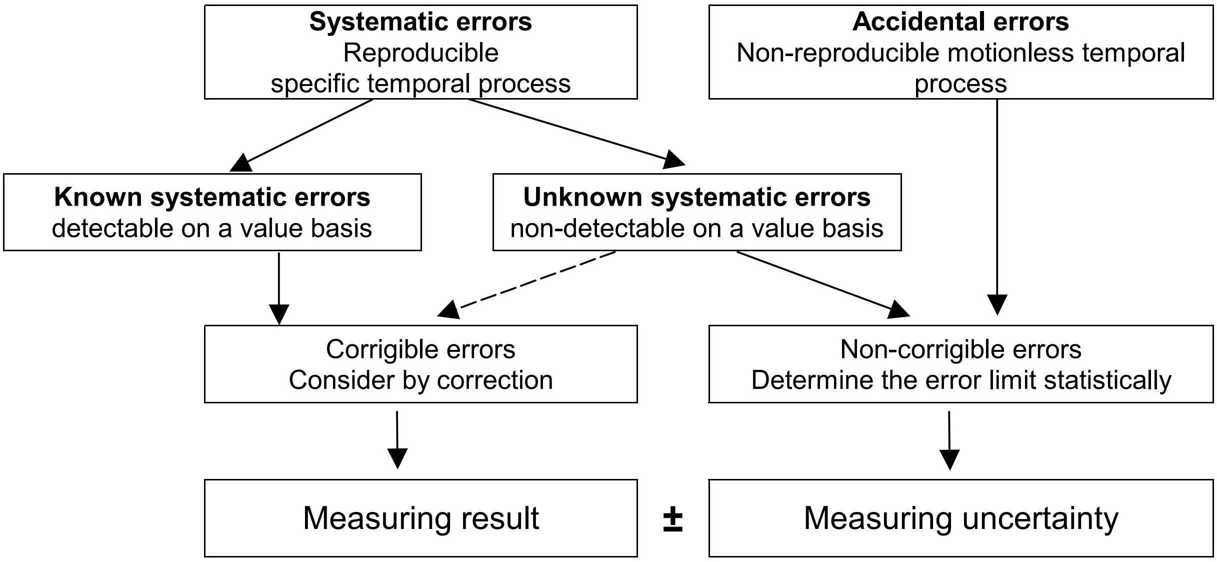
Measuring Uncertainty Differential Pressure Measurement
Comparison: Classic Transmitter – "autarkon"®

General introduction

Each measurement of a physical parameter is connected with uncertainties, i.e. the measuring result for the actual value is only an approximation. If the influential factors and their impact on the measuring result are known and can be detected, they can be used for the correction of the measuring result; this is known as systematic errors. The remaining influences which are unknown or which cannot easily be detected and corrected are called unsystematic errors. These unsystematic errors are summarised under the term measuring uncertainty.



Examination of a differential pressure transmitter

Next to the actual measuring signal, the differential pressure transmitter is also influenced by other factors which can falsify the measuring result. These are, e.g., the working point, ambient temperature, static pressure, installation type, temperature of the medium, distribution voltage, ageing, etc. Some of these influential factors are known and can eventually be corrected; others are unknown and thus increase the measuring uncertainty. The measuring uncertainty is not a static factor. The measuring uncertainty changes over the years due to the ageing and wear of the many components involved in the measuring process.

The ideal measuring system has a clearly defined relationship between the physical parameter and the measuring signal or result.

In the case of a differential pressure transmitter, the output current is a function of the differential pressure.

$I = f(\Delta p)$, in which there can be a linear $I = a_0 + a_1 \times \Delta p$ relationship or a $I = b0 + b1 \times \sqrt{\Delta P}$ relationship with an extracted root.

Detection and implementation of the differential pressure onto a flow is always connected with errors. A measuring uncertainty is stated to restrict errors. This measuring uncertainty states that the measuring result is - most probably - within an interval.

If the physical value is formed from the measuring result, an uncertainty (U) always has to be taken into account.

$$\Delta P = f(I) \pm U$$

A practical usable measuring system not only has to determine the measuring result with a possibly small uncertainty at one working point, but also within a certain measuring range. Therefore, the measuring uncertainty has to be observed over the entire measuring range.

Today, practicable measuring ranges for the volume or mass flow are from 1:10 to 1:30, in special cases also up to 1:100.

In the case of classic measurements based on throttle devices which generate the differential pressure in proportion to the flow, a measuring range of 1:3 is practicable. This is based on the circumstance that the relationship between the flow (Q) and differential pressure (Δp) is not linear, but quadratic and that therefore the measuring uncertainty greatly increases with larger measuring ranges.

$$\Delta P = Q^2$$

or

$$Q = \sqrt{\Delta P}$$

Q	Δp
1:3	1:9
1:10	1:100
1:30	1:900

For a flow measuring range of 1:3 the differential pressure has to be detected in an area of 1:9.

In order to evaluate the measuring uncertainty, the influence of the differential pressure transmitter on the measuring result has to be observed over the entire measuring range.
Depending on the measuring point, the influential factors mentioned above have different impacts on the measuring result. General experience has shown that the

relative influences on the current value at the lower measuring range value are much stronger than with measuring values near the upper measuring range value.

The measuring uncertainty is either stated as a relative value (%) and refers to the measured value (v. M.) or the upper measuring range value (v. E.) or as an absolute value (constant over the measuring range). In the case of differential pressure transmitters the statements usually relate to the upper measuring range value. Since the measuring ranges can be scaled (turn down), not only the uncertainties related to the set measuring range but also the uncertainties related to the maximum measuring range have to be observed.

Common transmitters of the reference class state, e.g., a measuring uncertainty (U_{vE}) of 0.1 % v. E. (from the upper range value). If this value is applied to the actual measured value, there are clearly more measuring uncertainties.

Q	Δp	U_{vE}	U_{vM}
1:1	1:1	0.1 %	0.1 %
1:3	1:9	0.1 %	0.9 %
1:10	1:100	0.1 %	10 %
1:30	1:900	0.1 %	90 %

The measuring uncertainty related to the upper range value can be converted into the measured value as follows: $U_{VM} = \frac{U_{VE} \times \Delta p_E}{\Delta p}$

This means for the measured differential pressure:

$$\Delta P_M = (a_0 + a_1 \times \Delta P) \times (1 + U_{vM})$$
$$\Delta P_M = a_0 (a_0 \times U_{vM} + a_1 \times \Delta P) + (a_1 \times \Delta P \times U_{vM})$$
$$\Delta P_M = a_0 \left(\frac{a_0 \times U_{VE} \times \Delta P_E}{\Delta P + a_1 \times \Delta p} \right) + \left(a_1 \times \Delta P \times U_{vE} \frac{\Delta P_E}{\Delta P} \right)$$
$$\Delta P_M = a_0 \left(\frac{a_0 \times U_{VE} \times \Delta P_E}{\Delta P + a_1 \times \Delta p} \right) + (a_1 \times U_{VE} \times \Delta P_E)$$

This shows that the actual measuring result is overlaid not only with the ideal relationship $(a_0 + a_1 \times \Delta P)$ but also with an uncertainty related to the upper range value $(a_1 \times U_{VE} \times \Delta P_E)$ and an uncertainty related to the measured value $\left(a_0 \times U_{vE} \frac{\Delta P_E}{\Delta P} \right)$.

Since these uncertainties are not known according to definition, they can only be minimised by regular recalibrations.

Examination of the "autarkon" system

a0 and a1 are known due to the factory calibration.
The equation stated above shows that the influence of a0 on the total measuring uncertainty becomes maximal for small differential pressure. Due to hydraulic zero-balancing, i.e. a differential pressure of 0 mbar is generated by magnetic valves, a new $a0_k$ can be determined which is then used for the conversion to the corrected measured value ($\Delta p_{M,k}$).

1. Calibration: $\Delta P_M = a_0 + a_1 \times \Delta p$

in operation, t > 0: $\Delta P_M = a_0 + a_1 \times \Delta p + U(t)$

Auto calibration: $\Delta P_{M0} = a_0 + a_1 \times 0 + U(t) \Rightarrow a_0$

$\Delta P_{M0} = a_0 + U(t) = a_{0k}$

2. Calibration: $\Delta P_{M,k} = a_{0k} + a_1 \times \Delta P$

This automatic calibration cannot be carried out without a residual uncertainty. Depending on different circumstances this is at ± 10 ... 50 µbar.

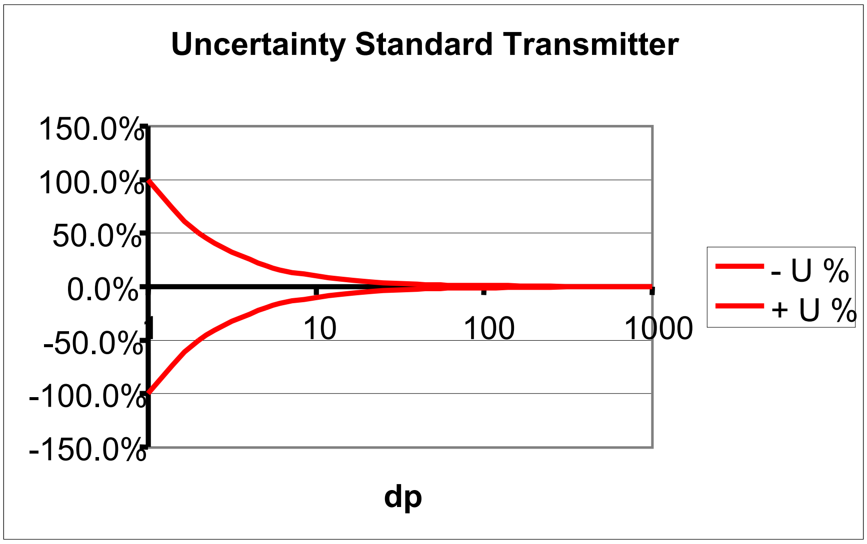
This results in a measuring uncertainty for the **"autarkon"** system of:

$$U_{vM} = U_{vE} + U_0 = U_{vE} \pm 10 \ldots 50\ \mu bar$$

For a standard differential pressure transmitter with $U_{VE} = 0.1\%$ the measuring uncertainty is:

$$U_{vM,k} = U_{vE} \frac{\Delta P_E}{\Delta P_M} + U_{vM} + U_0 = 0.1\,\% \times \frac{\Delta P_E}{\Delta P_M} + 0.0 + 0\ mbar$$

$$U_{vM,k} = 0.1\,\% \times \frac{\Delta P_E}{\Delta P_M}$$



For an **"autarkon"** transmitter with $U_{vE} = 0.1\,\%$ and $U_0 = 50\ \mu bar$ the measuring uncertainty is:

$$U_{vM,k} = U_{vE}\frac{\Delta P_E}{\Delta P_M} + U_{vM} + U_0 = 0.0\,\% \times \frac{\Delta P_E}{\Delta P_M} + 0.1\,\% \pm 50\ \mu bar$$

$$U_{vM,k} = 0.!\% \pm \left(\frac{50\ \mu bar}{\Delta P_M}\right)$$

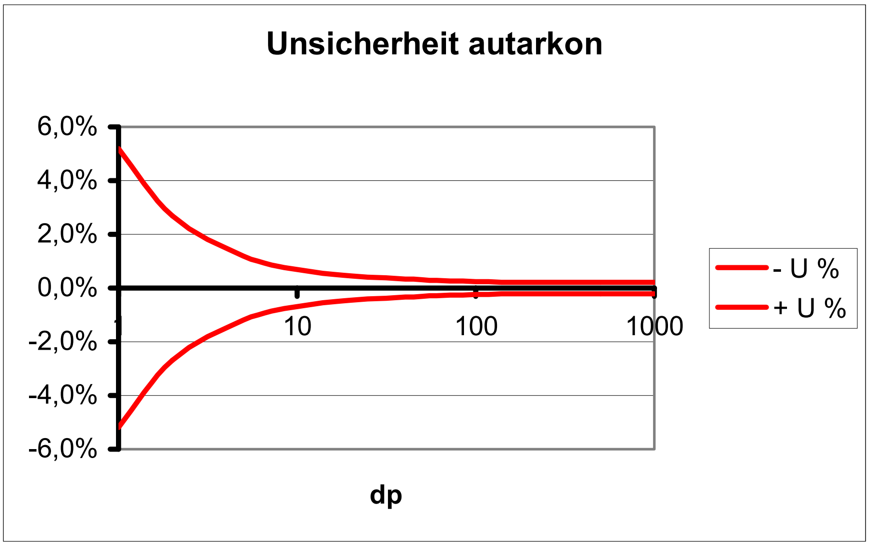


Figure: Uncertainty autarkon

Long-term stability "autarkon"

The "autarkon" measuring system has been used for approx. 25 years. Since 1981, it has also been used where calibration is required for the measurement of thermal energy in water. These measuring devices are calibrated on accredited test benches. Measuring devices used for billing purposes have to be recalibrated after 5 years. The PTB (Physikalisch-Technische Bundesanstalt (PTB) – German Metrology Institute providing scientific and technical services) stipulates that a control sample (K20) has to be taken from these recalibrated devices; this sample then has to undergo an input check. Here it is determined whether the devices are still in the calibration error limit (3 %) or the duplex calibration error limit. The results have to be sent to the PTB. The PTB then specifies for the respective measuring system whether the calibration intervals have to be changed.

According to our experience, 96 % of the checked devices are within the calibration error limit after 5 years of operation and 100 % within the duplex calibration error limit as far as there are no other defects.

This leads to the conclusion that the long-term stability related to the measured value is better than the calibration error limit. The devices are calibrated in the flow measuring range of 1:30, this equals a differential pressure measuring range of 1:900. This means an ageing of less than 0.06 mbar ($U_{\Delta P} \approx 2 \times U_Q = 6\,\%$ of 1 mbar) or 0.006 % of the measuring range in relation to the lower measuring point after 5 years.

Long-term stability standard transmitter

The long-term stability is usually stated as an uncertainty related to the upper measuring range value. For practical applications, this value has to be converted into the actual measuring range.

If 0.1 % from the upper range value is assumed for the long-term stability per year, the uncertainty at measuring point $\left(U_{\Delta P} \approx 2 \times U_Q\right)$ is:

Δp	**U_{vE} Δp**	**U_{vM} Δp**
1:1	0.1 %	0.1 %
1:9	0.1 %	0.9 %
1:100	0.1 %	10 %
1:900	0.1 %	90 %

Q	**U_{vE} Q**	**U_{vM} Q**
1:1	0.05 %	0.1 %
1:3	0.05 %	0.5 %
1:10	0.05 %	5 %
1:30	0.05 %	45 %

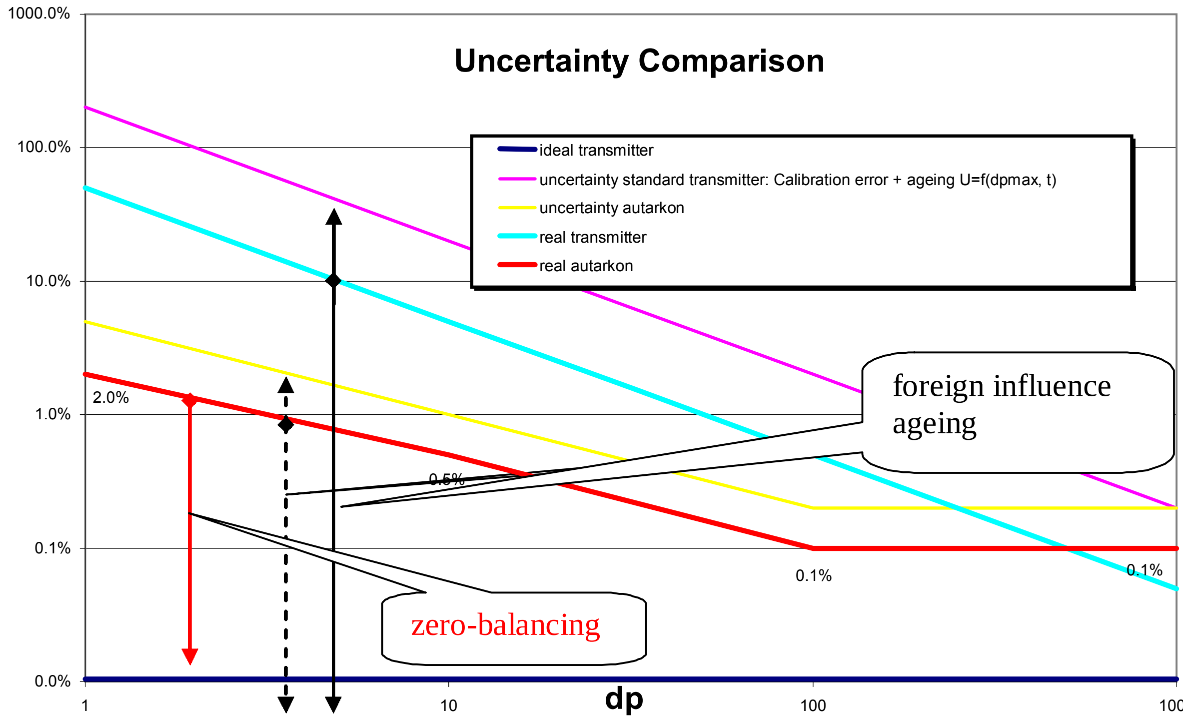
Calibration interval standard transmitter

From this it is possible to deduce the calibration interval. In the case of a flow measuring range of 1:3 and an accepted ageing-related uncertainty of 1 % of the differential pressure, the transmitter has to be recalibrated every 12 months. In the case of a measuring range of 1:10, the transmitter has to be recalibrated every month and in the case of 1:30 every 4 days.

Calibration interval "autarkon"

Since the autarkon system automatically recalibrates itself on a regular basis, the zero point related uncertainties are largely eliminated. Therefore, only the ageing which influences the upper measuring range value has to be taken into account for the specification of the calibration interval. In the case of an accepted ageing-related uncertainty of 1 % of the differential pressure, the transmitter has to be recalibrated every 5 years.

Graphical presentation of the measuring uncertainty (double logarithmic presentation)



Comments:

- Here, **"autarkon"** is a synonym for all METRA differential pressure measuring systems with automatic zero-balancing, similar to the "orikon" family: VMT 1xx, EWZ1xx,
- DT 31x
- all uncertainties are to be understood as ±, if not stated otherwise