An overview of Coriolis Mass Flowmeter as a Direct Mass Flow Measurement Device

Vikram A. Kolhe\textsuperscript{1}, Ravindra L. Edlabadkar\textsuperscript{2}

kolhe.vikram@gmail.com\textsuperscript{1}, dredlabadkar@gmail.com\textsuperscript{2}

Department of Mechanical Engineering\textsuperscript{1,2}
Sandip Institute of Engineering & Management, Nashik\textsuperscript{1},
Pune Vidyarthi Grūh's College of Engineering & Technology, Pune, India\textsuperscript{2}

ABSTRACT
Measurement of mass flow rate is an important aspect in various industrial & irrigation applications. In recent years, Coriolis mass flowmeters have emerged as the fastest growing fluid metering technology due to its ability of direct mass flow measurement with greater accuracy & reliability. This paper gives a brief overview about the important research efforts undertaken experimentally and theoretically in the development of Coriolis mass flow meter. The paper mainly focuses on the research efforts conducted on various aspects of the meter like tube geometries, vibration, dynamic response of the meter, effect of velocity profile on the performance of metre.

Keywords
Coriolis mass flow meter, parameters, performance factors, and mass flow measurement.

1. INTRODUCTION
In many applications of the flow measurement, mass flow rate is more important than volume flow rate. For example in food and beverage industry mass flow rate is more important rather than the volume flow rate of a commodity. A company’s profit or loss mainly depends upon accurate mass flow measurement of the flowing substance.

Coriolis flowmeters were developed in the 1980s to cater the need of direct mass flow measurement. Over the past decade, Coriolis mass flowmeters have emerged as the fastest growing fluid metering technology because they are unaffected by changes in fluid parameters like pressure, temperature, viscosity, and density. Coriolis meters do not have moving parts as like turbine and positive displacement meters which are subject to wear. These meters require low maintenance and can handle corrosive fluids and fluids that contain solids or particulate matter. Also, they do not require frequent calibration. In the initial stages of inception, these meters were
used mainly for liquids but now these are adaptable for gas applications also [2].

2. FUNDAMENTALS OF ORIOLIS MASS FLOW METER
Coriolis meter works on the principle of Coriolis force generated in a vibrating tube through which the fluid is flowing. This force is proportional to the mass flow rate of flowing fluid. It typically consist of one or two vibrating tubes with an inlet and an outlet, an electromagnetic drive to generate vibratory motion of the tube, two electromagnetic sensors to detect the phase difference between the two vibrating arms of tube, a feedback circuit for maintaining vibrations at the functional frequency and electronic means for measuring the phase difference between signals received from the sensors as shown in fig.1.
When fluid flows through the meter, it is accelerating on the inlet side and decelerating on the outlet side which generates Coriolis force. The generated Coriolis force causes phase difference between the two vibrating arms of the tube which is proportional to the mass flow rate of the fluid [2].

3. REVIEW OF IMPORTANT SECTIONS OF CORIOLIS MASS FLOWMETER
3.1 Tube geometries
Presently numbers of tube geometries are available which are proprietary to the manufacturer. Some of them are shown in fig.2. Normally all the designs aim to magnify the effect of Coriolis force by the geometrical form of tubes. The tube carrying fluid may be single tube or dual tubes in parallel. In case of single tube, two different designs can be made, either single straight (or slightly bent) tube or bent to form a double loop. Slightly bent tubes offer further advantage of wider temperature range than straight tubes. Single tube designs are preferred due to ease of drainage & cleaning [37]. However, majority of commercially available Coriolis mass flowmeters prefers a double tube design. In dual tube design a flow splitter is required to split the flow in two tubes, which may be problematic in food processing industries with the fluids that are prone to plugging. Hemp [18] investigated changes in the sensitivity of a straight tube Coriolis mass flowmeter upon transition from laminar to turbulent flow. Gupta et al. [31] recently investigated on the sensor position for maximum sensitivity of different tube geometries and identified sensor positions for maximum sensitivity of S-tube and L-tube designs.
Cascetta et al. [13] presented the prototype mathematical model which consists of a straight rigid tube provided with elastic suspension and connected with the line by means of suitable metal bellows. They described that this new prototype optimized the structural & fluid-dynamic criteria adopted in the first prototype. J. Kutin and I. Bajsic [22] carried out a comparison of Shell-type Coriolis meter with the straight tube beam-type meter, based on the condition that both meters have the same pressure loss & they found that the shell-type meter has a higher working frequency and a larger phase shift due to flow.
3.2 Instrumentation

3.2.1 Drive Unit
The drive unit controls the amplitude & frequency of oscillation of tube. It carries a feedback circuit to maintain the functional frequency of vibrating tube. Usually tubes vibrate at resonance frequency which requires least amount of excitation energy.

3.2.2 Sensors
To measure the displacement of tube, two electrodynamic (coil & magnet) type of sensors are mounted on the arms of tube. Another method is optical which consists of photodiodes & modulating shutter [2]. Electrodynamic sensors offer a very good phase accuracy and very high reliability.

3.2.3 Signal Processing
The signals produced by sensors due to displacement of tube limbs are very small sinusoidal signals, which need to be amplified for the succeeding signal processing stages of the electronics [37].

4. FACTORS AFFECTING THE PERFORMANCE OF CORIOLIS MASS FLOW METER

4.1 Velocity profile
Hemp [20] applied a weight vector theory to simple flow meter to study the effect of velocity distribution & found that when a fluid flows through a vibrating tube, the interaction between the physical characteristics of tube & velocity of vibration give rise to a body force in the fluid. In weight vector theory the velocity vector is multiplied by the weight vector & integrated over the total volume of the fluid. Hemp discussed about the limitation of theory if applied to CMF with long tubes with larger amplitude. In second part Hemp and Henry [21] described the effect of viscosity on the meter sensitivity using weight vector theory. When viscosity is considered it causes additional contribution to secondary vibration at the boundary between vibrating tube & the fluid. Author concluded that neglect of viscosity can cause errors of a few percent & suggested to neglect viscosity in the vibration flow entirely & then to correct calculation by using weight vector with viscosity.

Bobovnik et al. [15] carried simulations for viscous fluid flow in the vibrating tube of shell-type meter, whose mode shape remained fixed during the transient simulation process and observed time responses of the integral anti-symmetric fluid forces acting on the inner wall of the measuring tube. The magnitude and relative variations are considered with the mass flow rate of the fluid for the integral estimation of the velocity profile effect. Author presented simulation results for different fluid velocities through the measuring tube and found considerable loss of flowmeter's sensitivity in the range of lower Reynolds numbers.

4.2 Reynolds Number
Vivek K. and Anklin M. [42] studied the effect of CMF performance at low Reynolds number experimentally & by Fluid-Structure-Interaction simulations (FSI). They concluded that a secondary oscillatory flow in the tube cross-section, induced by the interaction of Coriolis and shear forces, gives rise to a change in the calibration factor of the meter. The secondary
flow as shown in fig.2 is a function of the Reynolds number of the mean flow. Huber C. et al. investigated that the Reynolds effect may induce a secondary flow in the oscillating tubes of CMF, which would lead to change in the sensitivity of the flow meter.

Mills. et al. [5] evaluated the response of different flowmeters (Twin tube 6 inch with max. flow rate 250 kg/s for H & I meter) across a range of high viscosity conditions (Six test fluids – Kerosene, Gas Oil, Velocite, Primol, Siptech, & Aztec with viscosities from 2 to 1500 cST) & found that max. errors were -0.964 & -0.56 %for meters H & I respectively even at Re as low as 200.

Bobovnik et al. [15] investigated flow profile effects in a straight-tube Coriolis meter using CFD. According to their research there is shift in the calibration factor of the meter due to change in axial flow profile, because of the variation in the Reynolds Number.

4.3 Vibration & Dynamic Response

Cheesewright R. et al. [10] studied the response of a simple Coriolis meter subjected to external mechanical vibrations and corresponding finite element analysis of three commercially available meters. They concluded that vibrations produces additional components in the meter sensor signals but these components are only at the frequency of the vibrations. The results shows that errors reported in vibration experiments, using any frequency except the meter drive frequency, are due to failure of the determination of the phase difference between the sensor signals. Clark et al. [45] explained a very high response rate Coriolis flowmeter based on a commercial twin straight-tube meter with the developed digital transmitter. Their results suggested an order of magnitude, at least, increase in response speed.

Dezhi Z. et al. [44] verified the measurement accuracy of the measuring tube with different vibration amplitudes, which evidences that nonlinear influences become more serious with the vibration amplitude rising.

4.4 Two phase fluid

Al-Khamis et al. [35] modified the available U type Coriolis mass flowmeter & conducted test for crude liquid having entrapped gas particles & found that accuracy of rate measurements of all the meters deteriorates significantly when gas flows with the crude oil. Severino J. & Bermudez F. [25] investigated the performance of type Coriolis Mass Flowmeter under two phase flow conditions & found that the type Coriolis Mass Flowmeter do not perform accurately for two phase liquids like gas-liquid mixtures. They found average relative error upto 65% in mass & density measurements. Conrad K. and Clancy J. [36] investigated the application of type Coriolis
Mass Flowmeter for natural gas and found that the flow profile disturbances & swirl flow have little or no impact on the measurement of accuracy. They studied large sized type Coriolis Mass Flowmeter for mass flow rate & suggested the simplified installation, reduction in size & overall cost.

Henry M. et al. conducted trials on commercial three-phase Coriolis meter with three-phase (oil/water/gas) mixture and found suitability of Coriolis technology for three-phase mixtures. Also authors suggested to determine the range of parameters suitable for field performance of the meter. Emir Kupanovac T et al. investigated on the suitability of commercial available Coriolis flowmeters and found unreliable results for slurry measurement. Authors presented a comparison analysis of two flowmeters and concluded about a wrongly applied method for slurry in the production of a detergent powder plant and finally installed a suitable meter for the same.

5. SOFT COMPUTING TECHNIQUE

Soft Computing Technique involves artificial intelligence methodologies like Fuzzy Logic (FL), Artificial Neural Networks (ANN) and Genetic Algorithms (Gas). Patil P. et al. [27] developed a Copper type Coriolis Mass Flowmeter & modeled the phase shift, mass flow rate model by adaptive neuro fuzzy inference system (ANFIS) and compared with MFNN model. The results reveal that ANFIS models could be effectively used in the expansion of type Coriolis Mass Flow sensors. Patil P. et al. [28] used Neural Network (NN) approach to predict the performance of the omega tube type Coriolis mass flow sensor. They resulted that NN has the capability to map the input-output relationship, i.e., predict the performance under different operational conditions depending on the availability of the experimental data. In another paper, Patil P. et al. found that ANN based model can be used with a high degree of accuracy and reliability. The practical benefits of this model can be extensive to any proportion/combination of design parameters for their prospective applications in mass flow sensing.

6. DISCUSSION & CONCLUSION

After referring the available literature, it is found that the majority of research is being carried in analyzing the performance of available meters for various applications in terms of vibrations, dynamic response, tube geometries etc. of the meter. Research is also going on to find the suitability of meter for two-phase & three-phase flow. During the past years, the advancement of Coriolis mass flow meters has been strongly affected by the use of numerical simulations with finite element methods. There are two important applications for numerical simulation: first, finite element methods is an efficient tool to optimize the design during product development and, second, numerical simulation is an important tool to get a better insight into different physical effects, thus improving the performance of Coriolis mass flow meters.

Further a test series conducted at National Engineering laboratory (NEL), Scotland reported about the performance of conventional flowmeters when applied to viscous fluids and concluded that the conventional liquid flowmeters cannot simply be relocated from low viscosity to high viscosity service without suitable consideration, characterization or modification. The results also show that the performances of devices of the same technology are not necessarily similar as there are many other variables. At low Reynolds number, a CMFM reading may deviate under the influence of fluid dynamic forces.

In most of the research, the geometrical configurations studied are those of straight tube type. Very limited studies for other tube configurations have been carried out. This could be due to the lucidity of the analysis of straight tube using known mathematical models and also due to the relative ease in conducting experimentation with this configuration.
REFERENCES


