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Simulation of S Shape Coriolis Mass Flow Sensor

Rushali Pant, Pravin P Patil, Resham Taluja

Abstract: ***The paper intent in modelling of S-shape coriolis mass flow sensor and then per-forming the simulation for determining the desired phase-shift. The coriolis mass flow sensor is a device that measures mass flow rate of a fluid inside the tube. It is also known as inertia flow meter. The phase shift appears due to the twist in the structure as a result of interactions between the vibration and fluid flow. The phase shift calculated at different sensor positions is helpful in calibrating the ac-curate mass flow rate and to ascertain the optimal sensor position. The coriolis mass flow sensor is modelled in CATIA V5 and simulation is performed in ANSYS 16.2. Tube material is copper and working fluid is water.***

Keywords: Coriolis, CMFS, FEA, flowmeter

I. INTRODUCTION

Coriolis mass flow meter is an instrument used to measure the mass flow rate and density of a fluid flowing through the pipe. It is based on principle of Coriolis Effect. Vibration is induced to the tube through which the fluid passes. Inertia created by the fluid flowing in the pipe causes the tube to twist which induces phase shift in the dis-placement signals. The phase shift calculated is found to be proportional to the mass flow rate and this acts as a working principle for coriolis mass flow sensor. Coriolis mass flow sensor are being increasingly accepted for mass flow measurement. This is ascribed to the direct measure of the true mass flow rate unlike other instruments that measures volumetric flow rate. The fluid volume being a function of physical state of the fluid such as pressure, temperature and density fail to provide accurate results in changing physical environment. On the other hand mass does not depend on the state of the fluid. This makes coriolis mass flow sensor independent of physical fluid properties and fluid profiles and also provide a principle that can be used for both liquids as well as gases. It can be recognized that coriolis mass flow sensor are multi-variable instruments for it is used to simultaneously calculate mass flow, viscosity, density, temperature and pressure. Coriolis mass flow sensor when compared with traditional volumetric flow meters gives high measuring accuracy.

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***** Correspondence Author
Rushali Pant*, Department of Mechanical Engineering, Graphic Era Hill University, Dehradun, India. vrushalipant28@gmail.com
Pravin P Patil ,Department of Mechanical Engineering, Graphic Era deemed to be University, Dehradun, India. dr.patil@geu.ac.in

II. LITERATURE REVIEW

Smith JE (1980)[1] described a U shape coriolis mass flow sensor. The mass flow rate was described as a function of time delay between two sensor positions and geometric constants. The mass flow rate was measured by sensing the force or torque created by it. Coriolis force being very small, thus, could not provide accurate flow measurement. Introduction to time lag as measuring unit eliminated all these problems. The phase shift is in direct pro-portion to mass flow rate was also stated. Bobovnik et al(2004)[2] was the first to simulation straight beam mode coriolis mass flow meter using computational fluid dynamics(CFD). Sensitivity of coriolis mass flow meter was evaluated by measuring the moment created by the fluid flow at each step. The deflection in tube structure was however not considered in this study. D Zheng et al(2009) [3] uses the analytical method to perform a theoretical study on the straight CMF tube and its nonlinear vibration characteristics, and the influences on CMF. Wang et al (2011) [4] discussed the application of coriolis flow meter in nuclear industry. Post et al (2012) [5] introduced application of inertia flow meter in biomedical field. They proposed the use of coriolis sensors in machine perfusion system for organ preservation. PravinPatil et al(2012)[6] have used response surface method(RSM) and ANFIS advanced tools for optimization and performance evaluation of omega coriolis mass flow meter. Coriolis mass flow sensor manufactured now are found not be affected by the viscosity and densty of the working fluids. Also the velocity profile and Reynolds number does not have any significant effect on the operation of coriolis flow sensors as com-pared to other sensors based on volumetric measurements.

III. CAD MODEL

A three-dimensional mode of coriolis mass flow sensor is required for a quantitative analysis. The sensor tube for this study is considered to be a S shape tube. The pro-file's dimension is: the height is 400 mm and the semi distance is 300 mm. The outer and inner diameter for all three configurations is kept the same. The outer diameter of the tube is 12.7 mm and inner diameter is 10.9 mm. The CAD software CATIA V5 is selected to prepare the solid model of the S shape flow meter. The CAD model of profile is given in Fig.1. After completing the designing the *.stp file is imported from the CATIA V5 to ANSYS 16.2 software for the analysis. The main step of the FEA based analysis is to divide the tube in small pieces called elements and these elements are connected at nodes. Number of nodes and elements generated in geometry are 86432 and 60871.

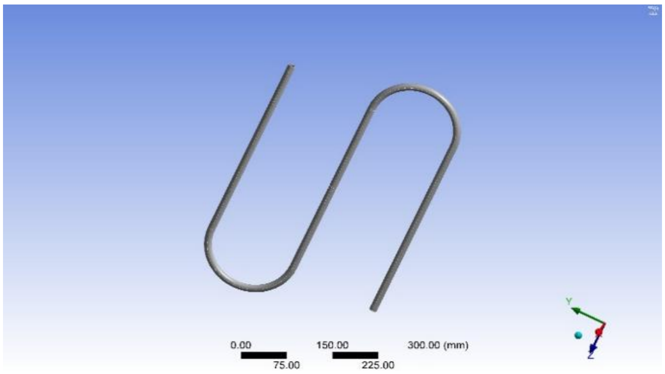


Fig. 1.Cad model of the profile.

IV. MATERIAL PROPERTIES AND BOUNDARY CONDITIONS

A coriolis mass flow meter is analysed under fixed fixed boundary condition for modal analysis. The transient analysis is performed under the same condition with vibration amplitude of 25 micrometer. The natural frequency of vibration is achieved from modal analysis. The fluent steady state analysis is performed for 20m/sec flow velocity. The flow velocity is varied between 10 m/sec to 20 m/sec for analysis carried out to optimize the sensor position.

Mechanical properties (Young's modulus, Poisson ratio and bone mass density) are required to analyze the coriolis mass flow sensor. These are very important parameters for the vibration analysis of the flow meter. The property of Copper are: Young's modulus – 128 GPa, Poisson ratio-0.36, Density- 8940 kg/m3, co-efficient of thermal expansion-17.10e-6. The property of water are: Young's modulus- 2.2 GPa, Poisson's ratio- 0.2, Density- 1000 Kg/m3 and Co-efficient of thermal expansion- 2.14e-5.

V.MODEL ANALYSIS

The first and necessary step in simulation is to perform modal analysis of the S shape tube subjected to fixed boundary constraints. This is important step in simulation process of coriolis mass flow sensor because here we deduce the resonant frequency of the tube, and this is the frequency at which the coriolis sensor tube is vibrated. It is considered that the tube is filled with fluid (water).

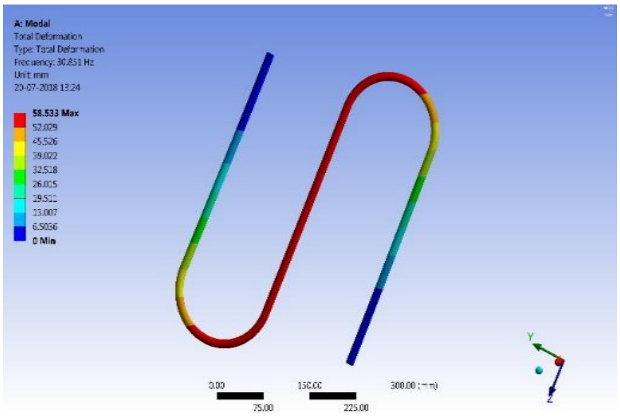
First natural frequency achieved in modal analysis is known as fundamental frequency. It is the resonance frequency for S SHAPE tube filled with the fluid (water).

Table I gives the natural frequency of the tube.

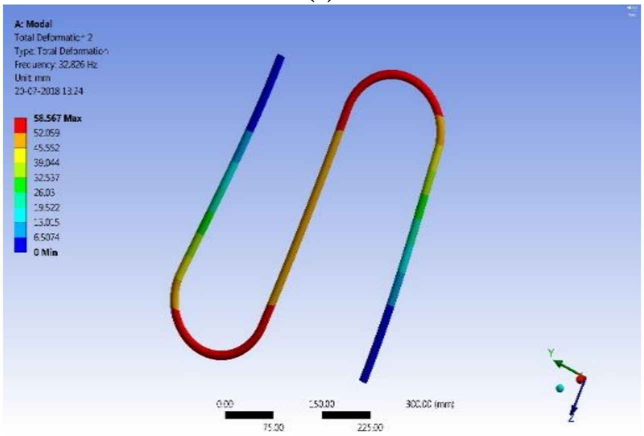
Table- I: Natural frequency of tube

Modes	Natural Frequency(Hz)
1	30.85
2	32.82
3	35.17
4	79.63
5	94.19
6	113.78

From analysis for fixed boundary condition frequency range variation is from 30.85 Hz to 113.78 Hz. Mode shape results of six modes are shown in Fig. 2.



(a)



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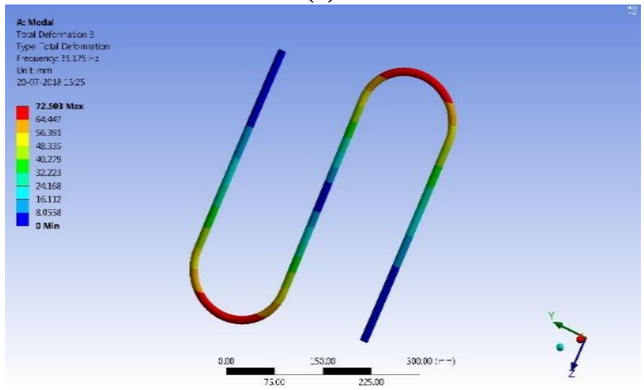

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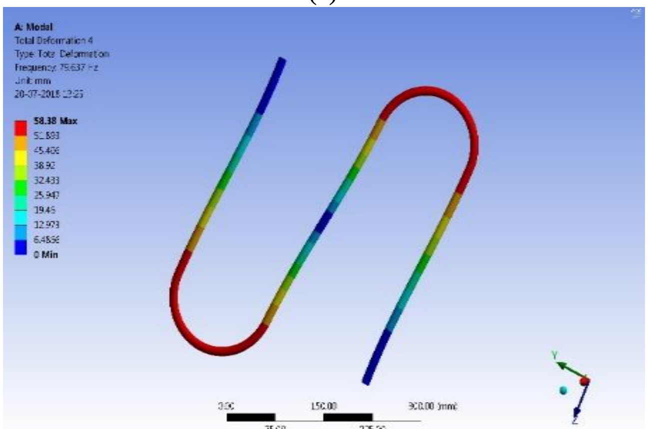

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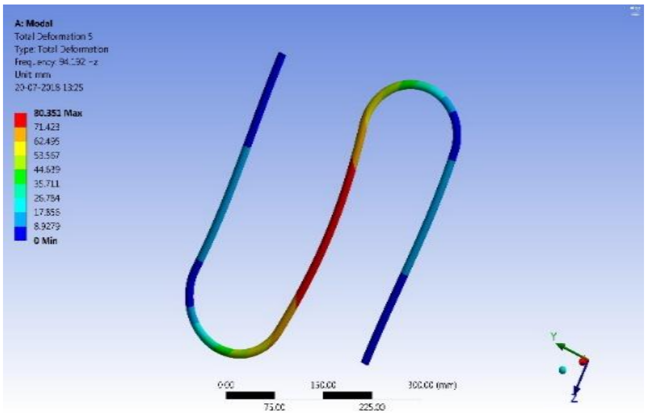

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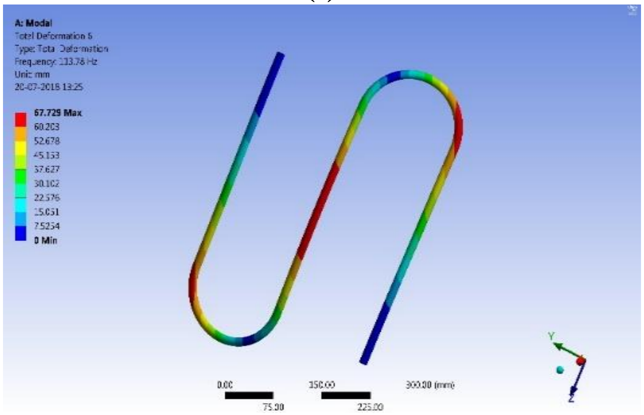

(f)

Fig. 2.Mode shape results of tube(a. Mode 1, b. Mode 2, c. Mode 3, d. Mode 4, e. Mode 5, f. Mode 6)

VI. SYSTEM COUPLING ANALYSIS

After finding the resonant frequency for the tube, two way coupled fluid solid interaction(FSI) analysis is performed. The aim of this simulation is to- set up the transient structure case for the flow meter pipe, set up the transient fluent case including coupling effect and lastly to set up coupled flow case. To perform the following simulation the process is divided into three modules: Transient Structural, Transient Fluent and System coupling. The following simulation considers flow through vibrating coriolis flow tubes. The flow causes a phase-shift between the two ends of the meter which is used to calculate the mass flow rate.

A. Transient Structure Analysis

It is the first step in this process. The main aim of this module is to apply the accurate Fluid solid interaction(FSI) and forcing displacement(y) in fixed boundary condition and to specify the nodes in the geometry where the displacement shift is desired. The transient structure analysis starts by applying fixed support at the upper faces of the tubes. The forced displacement is given at the resonant frequency of the tubes. Resonant frequency of the tubes is already calculated in modal analysis. The forced dis-placement is given by the equation: y=a*sin (ωt), where, y is the displacement, a is the amplitude, ω is the natural frequency and t is the time. The displacement is applied to the face of the tube as shown in the Fig.3. Displacement applied is considered to be of the amplitude 25µm. The excitation frequency for the tube is choosen to be 30.85 Hz.

The fluid solid interface is inserted and deformation trackers at nodes 1_1, node 2_1 node 3_1, node 1_2, node 2_2 and node 3_2 is also inserted. These trackers will pro-vide the displacement history at these nodes. The displacement of node 1_1 and 1_2 is shown in chart 1, the node 2_1 and 2_2 displacement are shown in chart 2 and chart 3 gives the displacement of node 3_1 and 3_2. The location for the displacement trackers are the upstream and downstream bends of the tube where a phase-shift is considered to occur. The sensor positions are shown in Fig.4.

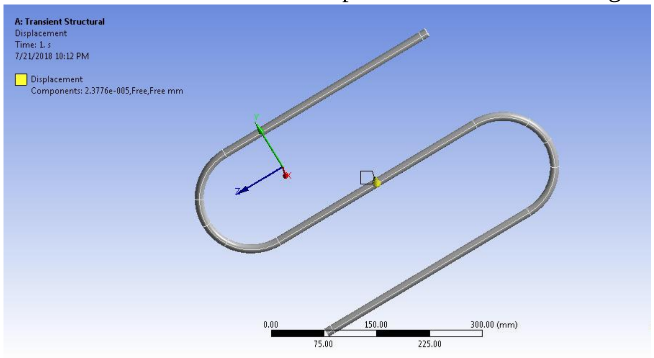

Fig. 3 . Displacement applied to the tube.

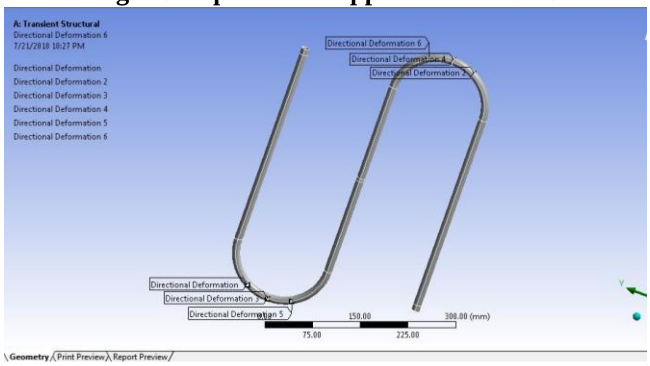

Fig. 4.Sensor positions on the tube.

B. Transient Fluent Analysis

The fluid flow analysis is performed in fluent. First the analysis for steady state is done. The results achieved in steady state are taken as input for transient state analysis. The steady state analysis is performed for laminar flow using k-omega (2 equation) with SST model. The Curvature Correction was enabled for this process. The velocity of the fluid is taken to be 20m/sec. Boundary conditions at inlet are applied as- Turbulent Intensity of 1% and Turbulent Length Scale to 0.02. At the outlet the Guage pressure remains to be 0 Pa and Turbulent Intensity is 1% and Length Scale is 0.02. For flow velocity 15m/sec the boundary condition at inlet applied are: Turbulent Intensity of 1% and Turbulent Length Scale to 0.015. At the outlet the Guage pressure remains to be 0 Pa and Turbulent Intensity is 1% and Length Scale is 0.015. For flow velocity 10m/sec Boundary conditions at inlet are applied as- Turbulent Intensity of 1% and Turbulent Length Scale to 0.01. At the outlet the Guage pressure remains to be 0 Pa and Turbulent Intensity is 1% and Length Scale is 0.01. The solution is calculated using couples scheme with psuedo transient and high order term relaxation enabled. Number of iterations performed are 200. The results are used as the input for the transient analysis of fluid.

The solution method for transient formulation is set to Second Order Implicit. The fluid solid interface is defined and the Number of Time steps selected is 1 and number of iterations/Time step is set to 5.

C.System Coupling

System coupling is done between the Structural and Fluid System. The Transient Structure and Transient fluid is connected by system coupling. The coupling helps to facilitate the two way Fluid Solid Interaction Analysis. The fluid solid interface defined for Transient Structure and Transient Fluid are selected to create Data Transfer Sytem between the two modules. The analysis settings are adjusted as follows: End Time to 0.1 second and Step Size to 0.0005 second. After the system coupling run is successful. The results of the Transient Structure and Transient Fluid are updated automatically. System coupling simulation is first performed for all the three geometries considering the flow velocity to be 10 m/sec. The simulation in then performed by varying the flow velocity to 15 m/sec and 20 m/sec. The results obtained are then used to determine the accurate sensor position. The result is used to calibrate the graph between the mass flow rate and the phase-shift.

VII. RESULTS AND DISCUSSION

The figures 5, 6 and 7 shows the displacement calculated at three sensor positions for the tube for 10m/sec flow velocity. The resulted displacement difference due to the fluid flow is used to determine the phase-shift in the tube. The phase-shift calculated for profile at three different sensor positions is given in Table II.

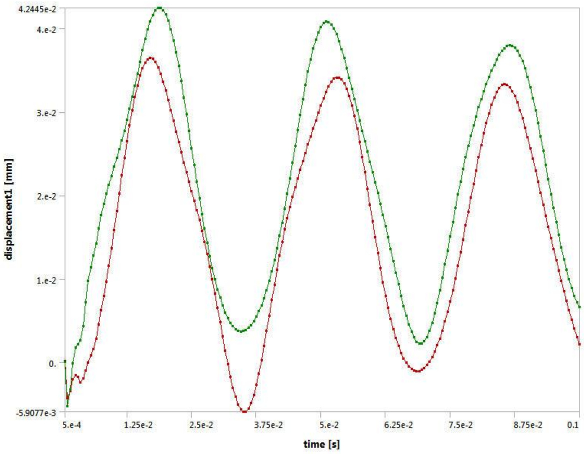

Fig. 5.Displacement between sensor position 1_1 and 1_2.

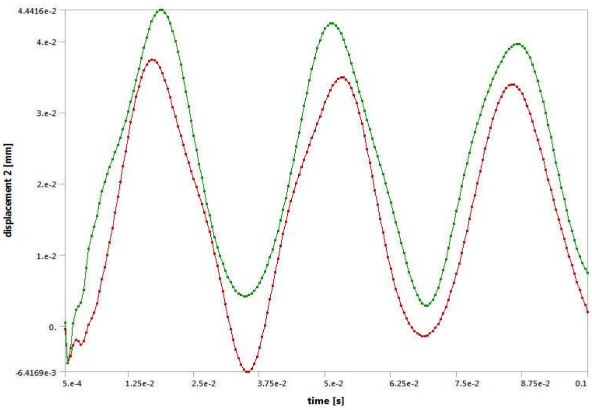

Fig. 6.Displacement between sensor position 2_1 and 2_2.

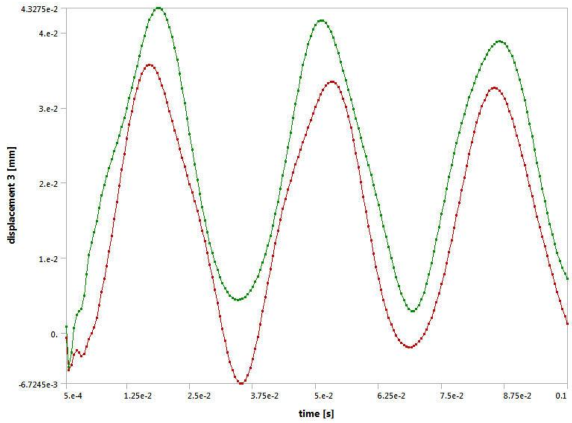

Fig. 7. Displacement between sensor position 3_1 and 3_2.

Table- II: Phase-shift at three sensor positions for the profile (flow velocity 10m/sec).

Sensor position	Phase-shift
1	44.54˚
2	69.17˚
3	95.35˚

The displacement at three sensor position for 15 m/sec flow velocity is shown in fig 8, fig 9 and fig 10.

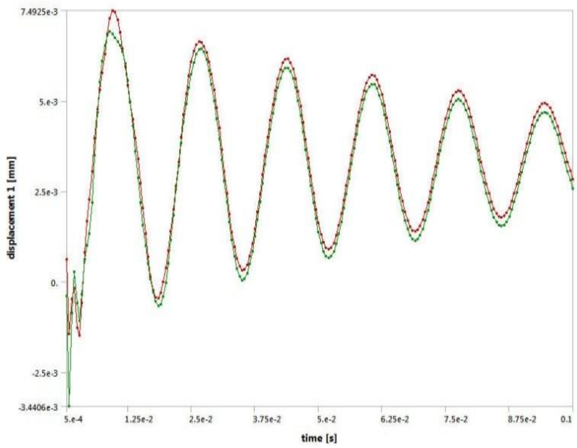

Fig. 8.Displacement between sensor position 1_1 and 1_2.

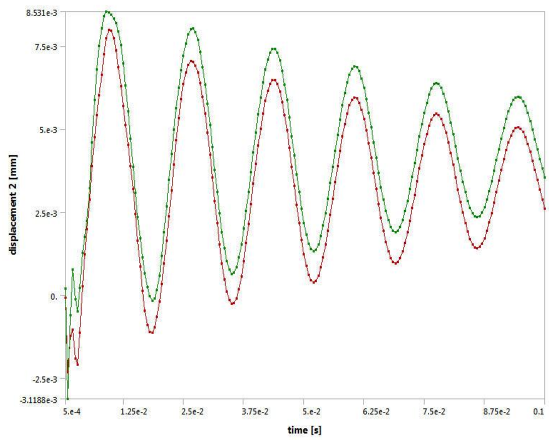

Fig. 9.Displacement between sensor position 2_1 and 2_2.

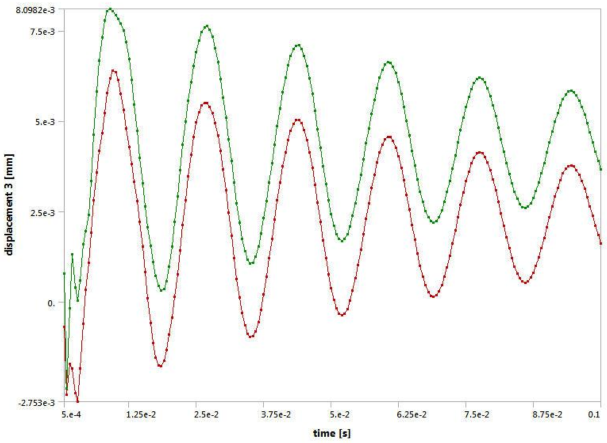

Fig. 10.Displacement between sensor position 3_1 and 3_2.

Table- III: Phase-shift at three sensor positions for the profile (flow velocity 15m/sec).

Sensor position	Phase-shift
1	15.35˚
2	29.52˚
3	35.72˚

The displacement at three sensor position for 20 m/sec flow velocity is shown in fig.11, fig.12 and fig. 13.

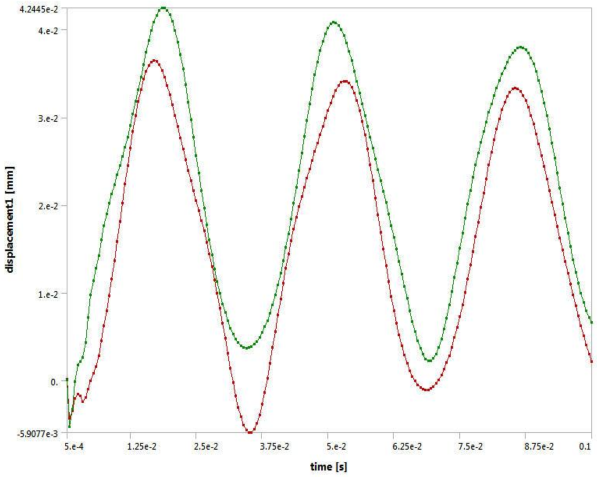

Fig. 11.displacement between sensor position 1_1 and 1_2.

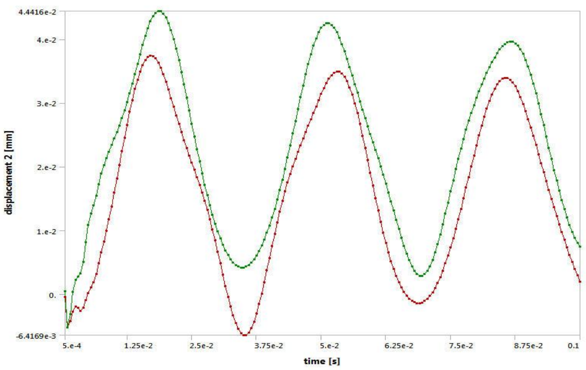

Fig. 12.Displacement between sensor position 2_1 and 2_2.

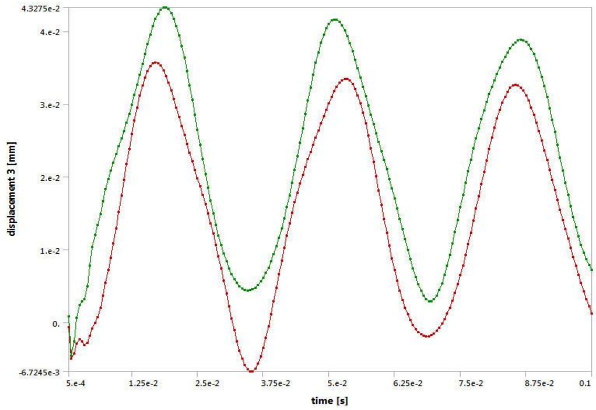

Fig. 13.Displacement between sensor position 3_1 and 3_2.

Table- IV: Phase-shift at three sensor positions for the profile (flow velocity 20m/sec).

Sensor position	Phase-shift
1	20.25˚
2	35.25˚
3	51.79˚

The mass flow rate for measured phase shift is calculated. The graph between the mass flow rate and phase shift is drawn for each sensor location of all three geome-tries. Fig. 14.shows the variation of phase shift with change in mass flow rate for all three sensor locations. Fig. 15.shows influence of sensor position on phase shift at different mass flow rates.

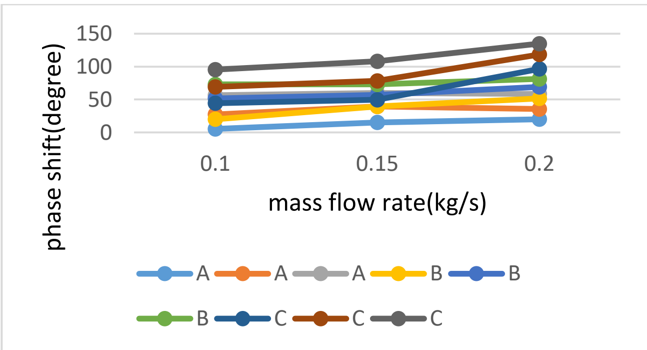

Fig. 14.Phase shift Vs Mass flow rate for all sensor locations.

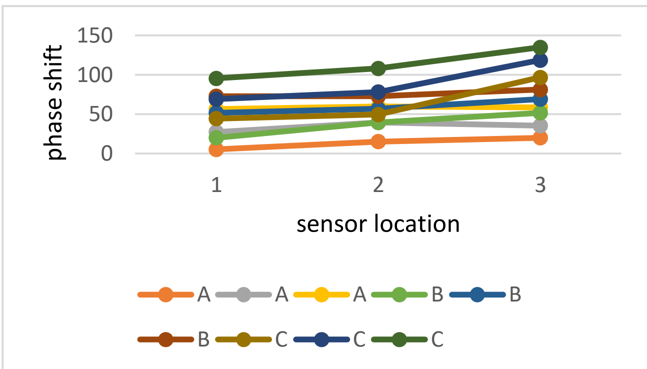

Fig. 15.Phase shift Vs Sensor location for varying velocity.

VIII. CONCLUSION

In the present work modal and system coupling simulation have been conducted on S shape Coriolis mass flow sensor. The simulation was carried out for S shape tube. Simulation was run for varying flow rates or velocities and sensor locations.

A. Effect of mass flow rate

Simulation is performed on a Copper S shape Coriolis mass flow meter for different mass flow rates. The phase shift between the vibrating limbs is measured for different flow rates. It is observed from Fig. 14 that the mass flow rate varies linearly with the phase shift at different sensor locations.

B. Effect of sensor position

In order to determine the optimal position for the sensor, simulation is run to study the effect of sensor location on phase shift at different mass flow rates. Graph 5.14 depicts the variation of phase shift with sensor locations for 0.1 to 0.2 kg/s for all three S shape profiles. It is observed that the maximum phase shift is at sensor location 3 and minimum at sensor location 1. Therefore we can conclude that the optimal position for sensors is at location 3 i.e at the distance of 225mm for the third geometry, from the utmost arms of the tube..

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AUTHORS PROFILE

Rushali Pant. Rushali pant is an assistant professor in Graphic Era Hill University, Dehradun. She has completed her B-Tech in Mechanical Engineering from HNB Garhwal University in 2016. She has completed her M-Tech in CAD/CAM and Robotics IN 2018 and is pursuing PhD from Grpahic Era deemed to be university, Dehradun. She has published three research articles in international journals and conferences.

Dr. Pravin P Patil. Pravin P Patil is working as a Professor in department of mechanical engineering, Graphic Era deemed to be University, Dehradun. He has completed M-tech and PhD from IIT roorkee. He has published hundred research articles in international journals and conferences.

Resham Taluja . Resham Taluja is an assistant professor in Graphic Era Hill University, Dehradun. She has completed her B-Tech in Mechanical Engineering from Grpahic Era deemed to be university, Dehradun.University in 2015. She has completed her M-Tech in Design Engineering IN 2019 from Grpahic Era deemed to be university, Dehradun. She has published three research articles in international journals and conferences.