

Coriolis-Massflowmeters:

State of the Art Review and Innovations

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1 INTRODUCTION

In the recent decades there has been a great deal of interest for Coriolis mass flowmeters (CMF). The market for CMF has grown dramatically in the late 80's and the 90's. Nowadays, CMF are widely accepted in many industrial fields and the performance of CMF has been improved steadily. One of the advantages of CMF is, that they are measuring directly the true mass flow. The high accuracy and rangeability of CMF is a further 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, titanium, zirconium or tantalum, they can be used for all kinds of liquids or gases.

The paper gives a state of the art review of CMF and focusses on recent innovations.

2 STATE OF THE ART REVIEW

Measuring variables. Coriolis mass flowmeters offer the best accuracy in flow measurement, which is $\pm 0,1$ % of rate for direct mass flow measurement. The zeropoint of the instruments is very stable, with an uncertainty of only 0,005 % of FS. The tubes are oscillated in resonance. The resonance frequency gives information about density as an additional measuring variable. Coriolis mass flowmeters are among the most accurate density meters ($\pm 0,0005$ kg/m³). Hence, together with the fluid temperature

three measuring variables are available from one measuring point.

Gas measurement. As with gases mass flowrates are smaller than typical liquid flowrates, gas flow measurements require extremely good zero point stability of the meter and sophisticated signal processing. Recent instruments meet these requirements and have proven in the field to offer excellent measuring solutions also for gas applications.

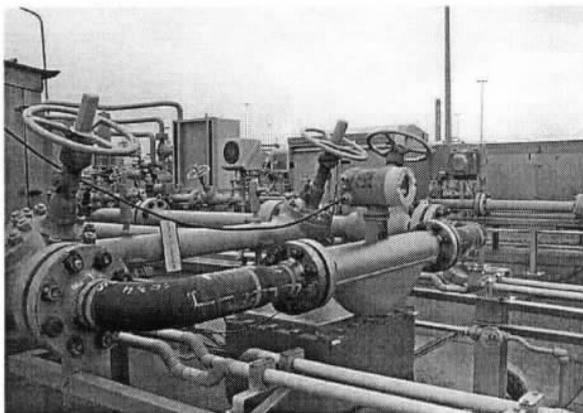


Fig 1: Endress+Hauser Promass F DN 80; The meter is compact, so it was easily installed without need for additional pipeline support

As an example, ethylene is very common in the process industry, and it is used under very widely differing process conditions. Figure 1 shows the metering of ethylene gas at pressures from 75 to 95 bar and a medium temperature of 10°C. Gas flow has to be metered in the range from 10 to 40 metric tons per hour. Originally turbine meters were used to measure volume flow, so density also had to be

measured before mass flow could be calculated. Turbine meters, moreover, are subject to strict limitations in terms of turndown. These were the reasons why this operator decided to test a Coriolis sensor specifically for this application.

The application was an ideal opportunity to display all the strengths of this Coriolis meter: its characteristics are high measuring accuracy and reproducibility. The sensor has a high oscillation frequency (600-800 Hz) and is inherently immune to pipeline vibrations, which are generally down in the 50-200 Hz range. Consequently, vibrations in the piping system have no effect whatsoever on the results obtained by the meter. The design is robust with a standard secondary containment, so the device is also immune to external influences such as shock loading and stresses and strains in the pipeline.

Today, Coriolis meters are working in innumerable gas applications, and have returned excellent results in tests by renowned calibration institutes such as PIGSAR and SWRI. Extensive testing by customers on their own calibration systems reconfirmed the outstanding performance of Coriolis meters. As well as attesting the high measuring accuracy of these devices, customers were also very impressed by their long-term stability and the significantly better turndown they show in comparison to turbine meters.

Coriolis meters have demonstrated that they are eminently suitable for use in gas metering. The reasons are many and varied: fast response times and superb accuracy despite changes in pressure are definitive arguments in favor of Promass in carbon-dioxide applications in breweries and the plants that produce soft drinks. The pressure range for air metering extends from 3 bar (beverages batching and filling) to 300 bar (compressors for airbag gas generators). Typical applications include compressed natural gas and low pressure gas - both CNG and LPG are used as fuels for passenger cars and busses. Applications in the low-pressure sector range from oxygen through cyanogen chloride gas to hydrogen metering in the manufacture of semiconductors, and in the hydrogenation of fat, for example.

Hygienic design. The physical principle of operation of Coriolis meters is very elegant, because there are no moving parts in the measuring tube. Straight tubes or slightly curved tubes offer a very good cleanability and versions with 3A authorization. With straight tube meters with completely welded process connections, even pigable versions are available. Single tube meters are certified according to EHEDG.

Installation requirements. In the early years instruments have not been as stable as they are now. Early instruments had no balanced system, resulting in an inadequate immunity against pipeline vibrations.

With double tube meters vibration immunity results from the counterphase motion of the two symmetric tubes. With single straight tube meters vibration immunity over a wide density range was first obtained for the first with the introduction of the so called TMB™ system by Endress+Hauser in 1997. With TMB™ installation and performance of a single straight tube meter became similar to double tube meters, requiring no special support of the meter.

3 INNOVATIONS

Additional Viscosity measurement: Four process variables from one meter

Viscosity is a crucial process variable indicating important fluid properties like concentration, consistency etc. which defines the quality of a product.

Now the single straight tube mass flowmeter Promass I measures viscosity besides flow, density and temperature. The balancing mechanism of this meter uses torsional oscillation (TMB™ –system: a pendulum is attached to the middle of the oscillating measuring tube, inducing torsional oscillations into the measuring tube; see Figure 3).

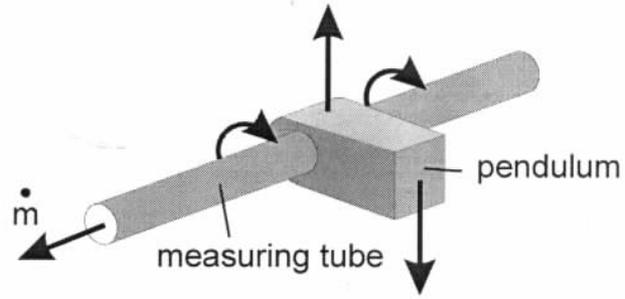


Fig. 3 Introducing torsional vibration to balance the measuring tube (TMB™)

Figure 4 is a cross sectional view of the measuring tube. Due to the additional rotational motion v_θ of the tube, the fluid is forced to a rotational motion. Depending on the viscosity, there are different velocity profiles $v_\theta(r)$ of the fluid, thus introducing shear forces. These shear forces can be measured via excitation current, which is necessary to maintain the tube oscillation.

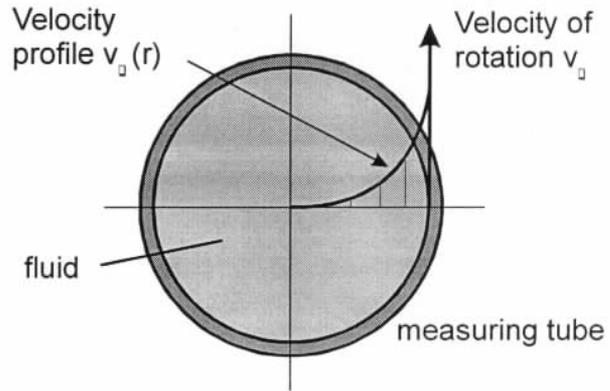


Fig. 4: cross sectional view of the measuring tube and velocity profile of the fluid

Figure 5 shows the results for the viscosity measurement. Several different fluids with different viscosities and also different densities were tested against a laboratory viscosimeter. An accuracy of $\pm 5\%$ was obtained with newtonian fluids.

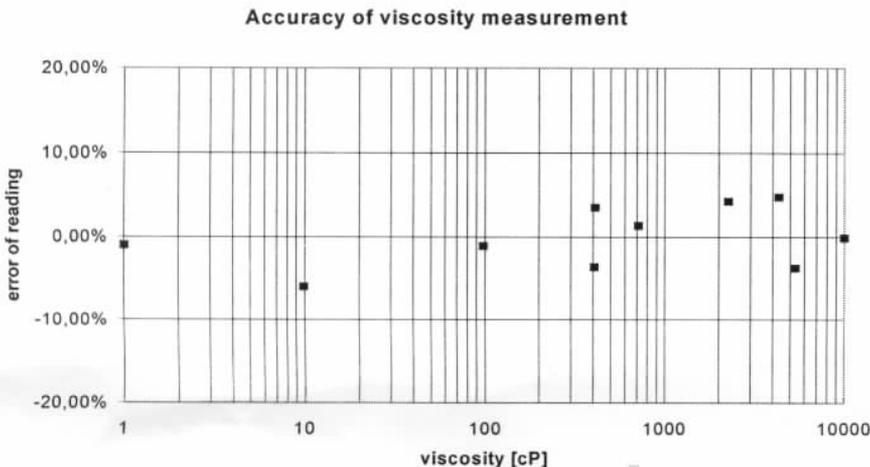


Fig. 5 Accuracy of the viscosity measurement for different fluids

Advanced Diagnostics: more information from the process

Advanced Diagnostics offers a new concept to evaluate the data provided by the sensor. The basic idea is to recognize changes in the measuring system early on by a trend analysis of process and sensor data. Such changes can be caused by e.g. build-up in the measuring pipe or by the mechanical influence of aggressive media such as abrasion or corrosion.

The data available for trend analysis comprise e.g. mass flow, density, pipe damping, and sensor symmetry. The basis of the trend analysis is the registration of reference data under reproducible conditions. For this purpose, it is possible to record a "finger-print" of the device.

The deviation between reference and comparison signal can continually be recorded e.g. as a current output. Deviations above a certain level can be displayed as a warning over the relay output.

A history of 10 variables is stored in the device to allow a trend evaluation.

High temperature applications

measure mass flow at temperatures up to 350°C. This sensor operates within the same error limits which are known from the standard sensor line.

This sensor provides a solution for oil and hydrocarbon processing industries, for chemical and oleochemical industries, where crude and lube oils are refined. Another important applications is asphalt production.

Big diameters

In petrochemical industry very big instruments to measure mass flow are needed. Loading and unloading of ships are applications for very big units. For these applications a new instrument was designed, which covers a measuring range up to 2200 t/h.

Of course these instruments, can also easily be installed without special installation requirements.

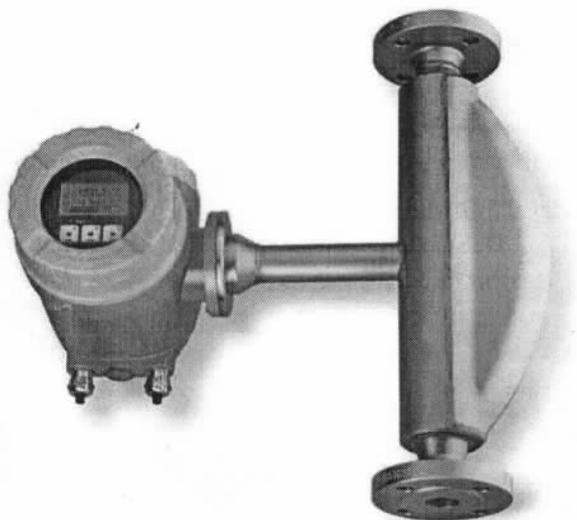


Fig. 6 Promass F for operation up to 350°C

For the measurement of massflow of liquids and gases a special sensor was introduced. This meter can

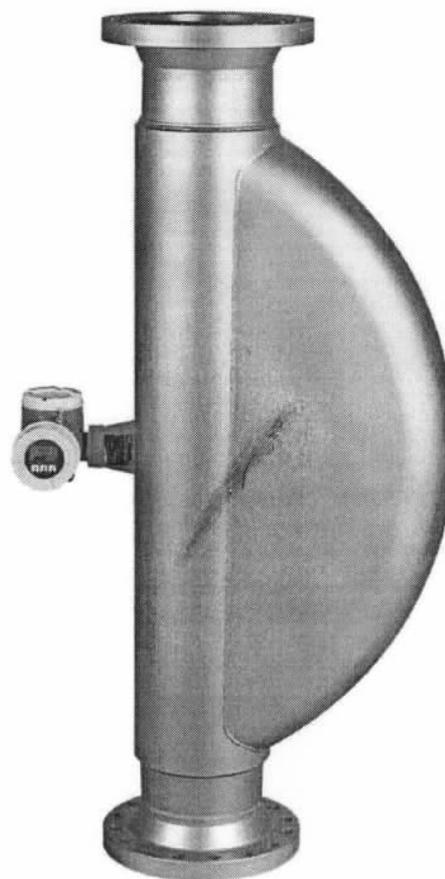


Fig. 7 mass flow measurement for very high flows; this instrument measures up to 2200 t/h with an accuracy of 0,1 %

New single tube sensor

For applications with high corrosive fluids a new single tube sensor was introduced, see Fig. 7.

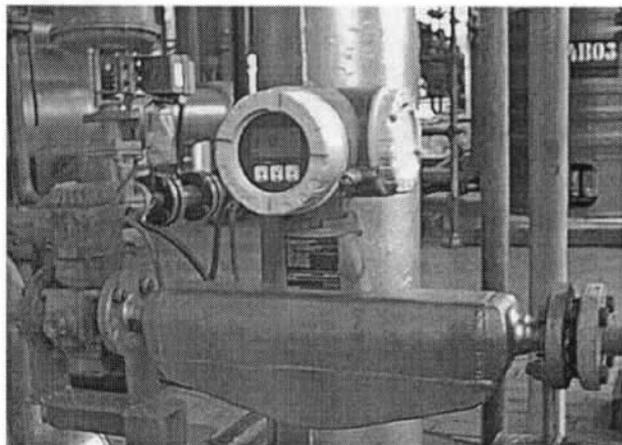


Fig. 7 Promass H for corrosive fluids; all wetted are made of zirkonium;

This is a single tube meter using a new balancing principle, the so called ITB™ (Intrinsic Torsion Balance). The slightly curved tube operates up to 200°C, which would not be possible with a straight tube due to the axial stress caused by thermal expansion of the measuring tube.