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Vortex Meter and Coriolis Mass Flow Meter

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Vortex meter

The vortex meter represents one of the most promising developments in flow metering over the last ten years.

It is a very robust meter and for smaller dimension also among the cheapest. Possibly the greatest advantages is the linear digital output and the possibility to calibrate the meter accurately under other than normal operating conditions.

Fig. 1 shows a typical vortex meter. It consists of a straight pipe with a bluff body obstructing the flow. The bluff body causes vortices to be shed alternately on each side as shown in fig. 2. This is the same effect as is seen by a flag waving in the wind. The flag pole is producing vortices in the flowing air and the flag is thrown alternately to each side. The frequency is proportional to the wind velocity.

Any obstruction in a pipe will cause vortices to be produced. The frequency and the minimum and maximum flow rate for stable vortex generation is given by the shape of the bluff body. A few different designs is shown in fig. 3.

For a particular design the calibration factor is given by the ratio of the width of the bluff body to the length of it. This is a rather teoretical approach since the bluff body is installed in a circular pipe and it is therefore difficult to determine the correct length to be used in the calculation.

On the other hand, when one vortex meter is calibrated the resulting calibration factor can be applied to other equal meters. Since the mechanical construction is very simple, it is not difficult to maintain the same dimensions within the appropriate tolerances.

When the mechanical dimensions are given the calibration factor is only depending on the Reynolds number. For most designs the calibration is linear within 1 or 2 percent for Reynolds number larger than 30 000 up to a limit given by the onset of cavitation. Its this property that is used when calibrating under conditions very different from normal operating conditions Once the calibration curve is determined versus Reynolds number for example under water calibration, the meter can be used for any gas or liquid as long as the Reynolds number is known.

In the early days of vortex meter it was often claimed that the calibration was very little dependent on the flow profile,and straight upstream lengths of as little as three pipe diameters were recommended by some manufacturers. Over the years the requirements have steadily increased and today most manufacturers specify 20 diameters upstream straight length.

In a general description it is difficult to give accuracy figures, but under the conditions outlined above the accuracy should be in the region of ± 1%. For more accurate results calibration of each individual meter under normal operation conditions is necessary.

Calibration of a vortex meter is complicated by the fact that the vortex generation is not regular. This means that a large number of pulses have to be counted to get the correct average. Also it makes the use of pulse splitting techniques very difficult.

It is very difficult to get manufacturers comments on installation effects. Only one is known to give details of calibration shift caused by the installation of meters in pipes with internal diameter that is not exactly equal to the meter internal diameter. In practise this is an almost unavoidable problem since the inner diameter of pipes with norminally the same diameter is depending on pressure rating.

At the calibration laboratory at Norsk Hydro, Porsgrunn, three different meters have been tested on installation effects. Since the time schedule did not permit the results to be discussed with the meter manufacturers, the results will not be reported in writing at this stage.

The results will be given in the lecture without refering to the manufacturers names.

Coriolis mass flow meter

As we have seen earlierin this seminar, we are normally interested in the mass rather than in volume and density. For a long time different methods of direct mass determination have been tried, with more or less sucess.

An instrument working by a completely new principle has now been on the market for 4 or 5 years. In basic principle it only measures massflow independent of how this mass is composed. Of course there are practical limits to this statment, but it is felt important to stress that the principle is a real mass flow measerment.

The instrument is shown in fig. 4. The only wetted part is a U-tube vibrating at its resonant frequency excited by a magnetic coil. If there is no flow through the tube the two legs of the U-tube will have parallell oscillatiens, but as soon as there is flow the two legs will twist relative to each other. This twist angel is proportional to mass flow rate.

To explain the mechanics behind the meter, lets first consider the coriolis force generally. This is the force caused by earth rotation that determine the wind directions around high and low pressure areas on the wether map. For the same reason a train on the northern hemisphere will always lean against the right rail on a straight track.

If we look at the boy on the turntable in fig. 4 we see that he will be leaning to the left if he is going to walk along a straight line painted on the turntable. This is because his velocity in the direction perpendicular to the direction he is walking is increasing proportionally to the distance from the center of the turntable. This velocity increase requires an aceleration force(coriolis force) and to take up this force the boy have to lean.

Exactly the same would happen if we mounted a straight pipe on the turntable. Any volume of mass that was passing through this pipe would be accelerated perpendicular to the pipe axis. The acceleration force would have to be taken from the pipe, and if the pipe was fixed at only one end it would therefore bend. If we change the flow direction the bending direction will also change.

Each leg of the U-tube is fixed at only one end and since the flow direction is opposite in the two legs the whole U-tube will twist. Because the U-tube itself is rotating in alternating directions (oscillating), the twist angle is oscillating at the same frequency. The angle itself can be detected as a phase difference between the two "corners" of the U-tube.

Basically the only factor influencing the tube twisting is the mass flow, indepent of density, viscosity, temperature and so on.

However since the U-tube is not rotating at a constant angular velocity, but oscillating, the meter is density dependent. This is because with changing density the oscillation frequency will change.

The vibration amplitude is determined by the magnetic force and the elasticity of the U-tube. The elasticity is temperature dependent causing the meter itself to be temperatur dependent.

Both density - and temperature effects are predictable and can therefore be compensated.

The meter is virtually independent of viscosity, the limiting factor being the pressure loss through the U-tube.

Its also independent of deposits on the tube wall if the density of the deposit is the same as the fluid density.

Corrosion or erosion may cause the elasticity of the U-tube to change, thereby changing the calibration.

The most important limitation on the use of the meter is the maximum tube diameter of 50 mm (at least at present time), and the requirement of a minimum mass flow rate compared to the U-tube mass, making the meter unsuitable for low pressure gas.

The original idea behind this lecture was to present results from a test of one of these meters. The reason this cannot be done is that the U-tube broke after four days operation in the flow laboratory.

Based on technical discussions with the inventor, visit at a user and theoretical study of the meter, I still regard it to be a break-through in direct mass measurement.

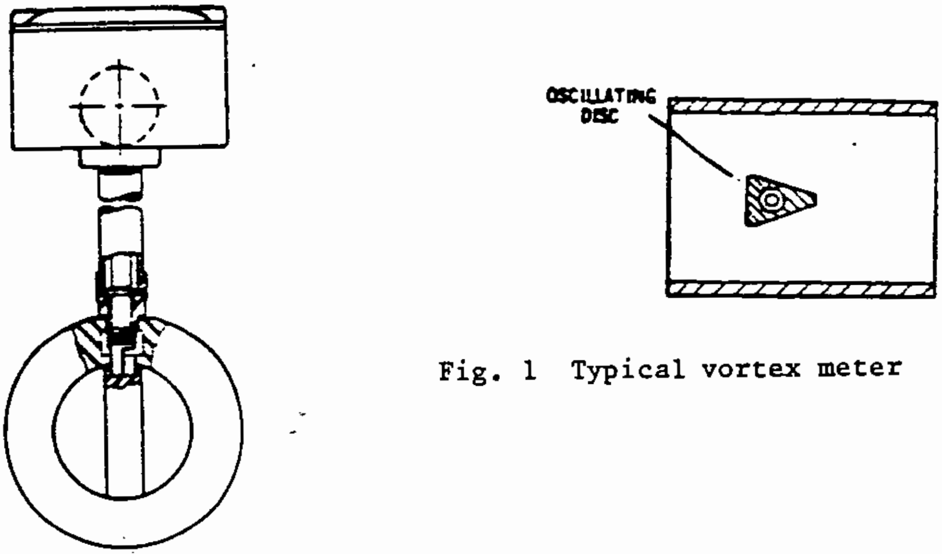


Fig. 1 Typical vortex meter

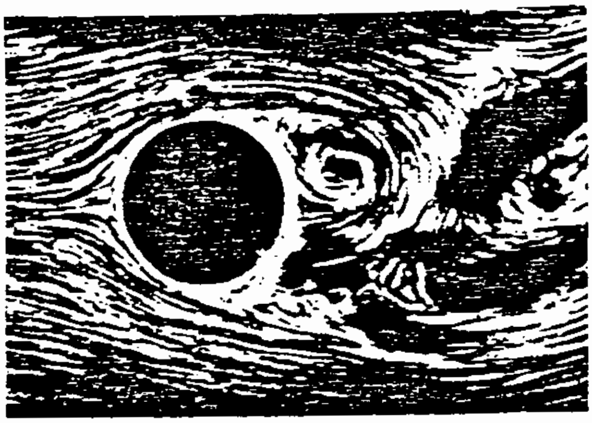


Fig. 2 Vortices behind a circular body

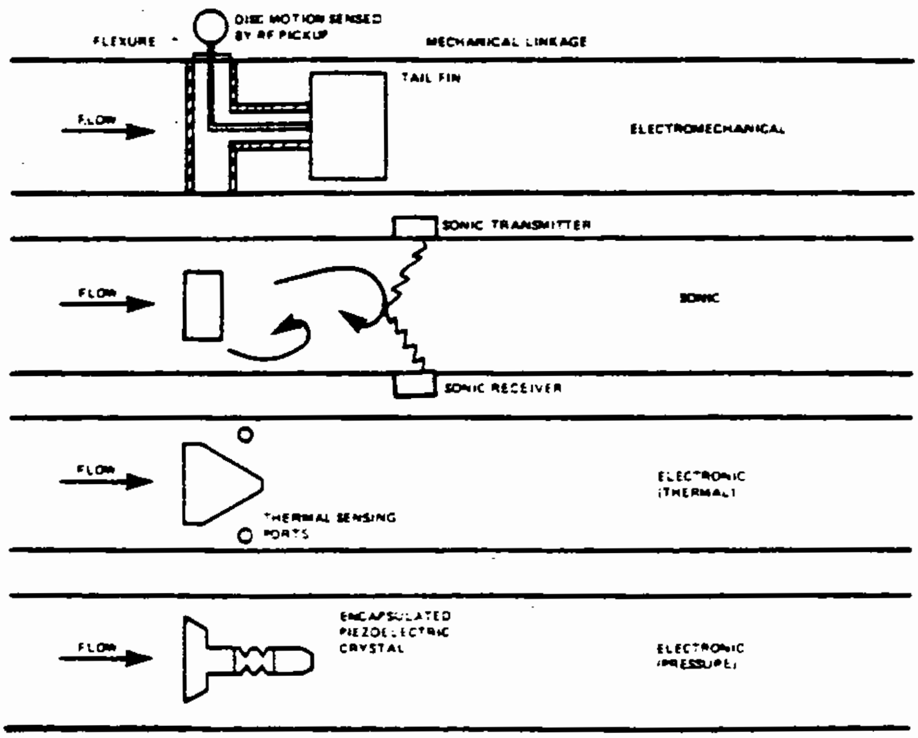
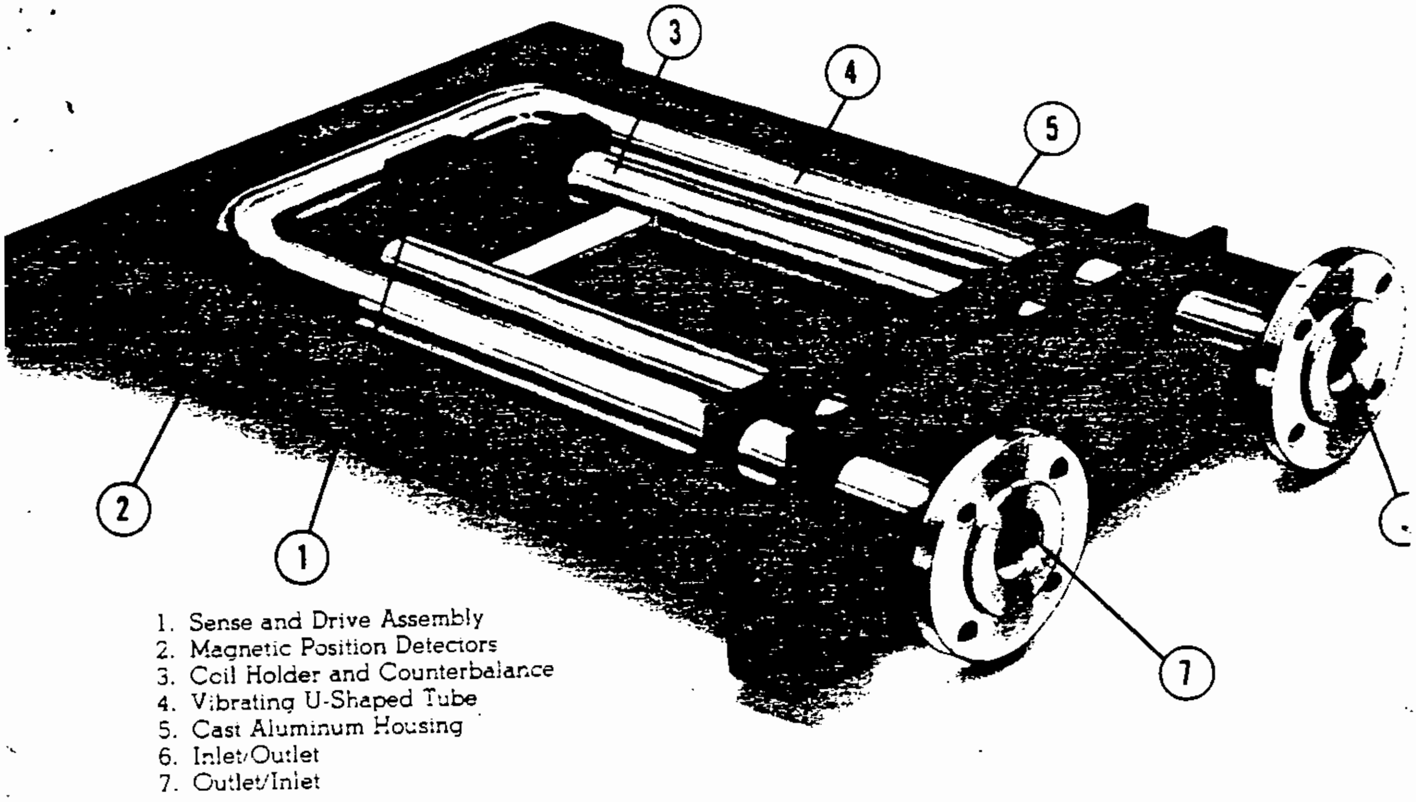


Fig. 3 Bluff bodies of different shapes



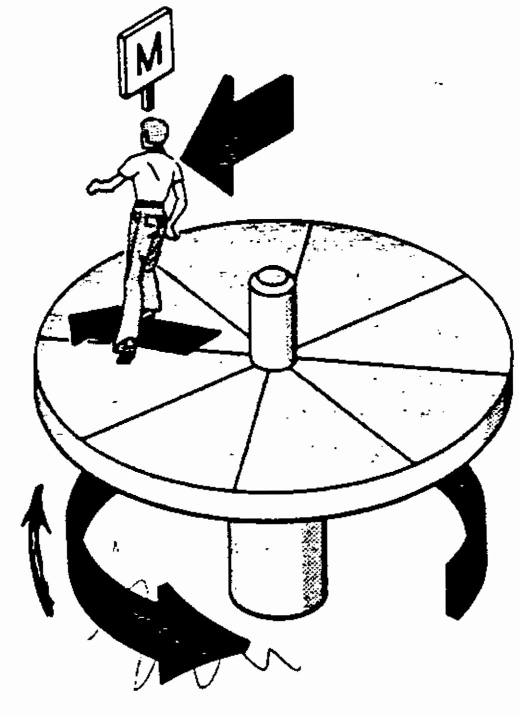


Fig. 3 If a person were standing at the center of a merry-go-round and tried to walk in a straight line toward the edge, he or she would have to lean sideways against the Coriolis force to stay on line. The Coriolis force, $\bar{F}_c$, can be calculated using the mass of the person's body, M, the velocity of travel, $\bar{V}$, toward the edge, and the angular velocity of the merry-go-round, $\bar{\omega}$. $\bar{F}_c = 2M\bar{\omega} \times \bar{V}$.

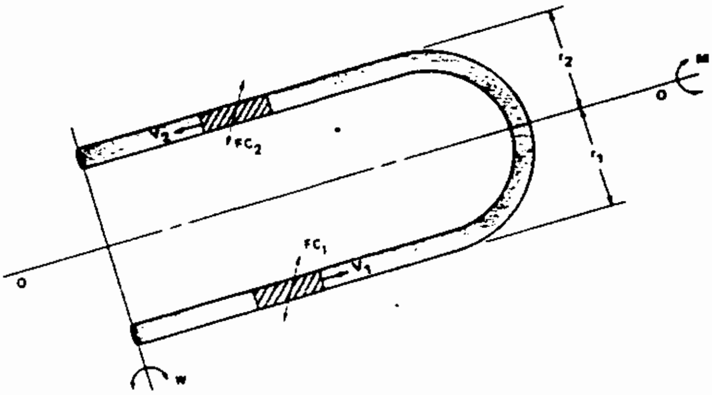


Fig. 5 In operation, the mass flow meter forces, f_{c_1} and f_{c_2}, create an oscillating moment, M, about axis, 0.

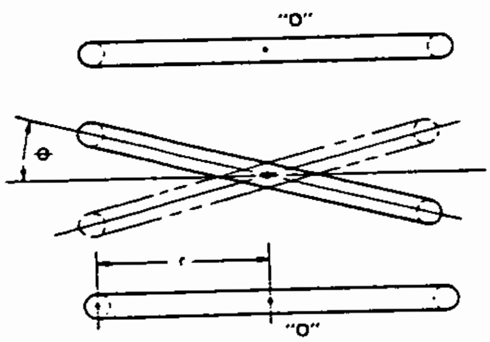


Fig. 6 End view of the U-shaped tube showing the parameters for calculating the torque and its relationship to the mass flow rate. The torque depends on the deflection angle, θ, of the pipe and its spring constant, K_s.

Fig. 4. Mass flow meter

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.