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Measuring tube construction affects the long-term stability of magnetic flow meters.

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Introduction

Electromagnetic flowmeters, also known as mag meters, are popular and proven devices for flow measurement of electrically conductive process fluids and for volumetric filling machine applications. Of prime importance to a mag meter's accuracy and long term performance is the condition of the metering section of the flow sensor.

Unlike in most processes, mag meters in filling machine applications are frequently subject to widely varying conditions during normal operation. As a result, they are viable candidates for evaluating their long term performance in an accelerated use environment. Therefore PTB, a German research and approvals agency, in association with KROHNE, undertook an extensive project to study the long term measurement stability of mag meters in filling machine applications.

Overview:

Faraday's law is the basis of a mag meter's measuring principle. The design generally features an electrical isolating liner on the inner wall of the mag meter measuring tube. Linings such as PTFE, PFA or polypropylene or for hygienic reasons, PFA (perfluoroalkoxy) are used. Pressure bearing ceramic pipes are also used. PFA is known to absorb moisture, it can flow under pressure and temperature which means that it changes structure and shape which, in turn, affects the interior diameter of the measuring tube. Changes in the inner diameter of the measuring tube lead to measurement errors. This can lead to problems, especially when extreme precision or repeatability are at stake. This only takes effect after the devices have been in use for longer periods of time and through the corresponding frequent cleaning processes using liquid or steam as are common in the food industry.

The effect is particularly significant when it comes to mag meters used on filling machines for filling PET bottles ("Filling mag meter"). In this case, an extremely high degree of repeatability is required and the quality of the filling process is directly visible in each individual bottle.

That is why, in a joint research cooperative with the Physikalisch-Technischen Bundesanstalt (National Metrology Institute) (PTB), Krohne Messtechnik tested the measurement stability of filling mag meters. Filling mag meters with PFA liners and filling mag meters with ceramic measuring tubes were both tested. The PTB was interested in this test because for more than 20 years Magmeters with ceramic measuring tubes have been the norm in the normal PTB measuring systems as well as in many other calibration test stations. Thanks to this test, the PTB was able to gain additional knowledge about the behavior of these devices under difficult conditions.

Magmeter Construction

With electromagnetic flow meters with PFA lining, the plastic is put into the stainless steel measuring tube of the mag meter in granulate form and there, at approximately 570°F(300°C) it is melted down to a thin (about 1/8 in. / 3 mm thick) plastic hose. This hose shrinks noticeably during cooling and hardening. A gap then forms between the stainless steel tube and the PFA liner. The necessary metal electrodes are inserted into the sensor following the lining process.

In operation, when the pressure and temperature values are sufficiently high, the hose expands to touch the interior wall of the stainless steel tube. The inner diameter of the PFA-lined measuring tube then changes by a maximum of double the breadth of the gap. The mag meter changes accordingly. In addition, water (steam) may diffuse through the PFA liner and can condense behind the liner. When heated, this moisture can turn back into steam, distorting the liner. These changes can occur any number of times because PFA flows, in other words its shape constantly changes.

To reduce such effects, mag meters such as those produced by KROHNE have the PFA supported by a fused-in stainless steel grate. This gives the liner a certain amount of stiffness and stability against vacuum conditions which often occur in the food industry due to the rapid and regular fluid temperature changes.

Magmeters with a ceramic measuring tube do not have a plastic liner as an isolating element but rather a pressure-bearing tube made of fused-in high-tech oxide ceramic. Metal-ceramic electrodes (so-called CERMET electrodes) are integrated in this liner ceramic using a sintering process at temperatures above 3000°F(1700°C) making them absolutely gap-free(Fig. 1+2).

Fig. 1 SEM micrograph of the CERMET electrode fused into the Ceramic Measuring tube

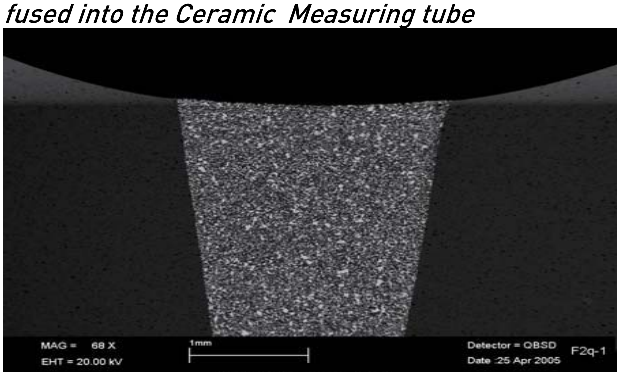


Fig. 2 Ceramic measuring tube with visible electrode

The CERMET material is made of approx. 70% ceramic and 30 % platinum powder. This allows the electrode material to adhere well to the ceramic material when sintering. This means there is no risk of the liquid by-passing the electrodes and entering the electronic housing.

In addition to its high pressure stability, oxide ceramic possesses a high temperature shock resistance. This is particularly important during cleaning cycles when hot water or steam flows through the device for short intervals instead of the normal cold product. With a temperature gradient of 3°K/ second, the ceramic is rated shock-resistant for common cleaning with water or steam.

Demands on mag meters in filling machines

Demands placed on the Mag meters in filling machine service are among the highest in the entire process industry. The filler operator expects the filling volume to remain exactly the same over the entire life cycle of the machine, regardless of whether it is filling simple products like water or lemonade or difficult products such as hot juice with solids content.

As quality of the filling process is often constantly controlled and documented. Under filling is illegal and overfilling is considered a loss.

The application difficulty is compounded by the fact that these systems must comply with high hygienic standards and thus must often be subjected to hot water, chemical solution or steam cleaning (CIP/SIP). The frequent (e.g. daily) steam cleaning at 275°F (135°C) can be particularly hard on the mag meter's liner material over time.

As mentioned earlier, the flow of the PFA liner material and the steam diffusion affects the geometry of the measuring tube. As a result, it no longer corresponds to the meter's geometry at the time of the factory calibration. For example, a change of 1 thousandth of an inch (30 μm) in a nominal ½ inch(DN 15) flow meter diameter can result in flow measurement deviations of 0.2% to 0.4%. This illustrates that even small changes can have a tangible influence on filling accuracy. Usually, filling machines are calibrated only once, followed by many years of use without the need for recalibration. The prerequisite for this is the stability of the filling mag meter and its stable measuring tube geometry.

Fig. 3 Filling machine for PET bottles

Test installation
To determine the short and long-term impact of pressure, temperature and cleaning processes on the accuracy of Magmeters, the PTB installed 3 devices with PFA and 3 with ceramic lining in an approximately 4 foot(1.5 m) long stretch of stainless steel pipe. (see Fig. 4) This measurement section was left in this condition during the time in which the tests where being run by the PTB.

Fig.4 Installed MAGMETER in the PTB test section

The measurement inaccuracy of electromagnetic flow meters was then tested according to the following table at 3 different flow rates (0.5 m/s; 1.0 m/s and 2.0 m/s); these rates correspond to approx. 20, 35 and 72% of the set measuring range. To test the effect of media temperature and pressure on MAGMETER measurement inaccuracy as well, measurements were made at 18 °C and 81 °C and at 2 bar and 4 bar. These tests were conducted by the PTB on a gravimetrically normal measuring system with an uncertainty of 0.05%.

Table 1: PTB Test Protocol

No.	Testing	Flow values [m3/h]	Temperature [°C]	Pressure [bar]	Number of measuring cycles
1	In new condition	0.32; 0.63; 1.30	approx. 18 °C approx. 18 °C approx. 81 °C approx. 81 °C	2 42 4	10 measurements/test points 10 measurements/test points 10 measurements/test points 10 measurements/test points
2	Simulation Hot water (CIP)	approx. 2	Change from 18 °C to 81 °C Time approx. 5 min.	4	600 cycles
3	SIP Steam, 30 min. Water, 20 min.		134 °C approx. 20 °C	2	60 cycles
4	CIP cleaning	approx. 2	approx. 90 °C	4	1 cycle, HNO_3 3%, 20 minutes
5	After CIP/ SIP Simulation	0.32; 0.63; 1.30	approx. 18 °C approx. 18 °C approx. 81 °C approx. 81 °C	2 42 4	10 measurements/test points 10 measurements/test points 10 measurements/test points 10 measurements/test points

Then, to simulate the effects of CIP cleaning procedures on measurement accuracy, devices under test were operated at 5-minute intervals with alternating medium temperatures of 81 °C and 18 °C at approx. 2 m3/h. This simulation of a CIP cleaning process was conducted 600 times in succession. The devices then underwent hot steam sterilization (SIP) 60 times. And since the PTB does not have the facilities to carry out hot steam sterilization, this test was run at the Dutch TNO (Netherland Organisation for Applied Scientific Research) and EHEDG (European Hygienic Equipment Design Group). Cleaning was performed each time for about 30 minutes with hot steam at 134 °C and then cooled with water at room temperature. The next sterilization process followed. Following final CIP cleaning of the measurement section, the PTB calculated the measurement uncertainty of the devices under test at 3 different flows, temperatures and pressures. Table 1 illustrates the schedule of the tests.

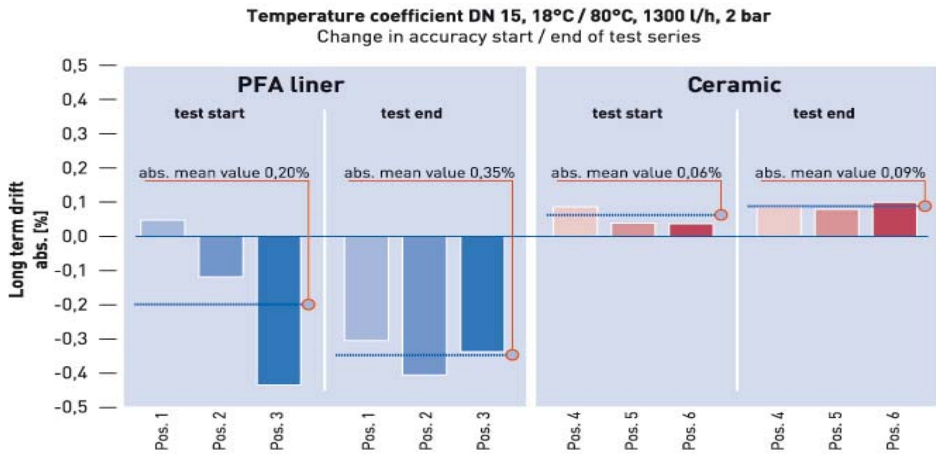
Table 2 PTB Mag Meter Liner Permeation

Liner	**FDA conforming PFA, 1mm thick**	**Fused-in-place high-tech ceramic 1 mm**
Permeation rate for water, 23°C	0.046 cm3/ ´(m2 x day x bar)	0
Water absorption	< 0.03 %	0
Melting point	302-310°C	2650°C

Test results

Temperature dependency

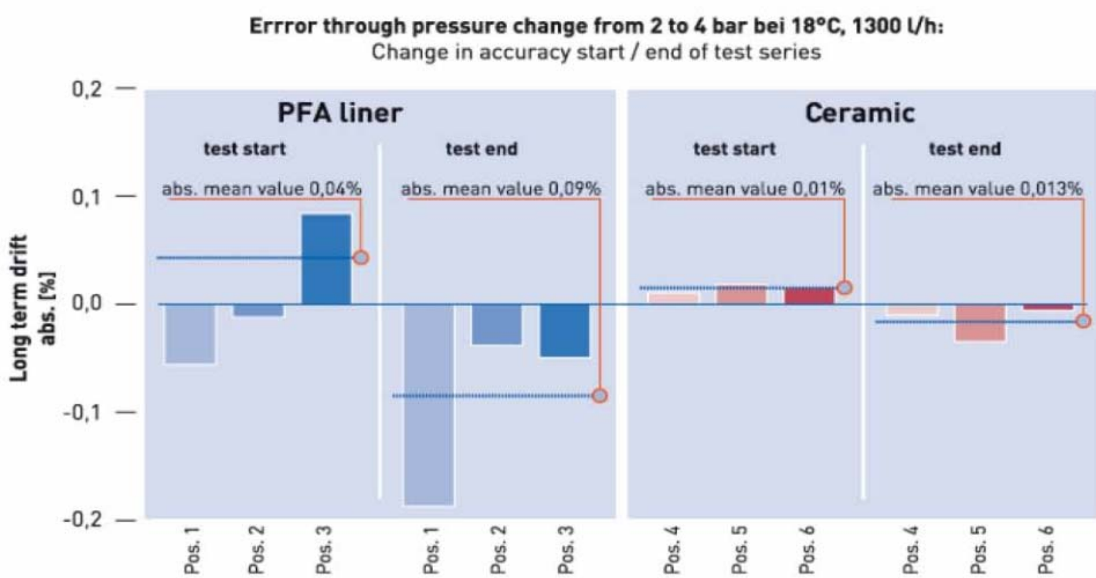
In the following diagrams you can see the effect of filling temperature on the devices.



To prevent negative and positive measurement deviations from canceling each other in a series of measurements, the absolute values of the measurement deviations were used for averaging. If the measurement deviation for the filling mag meter with a PFA-lined measuring tube is 0.20 % in new condition (averaged absolute), by the end of the test it has risen to 0.35%. Interestingly, if the devices show positive and negative deviations in their original condition, they are all in the minus range after the tests. For the ceramic designs, there are only very small differences after the test series. These differences lie in the extent of the uncertainty of the test stand.

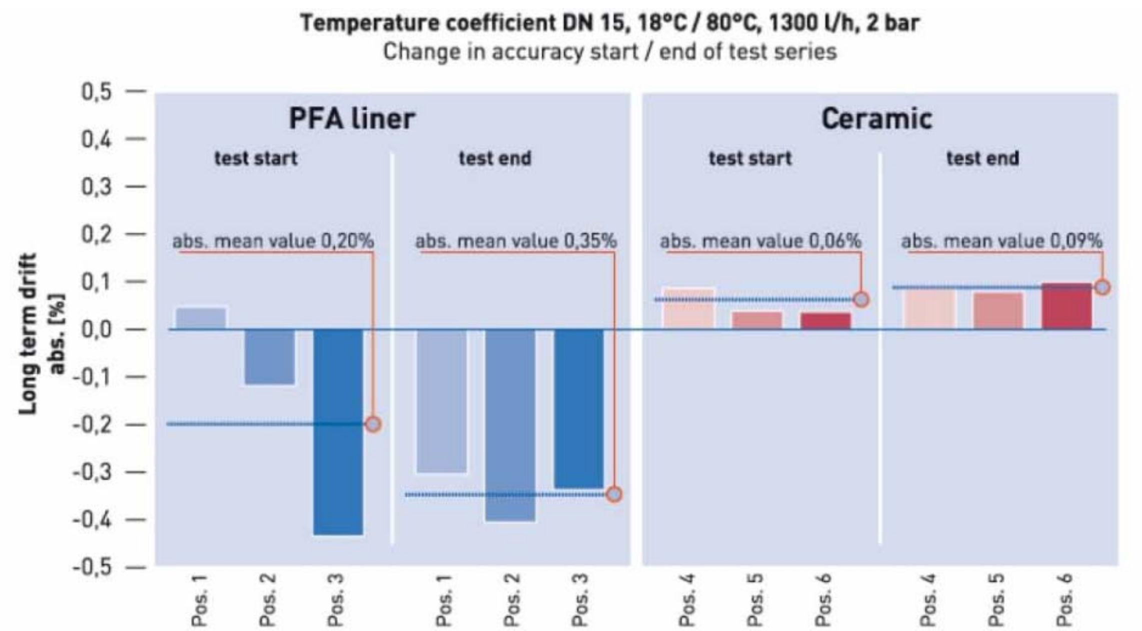
Pressure dependency

No pressure dependency was detected in any of the different device models.



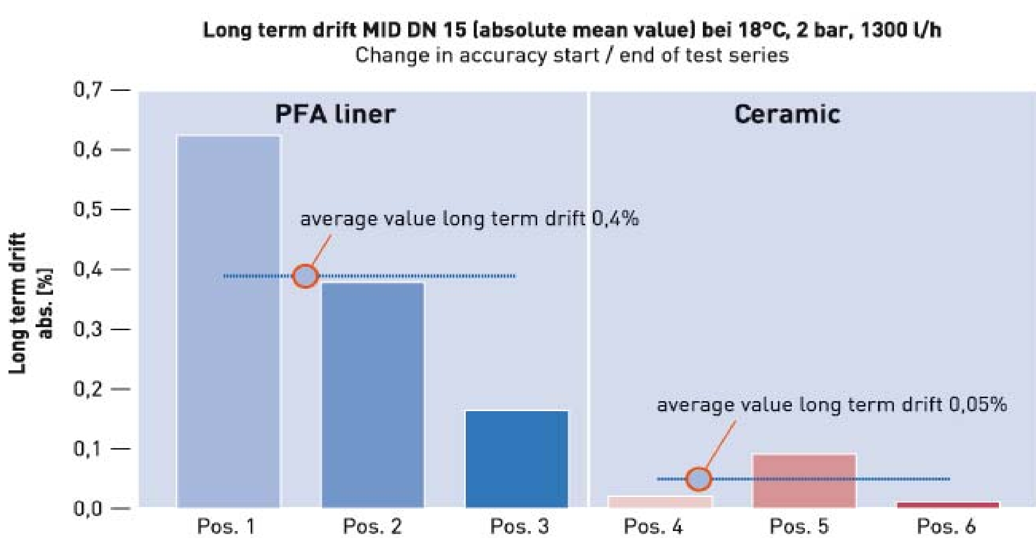
Deviations were negligible in cold water at 18 °C as well as in hot water over 80 °C. The PFA devices at pos. 1 and pos. 3 are somewhat noticeable. They show a changed pressure effect of approx. -0.15% in the test series. This suggests that either the inner diameter or the distance between electrodes has increased slightly during the course of the test due to PFA flowing. The display shows virtually no noticeable dependency on operating pressure when it comes to the Magmeters with ceramic measuring tubes. The change between the beginning and the end of the test is of similar magnitude as the uncertainty of the PTB test station.

At a medium temperature of 80°C, the pressure-dependency of the display is virtually non-existent on the devices with PFA lining. This suggests that the PFA liner is already pressed firmly to the inner wall of the stainless steel pipe at 80°C and 2 bar and that its diameter is no longer increased due to the higher pressure of 4 bar.



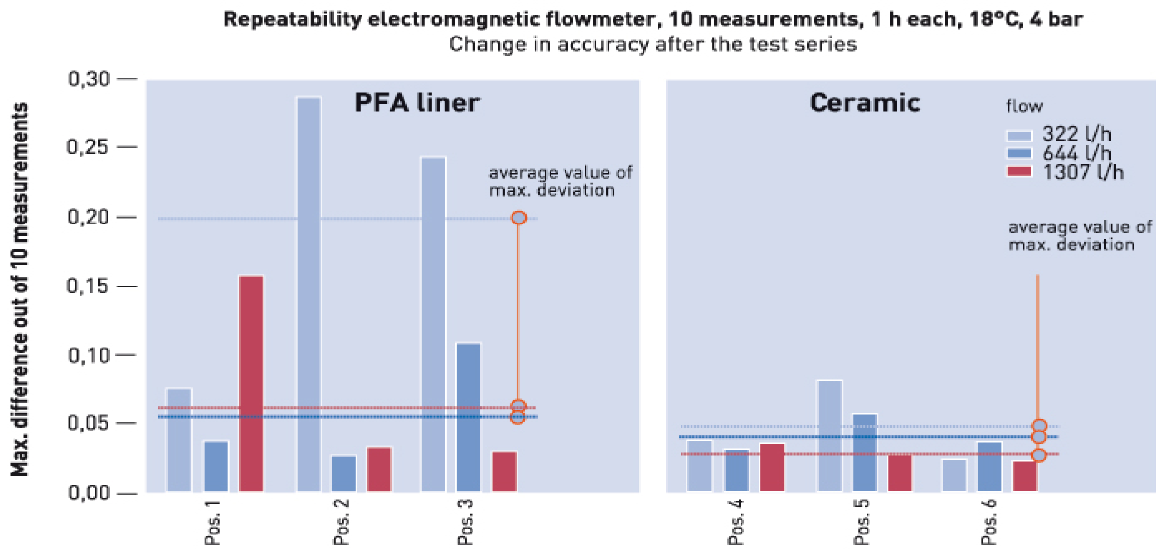
<u>Long-term behavior</u>

The following chart contrasts the measurement stability of the devices under test.



The chart contrasts the measuring accuracy in new condition with the accuracy following the various cleaning cycles for measurements at 18 °C at 72% of the set measurement range. The individual mag meters with plastic liners show changes between 0.16 and 0.63%; this is an average long-term drift of 0.4%. Given that the devices are supposed to have a repeatability of 0.1%, this represents a serious deterioration in measurement stability.
With the ceramic devices, the change was between 0.01 % and 0.09 %. Mathematically this is an average value of 0.05%, where these small values are close to the test station uncertainty.

Repeatability
At the end of the test the repeatability of the flow meters with different flow volumes was tested



once again. Each device under test was compared 10 times at a constant throughput for 1 hour to the PTB's gravimetrically normal measurement system.

The PFA Mag meters show a dependency on the flow volume. At the smallest throughput, two of the three devices exceed the 0.2 % mark; this can impact the repeatability of the filler during gradual filling ("fast-slow filling"). When it comes to "slow filling", in general the bottles ended up being filled at a rate of 450 l/h. The ceramic Mag meters show stable behavior across the various flow volumes.

Summary

In the field of application of filling Mag meters there are two different measuring tube constructions: There is the PFA lined stainless steel measuring tube and the pressure-bearing monolithic ceramic measuring tube.
The testing was done on ½ inch (DN15) nominal size mag meters, used very frequently in filling machines, at the PTB to clarify to what extent these tube constructions differ from one another in quality in terms of long term measurement stability. Since users in the filling machine field expect high availability and long-term stability, it was especially important to test the behavior after a certain period of use and following thermal load due to CIP and SIP cleaning.

Results from PTB testing conclude that when compared to PFA lined mag meters, the filling mag meters with ceramic measuring tubes have the following advantages:
• Ceramic meters have a temperature coefficient three times lower than the change in the flowing media temperature.

• Their long-term stability result is at least 3 times better, on average 8 times better
• Repeatability depending on flow speed of response is 2 to 3 times better
These results make it clear that when it comes to the long-term behavior of filling mag meters, there are qualitative differences between measuring tubes with plastic lining and those with ceramic measuring tubes.

The ceramic measuring tube remains mechanically stable despite the stress of heat and steam of rapid filling process changes and this can be seen in the constantly high repeatability of the MAGMETER, which results in constant filling quality.

While these tests and results deal specifically with filling machine mag meters, the implications may also affect other applications throughout the process industries, especially where accuracy and long term repeatability are key requirements.

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