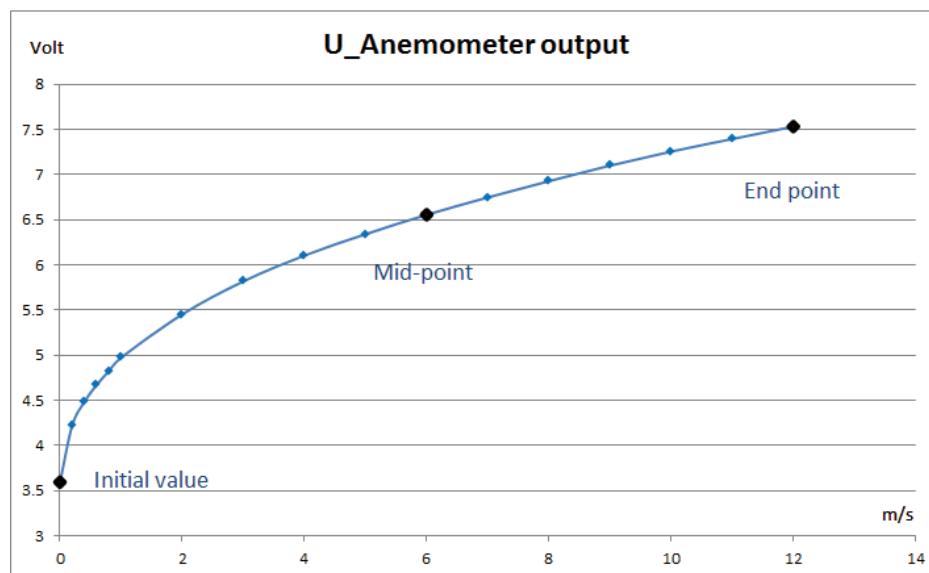
The n-parameter is close to 0.5 (0.48....0.52). Most of flow fitting modules (each with different FS7 sensor) and individually mounted into the flow fitting have the value $n = 0.51$. The k-value goes from 0.9...0.93, it is depending on the alignment of the sensor and the flow profile.

The values n and k can be determined by a flow calibration at 3 points:

1. Initial value (value U_0 at zero flow)
Point is at zero flow and adjusting the 3,6 volts at analog output. With this adjustment all tolerances of chip thickness, thickness of glass passivation (+/- 10 microns), and tolerances of heater resistances are compensated.
2. Mid-point of measuring range
3. End point of measuring range: full range value

Anemometer output calibration

Measuring curve from 0...12 m/s.





1.13.2 Linearization of Anemometer output

How to calculate k and n:

By using the calibration points of the anemometer output diagram an equation system can be set up. Calibration points according the diagram and equation system are:

$$U_0 = 3.6 \text{ V at } v_0 = 0 \text{ m/s}$$

$$U = 3.6V \cdot \sqrt{1 + k \cdot 0m/s^n} = 3.6V$$

$$U_{50\%} = 6.6 \text{ V at } v_{50\%} = 6 \text{ m/s}$$

$$U = 3.6V \cdot \sqrt{1 + k \cdot 6m/s^n} = 6.6V$$

$$U_{100\%} = 7.5 \text{ V at } v_{100\%} = 12 \text{ m/s}$$

$$U = 3.6V \cdot \sqrt{1 + k \cdot 12m/s^n} = 7.5V$$

Solving equation system:

A. Calculating n

$$\frac{\vec{v}_{100\%}}{\vec{v}_{50\%}} = 2$$

where:

B. Calculating k

$$k = \frac{\left(\frac{U_{50\%}}{U_0}\right)^2 - 1}{\vec{v}_{50\%}^n} = \frac{2.36111}{6^{0.5}} = 0.964$$

B. Results of Linearization

Together with the three calculated values U_0 , k and n we can find the linearized characteristic. By solving the equation system k and n were found. Assumed that n always can be set to 0.50, we only need the full range calibration point. This is the reverse function again of flow sensor (for linearization):

$$\vec{v} = \frac{[(U - U_0) \cdot (U + U_0)]^{\frac{1}{n}}}{(k^{\frac{1}{n}}) \cdot U_0^{\frac{2}{n}}}$$

v = velocity or later mass flow

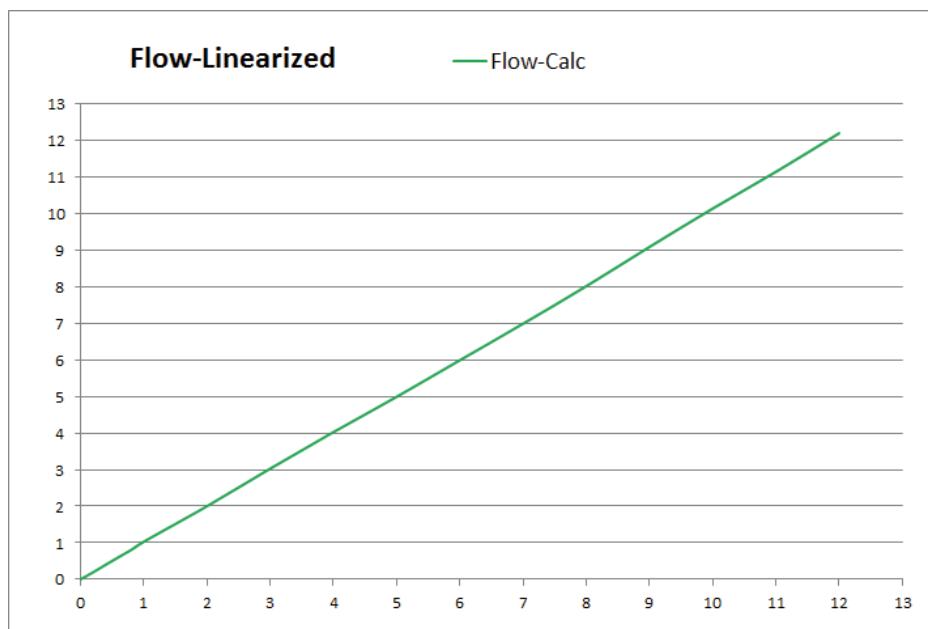
U_0 = 3.6 volts

U = measured voltage depending from mass flow n and k



CTA output linearization

By using the real measured n, k and U_0 voltage together with the reverse function for linearization we get the following curve.



1.14 Voltage Sensitivity (e.g. ESD)

IST AG's thermal flow sensors are based on platinum resistors and are passive components which cannot actively be protected against excess voltage events, such as ESD. In terms of ESD-sensitivity, they react similarly to thin-film resistors. This means, that the ESD sensitivity is inherent to sensor design and is typically a function of size. But also, base resistance, meander design and special coating might have an impact on ESD-sensitivity of platinum temperature sensors. ESD-induced damages of platinum RTDs are rarely observed in customer returns and are typically related to a specific assembly or application.

In case ESD-damages are observed on the customer side, we recommend taking normal ESD precautions when handling the sensors. IST AG can also support critical applications with special design and help with the selection of sensor type.

2. Additional Electronics

Document name:

Module:

DFFS_FSL_Module_E

DFFS_FSL_Module_D

3. Additional Documents

Document name:

Data Sheet:

DFFS7_E

DFFS7_D

DFFS74W_E

DFFS74W_D



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