Enhancing the Speed and Accuracy of Coriolis Flow Measurements

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This article describes a number of new developments in Coriolis flowmeters, including high-speed signal processing for faster and more accurate measurements, robustness achieved through the use of an anti-vibration mechanism, and high accuracy density measurement.

A Coriolis flowmeter directly measures mass flow rate, density, and temperature at the same time. Moreover, based on these directly measured three variables, the volume flow rate and concentration of mixture can be calculated.

The mass flow rate is measured by a Coriolis meter based on the interaction of Coriolis forces generated between the flowing fluid and vibrating measurement tube. The principle is outlined in Fig.1. The U-shaped tube is repeatedly swung around the fixed end as a pivot like a cantilever. When fluid flows in this tube, Coriolis forces are generated at both the inlet and outlet sides of the tube according to the ascent and descent of the tube. Since the directions of the forces generated at inlet and outlet sides are opposite, torque is created, generating a torsion angle in the tube. Because the Coriolis force is proportional to the mass flow of the fluid, the mass flow can be measured by detecting the torsion angle.

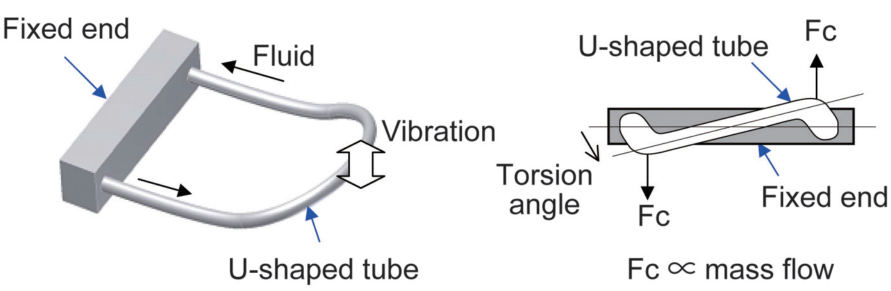

Fig.1: Measurement principle of the Coriolis flowmeter

Fig.2 shows the flowmeter with the major elements necessary for measurements and signals. A pair of a magnet and driver coil is mounted at the apex of the U-shaped tube, and two pairs of a magnet and sensor coil are arranged at the upstream and downstream sides, respectively. The positive feedback of electromagnetically induced output of the sensor coil to the driver coil leads to self-oscillation of the measurement tube at its resonant frequency. The torsion angle of the tube can be calculated based on the phase shift between the output signals of the two sensor coils. Hence the mass flow rate can be derived from the phase shift of the two signals. It is also possible to measure the density of liquids based on the signal frequency.

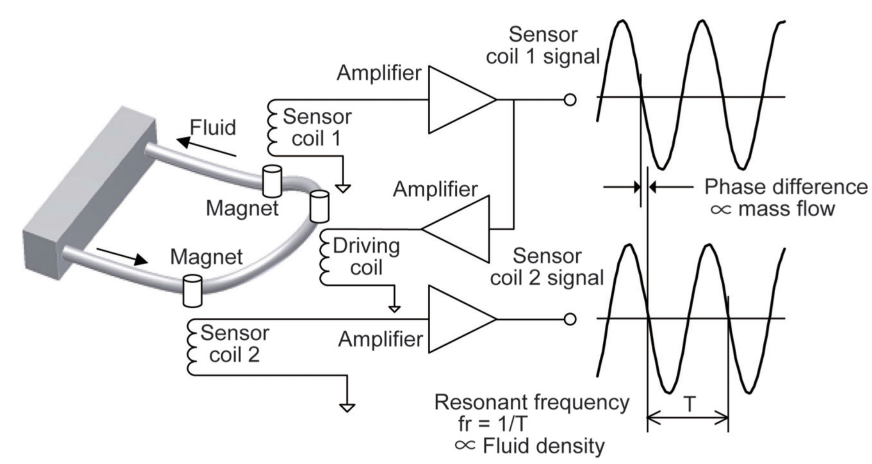

Fig.2: Elements of the measurement process in the Coriolis flowmeter

A Coriolis mass flowmeter can not only directly measure the mass flow rate based on the measurement outlined above, but can also measure the density of fluid based on the oscillating frequency. Moreover, it carries out the measurement of mass flow rate with a high accuracy of ±0.1%, and has a wide measurement flow rate range. It is not affected by the viscosity or density of the fluid; it does not require straight pipe sections upstream or downstream of the flowmeter; and it can measure non-conductive fluids.

The ability to measure the mass flow rate directly is very useful in chemical and pharmaceutical industry applications, where chemical reactions are generally described in terms of moles or masses of substances. Other types of flowmeter such as differential pressure, electromagnetic, and vortex have to convert volume flow rate to mass flow rate while compensating for temperature and pressure. And, while magnetic flowmeters can only measure electro-conductive fluids due to the principle of measurement, Coriolis mass flowmeters can measure non-conductive fluids. As a result, they are more widely used than other types in the chemical and pharmaceutical industries.

New developments

The development of the Coriolis flowmeter has been a process of continuing evolution coupled with new technological innovations in both detectors and converters. In the latest generation of instruments, new developments include digital signal processing, improved vibration resistance and extended measurement ranges (Fig.3 and Table 1). Based on a U-shaped measurement tube, these devices have a flow-rate range from less than 0.1 t/h to 500 t/h at the nominal flow rate and with a pressure drop of 0.1 MPa.

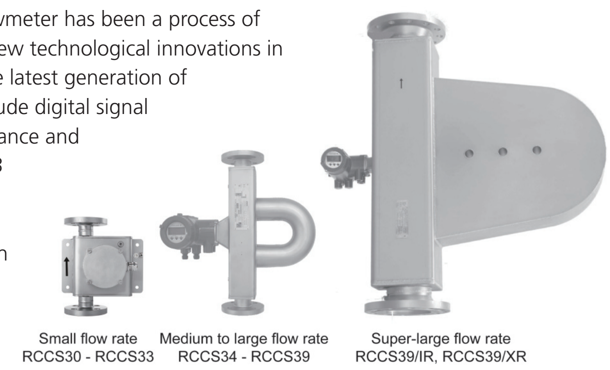

Fig.3: The Yokogawa ROTAMASS 3 Series of Coriolis flowmeters

	Model	Nominal flow rate Qnom [t/h]	Maximum flow rate Qmax [t/h]	Accuracy of mass flow rate measurement [% of flow rate]	zero stability [kg/h]	Accuracy of density measurement [g/cm³]	
						Standard	Option /K6
Small flow rate	RCCS30	0.045	0.1	± 0.1 ± Zero stability/ flow rate * 100	0.05	0.008	-
	RCCS31	0.17	0.3		0.0085	0.004	-
	RCCS32	0.37	0.6		0.019	0.004	0.0005
	RCCS33	0.9	1.5		0.045	0.004	0.0005
Medium to large flow rate	RCCS34	2.7	5		0.135	0.003	0.0005
	RCCS36	10	17		0.5	0.0022	0.0005
	RCCS38	32	50		1.6	0.0015	0.0005
	RCCS39	100	170		5	0.0015	0.0005
Super-large flow rate	RCCS39/IR	250	300		13	0.0015	-
	RCCS39/XR	500	600		25	0.0015	-

Table 1

High-speed signal processing

As indicated above, the mass flow can be calculated based on the phase shift of two sensor coil signals. In earlier models, the mass flow was calculated based on the time difference of the zero crossing point of the sensor coil signals. This method, however, was susceptible to noise superimposed on the signals. Now, with today's advanced technologies for analogue/digital conversion and digital signal processors advance, it becomes possible to digitise all the signals and then use a digital Fourier transform to calculate the phase shift. However, there are limitations to this technique because the wavelength interval of the tube vibration must be equally divided and sampling at those points is required – something that requires a complex sampling timing generation circuit.

This method also has the disadvantage that the output cannot follow the fluctuation of the density and temperature of the fluid to be measured, because the vibration frequency of the tube fluctuates depending on the density and temperature.

To solve these problems, a new signal processing method has been developed in which the phase angle is calculated using a Hilbert transform (Fig.4). In Fig.4, the signals from sensor coils 1 and 2 are assumed to be sin θ and sin (θ + Dφ), respectively. The Hilbert converter is a digital filter which shifts the phase of the input signal by 90° and outputs it. When the input signal is sin θ, the output signal of the Hilbert converter is cos θ. By using the outputs of each digital filter, the phase difference can then be calculated.

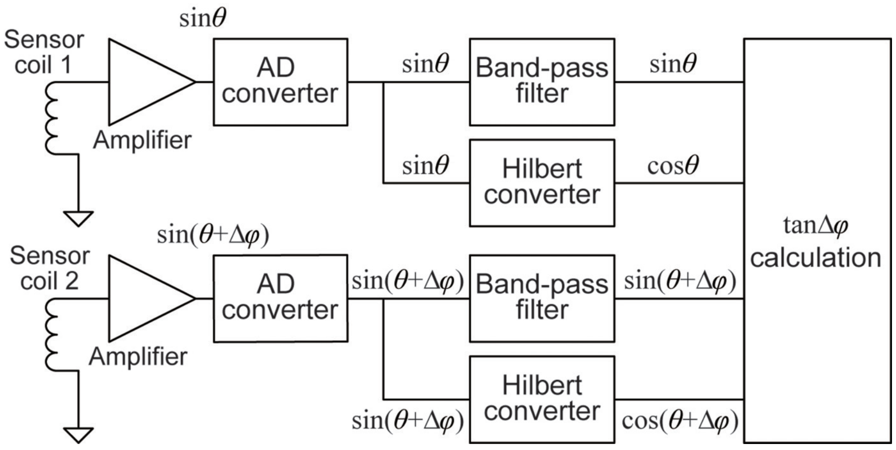

Fig.4: Signal processing in the ROTAMASS Coriolis flowmeter

This signal processing method has the following features:

1.Signals can be sampled at a fixed sampling frequency independent of the vibration frequency. Therefore, no complex timing generation circuit is required to follow the vibration frequency, which fluctuates depending on the density and temperature of the target fluid. In addition, accurate outputs can be obtained with a simple configuration using the inexpensive but accurate A/D converter.

2.Phase shift signals can be obtained at every sampling point, achieving high-speed mass flow rate outputs.

3.The amount of calculation required in the digital signal processor is about one-quarter that of the conventional FFT calculation method; the load for the calculation is light.

Vibration resistance

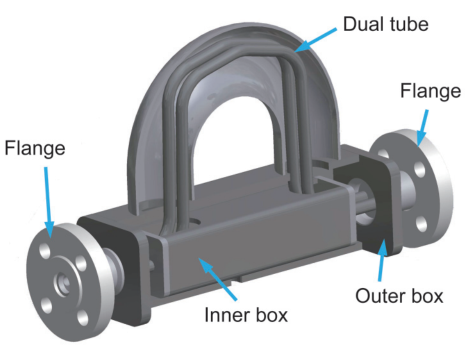

Fig.5: Structure of the ROTAMASS detector illustrating the "box in box" principle

Coriolis flowmeters measure flow rates by vibrating the measurement tubes like a tuning fork. Therefore, the measurements may be affected by external forces or vibrations transmitted through pipes. However, these problems can be overcome by using a structure called "box in box" which effectively eliminates the effects of external forces and vibrations.

Fig.5 shows the detector structure of the flowmeter. The inner box is mounted in the outer box, which is connected to the flanges. Both ends of the tubes are fixed to the inner box. This double structure enables external forces and vibrations applied through the flanges to be absorbed by the strong outer box, minimising the interference of the measuring tubes fixed to the inner box.

In addition, a two-tube structure is employed, with the two tubes vibrated in opposite directions. The sensor coils for measuring the vibration are mounted on one tube, while the magnet is attached to the other tube. Using this structure means that the tubes are not easily affected by external vibration. Moreover, tuning the resonant frequency of the tubes considerably higher than the expected vibration frequency of disturbances in the field minimises the impact of the external vibration.

Another very beneficial feature is the angle presented at the linear part of the U-shaped tubes. This enables the fluid in the tubes to drain by itself.

High rangeability

Generally, compared with other types of flowmeter, Coriolis flowmeters have wider "rangeability", which is defined as the measurable flow range: i.e. the ratio of the measurable maximum flow rate to the minimum flow rate. The practical rangeability of Coriolis flowmeters depends on the error of the zero stability which represents fluctuation at the zero point. The error of zero stability of the new generation of flowmeters is small, and so it maintains excellent measurement accuracy even at low flow rates. Fig.6 shows a diagram of the flow rate and the mass flow measurement accuracy. A rangeability of 20 is assured - assuming that the measurable maximum flow rate is the nominal flow rate and the necessary accuracy is 0.2%.

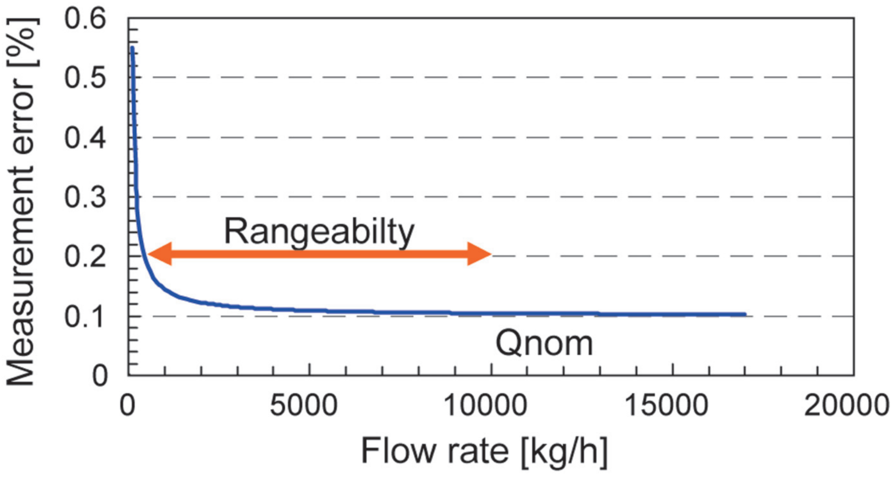

Fig.6: Accuracy of mass flow rate

Highly accurate density measurement

Improving the density measurement accuracy also enhances the accuracy of volume flow rate and concentration measurements because they are obtained as a function of density. It is now possible to achieve a density measurement accuracy of 0.008-0.0015 g/cm³ as standard, or an even more accurate measurement figure of 0.0005 g/cm³ with a special measurement option. To achieve this accuracy, Yokogawa has invested a lot in building expertise in density calibration with several different types of liquid. The flowmeter guarantees the accuracy of a wide range of 0.3-2.0 g/cm³ by calculating the correction factor based on the fluid of the temperature being controlled. Fig.7 shows the accuracy of volume flow rate measurement with the high-accuracy density measurement option of 0.0005 g/cm³.

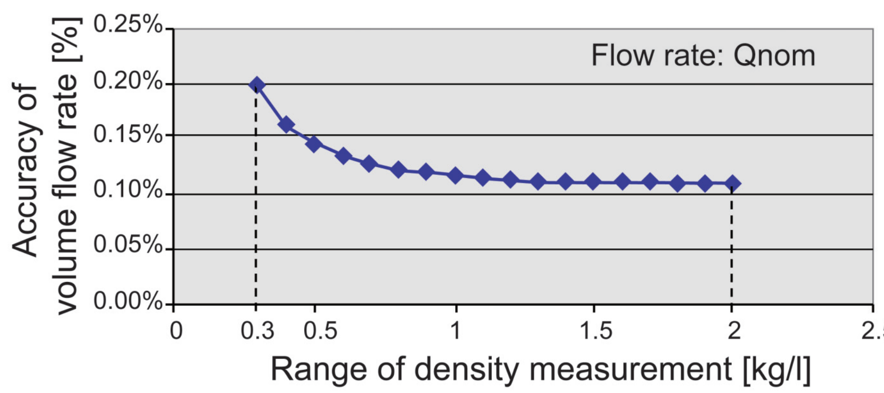

Fig.7: Volume flow rate measurement accuracy with high-accuracy density measurement

Applications

These new developments in Coriolis flowmeters open the door to a wider range of applications in different industries.

For example, Fig.8 shows an example of an installation in a road tanker for liquefied gas which utilises the high resistance to vibration of the "box in box" configuration. This flowmeter has proved itself over a substantial period by performing stable measurements in an environment with severe vibration.

Fig.8: Application example of a Coriolis flowmeter in a road fuel tanker vehicle

High rangeability and high-precision measurement at low flow rate are extremely effective features in the chemical and pharmaceutical industries. In the example shown in Fig.9, some solvents are supplied to multiple reactors, and it is crucial to measure the flow rate accurately. In this case, Coriolis flowmeters with high-precision measurements were adopted.

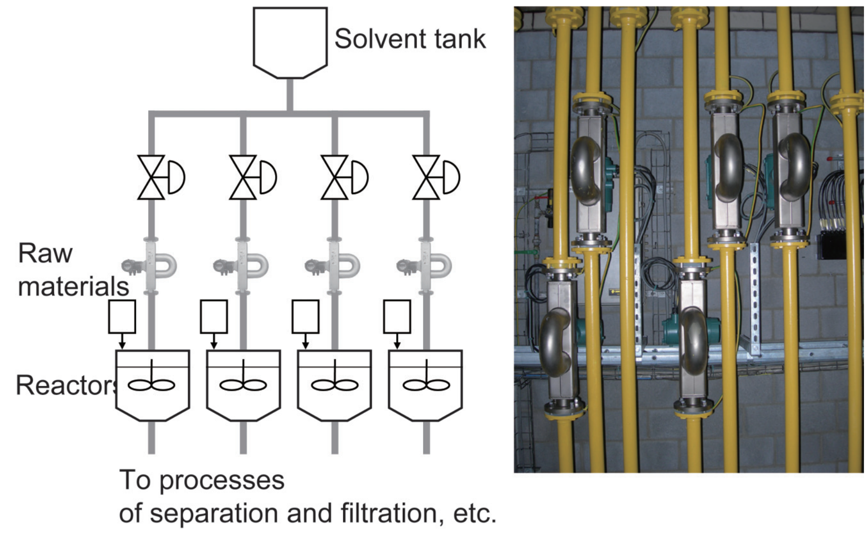

Fig.9: Application of a Coriolis flowmeter in a pharmaceutical process