

A NEW SLIGHTLY BENT SINGLE TUBE CORIOLIS MASS FLOWMETER FOR CORROSIVE FLUIDS

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Commercially available Coriolis mass flowmeters (CMF) show a broad variety of designs, which range from single to dual straight or bent tubes. The new single tube mass flowmeter presented in this paper is slightly bent. The advantage of bent tubes is that thermal stresses are reduced and that the instrument is capable to measure fluids up to 200°C. Furthermore, the slightly bent tube can easily be drained completely. Since the fluid is in contact only with zirconium R60702, mass flow can be determined for a wide variety of corrosive mediums. In particular, zirconium is used for hydro-chloride (HCl) applications, where it does not show corrosion even at high concentrations or at elevated temperatures of HCl.

This paper illustrates the working principle of the new single tube CMF and shows its experimental performance.

Introduction

Coriolis mass flowmeters (CMF) have proven to measure mass flow very accurately to better than 0.10% for water. The high accuracy and rangeability of CMF is one reason for its fast growth and acceptance in industry. The commercially available CMF show a broad variety of designs, such as single tube, dual tubes, bent tubes or straight tubes. Since CMF are available with different tube materials like stainless steel, Hastelloy and titanium, they can be used for all kinds of liquids or gases. However, there are only few designs, which can withstand highly corrosive fluids. Such sensors are made out of tantalum, zirconium or contain lined tubes. On one hand, tantalum shows a very good performance under acidic conditions, on the other hand it has the disadvantage of its high price, which leads to very expensive sensors. Zirconium is much cheaper and has nearly the same corrosive performance for many acidic and alkaline fluids like, hydrochloride acids, acetic acid, hydrogen peroxide, urea and others. The cheaper price of zirconium versus tantalum also allows to develop larger size sensors up to DN50 (2") with reasonable costs for the customer. Therefore, the design of the new CMF is made the way, that all wetted parts consist of zirconium R60702. The new single tube CMF is called Promass H and its design is schematically shown in figure 1.

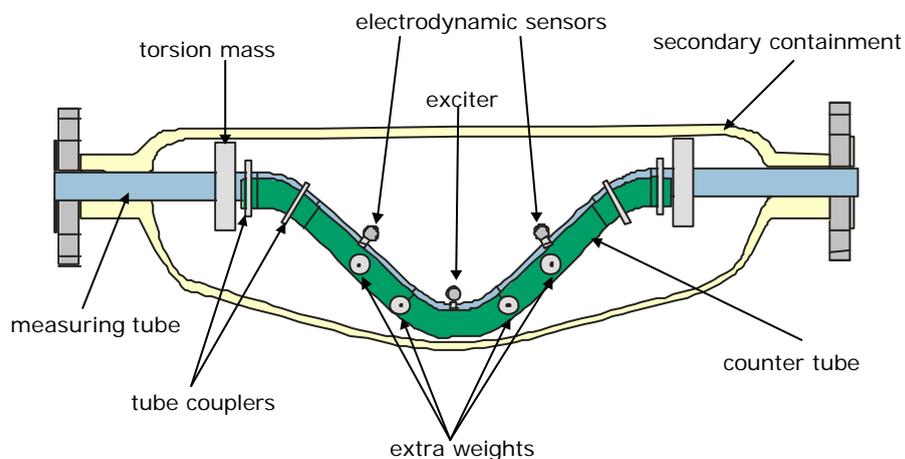


Figure 1 This figure illustrates schematically the design of the new single tube CMF, Promass H.

Working Principle

One of the main challenges for designing a straight or slightly bent single tube CMF is to ensure accurate flow measurements over a wide density range. The new sensor consists of two slightly bent tubes, whereas only the measuring tube is filled with fluid. The working principle of Promass H is explained by using the schematic layout shown in figure 2. Identically to dual tube CMF, the counter tube and the measuring tube are vibrating in counterphase. The two tubes are kept in oscillation at their resonance frequency, which mainly depends on the density of the fluid within the measuring tube. Extra weights are added to the counter tube in a way that the system is in balance with a previously defined reference density; e.g. the density of water at 20°C. Similar to most single tube balancing systems, the sensor is balanced perfectly at the reference density. For an ideally balanced system the force $F_{\text{measuring tube}}$ equals F_{balance} and rotation becomes zero ($M_{\text{torsion}} = 0$). Thus, the energy loss is at a minimum, which leads to an overall good performance and a high immunity against external disturbances. This manifests itself with a high zero point stability. As the density of the fluid differs from the reference density, the system becomes slightly out of balance causing a small rotation ($M_{\text{torsion}} \neq 0$). This weak torsion increases the forces acting at the flanges and, thus, increases the energy loss of the system. In order to maintain the good performance and to keep the sensor independent from any external disturbances over a wide density range, torsion masses are attached to inlet and outlet parts of the measuring tube. With this balancing system, the sensor has a negligible installation sensitivity and is robust against external disturbances and vibrations, and therefore, has a high reproducibility and zero point stability. This new balancing system is called Intrinsic Tube Balance (ITB™). The key to ITB™ is, that through the addition of two torsion masses, it is possible to eliminate selectively that part of forces and moments over a wide density range from 500 to 2000 kg/m³, which are critical to the instrument stability.

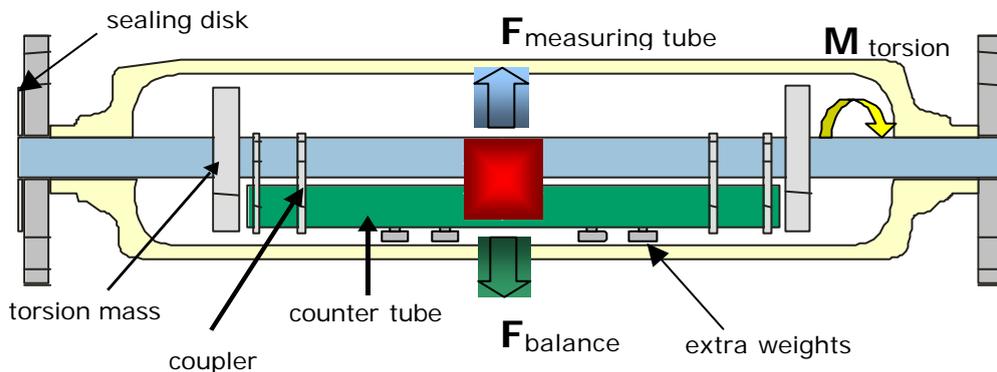


Figure 2 This Figure shows the working principle of the new coriolis mass flowmeter. The sensor consists of two tubes, where only one tube is filled with fluid. Extra weights are attached to the counter tube to balance the system for a predefined reference density (e.g. water at 20°C).

Performance

The new single tube mass flowmeters is tested for many environmental and process influences. The principle qualifications contain the accuracy of the mass flow and density measurements, as well as the influence of fluid density, vibrations, temperature and in-line pressure

Mass flow accuracy and zero point stability

Mass flow accuracy is generally tested through long term qualification runs as shown in figure 3. Figure 3 shows the deviation of the sensor, where 100% corresponds to 1/5 of the maximum specified flow rate for this instrument. Furthermore, figure 3 illustrates clearly the high zero point stability, as well as the excellent accuracy and linearity of the new CMF.

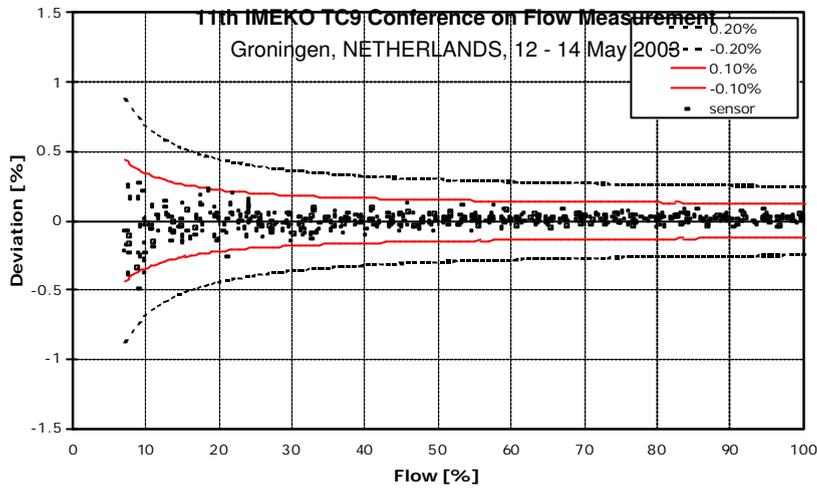


Figure 3 Verification the accuracy of the mass flow measurements for a Promass H DN15. This figure shows the high accuracy and the good linearity and zero point stability of the new CMF.

Density measurement and influence of density on mass flow measurement

It is well known that density is mainly a function of frequency and temperature. Similar to others single tube CMF, the function between density, frequency and temperature becomes complicated. The coefficients to calculate density are determined with different media ranging from 1 kg/m^3 to 1800 kg/m^3 and with water ranging from 10° to 80°C . With this calibration, the new CMF is measuring fluid density to better than 2 kg/m^3 . Knowledge about the density is also important to determine the true mass flow. Similar to Promass I, which is a straight single tube CMF, the accuracy of the mass flow reading is weakly influenced by the density of the fluid. For water the deviation of the mass flow reading is zero. The deviation is increasing the more the density of the fluid differs from that of water. E.g. without this correction, the mass flow determination of a fluid with a density of 900 kg/m^3 would be overestimated by roughly 1%. Since the density is well known this effect can be corrected for to nearly zero.

Influence of temperature on mass flow determination

Changing temperatures of fluid and housing will induce stress and change in elastic properties, which leads to some deviations of mass flow measurements. Since temperatures are well recorded, the mass flow reading of the CMF can directly be corrected for these temperature effects. For slightly bent tubes, the magnitude of this effect is mainly due to the changing modulus of elasticity of the measuring tube.

Furthermore, due to the design of slightly bent tubes, thermal stress can be reduced and fluid temperatures up to 200°C are acceptable.

Influence of in-line pressure on mass flow determination

The in-line pressure is also affecting the mass flow determination of CMF. There is a nearly linear correlation between pressure and deviation of mass flow measurement. For the new CMF, this correlation is about 0.015 % per bar. Unfortunately, the pressure is not recorded by CMF sensors, thus, the new Promass H can not automatically account for this effect. However, since the correction factor is well determined, the massflow reading can be corrected off-line, if process pressures are known.

Influence of external vibrations on mass flow reading

Within most applications, CMF are exposed to some external vibrations. Such vibrations range typically from 50 to 180 Hz and can occur due to the pumping system, neighboring vibrating devices, or may be flow induced as observed in pipeline systems. The new CMF is designed in a way, that the effect of external influences is minimized. The test shown in figure 4 is performed with an empty measuring tube, where the unbalance of the system is largest. The good immunity of the new CMF against external vibrations even in unbalance is shown for a Promass H DN8 in

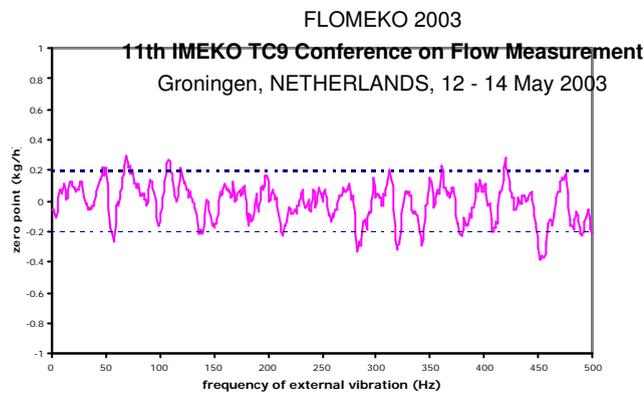


Figure 4 This Figure illustrates the sensitivity of the Promass H DN8 zirconium against external vibrations.

figure 4. For most external vibration frequencies, the deviation of the mass flow reading is within the specified zero point stability of ± 0.2 kg/h, which is 0.01% of the maximum flow rate.

Applications

Promass H with a zirconium measuring tube is ideal for a number of applications which require a highly corrosion resistant material. Among the many different corrosive fluids, Hydrochloric acid (HCL) is the most common and it is one of the most used active ingredient in various chemical processes. Therefore, Hydrochloric acid is a heavily produced chemicals all over the world. Typical application using HCL are manufacture of dyes, phenols and plastics, pickling and metal cleaning, industrial acidizing and resin regeneration and demineralizers. A typical application for HCL is shown in figure 5 using a Promass H DN25 (1"), which is located at one of the world largest companies.

However, the Promass H is not limited to HCL application, only. Various other applications that require the CMF to have a chemical resistant material like zirconium are also within the application range of the Promass H.



Figure 5 Promass H 25mm (1") installed in a HCL application

Conclusion

The qualifications of Promass H illustrate the good performance of the new single tube CMF. All wetted parts of this CMF are made out of zirconium R60702 and can therefore be used for highly corrosive fluids. Since it is a single tube instrument and since it does not need any flow splitters, the overall costs of the instrument can be kept low for the customers.