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Analysis of Split Mass Coriolis Mass Flow Meter Tube using ANSYS

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Abstract: Coriolis Mass Flow Meter (CMF) measures the mass flow of the fluid, such as water, acid, chemicals and gas/vapor. There are various designs of the Coriolis mass flow meter one such which is under research is Split mass flow meter type. This paper covers simulation done on Single U-Tube Split mass Coriolis mass flow meter in ANSYS. Various analysis like Pressure, Velocity and Frequency are done on the Split mass flow meter model along with other two non-Split mass type using ANSYS – WORKBENCH.

Keywords: Frequency analysis, ANSYS, Coriolis Mass Flow Meter, Split mass flowmeter

I. INTRODUCTION

Coriolis mass flow meters will measure the mass flow rate and actual density accurately irrespective of the nature of the fluid as long as the flow is single phase and the fluid is homogeneous. Being accurate, they are often used for custody transfer and critical reactor feed (ratio) control and also in streams where large variation in fluid composition will occur, which otherwise could not be measured. Coriolis flow meter is capable of measuring a wide range of fluids that are often incompatible with other flow measurement devices. The operation of the flow meter is independent of Reynolds number; therefore, extremely vicious fluids can also be measured. A Coriolis flow meter can measure the flow rate of Newtonian fluids, all types' non-Newtonian fluids, and slurries. Compressed gases and cryogenic liquids can also be measured by some designs.

Coriolis flow meters provide a direct mass flow measurement without the addition of external measurement instruments. While the volumetric flow rate of the fluid will vary with changes in density, the mass flow rate of fluid is independent of density changes. Coriolis flow meters do not have internal obstructions which can be damaged or plugged by slurries or other types of particulate matter in the flow stream. Entrained gas or slugs of gas in the liquid will not damage the flow meter. There are no moving parts witch will wear out require replacement. These design features reduce the need for routine maintenance.

The Split mass or Dual mass flow meter is mainly focused in this paper in comparison with the non-Split mass type. Basic Single U-Tube design is followed in all the three types over which the analysis is going to be done in ANSYS-Workbench. The Split mass type is under development and has not yet fully commercialized like Dual tube and Single tube Coriolis mass flow meters. The accuracy is the prime reason why CMF is the best choice to measure the flow in terms of mass. This the reason why Split mass type becomes so crucial as it can provide a higher amplitude of output signal thereby giving a better resolution to measure the phase difference providing more accuracy.

[1] The mass flow meter deployed in fuel measurement where the results show the accuracy is well within the defined standards of 0.1-0.2%. A study made on providing a better signal conditioning for the CMF using Prism based Notch filtering for the flow meter to measure the flow rate of the diesel fuel is discussed in [2]. Using Lorentz actuation in a µ-Coriolis mass flow meter sensor is discussed in [3] where three different configurations were used to determine the best response for the sensor. A similar study is made on the µ-Coriolis Mass Flow Sensor with Resistive Readout which includes the sensitivity measurements of three different design used during the experiment is briefly given in [4]. A new finding which gives the design aspect of the CMF considering the pressure difference in the tubes with an objective to reduce the overall installation cost is given in [5].

The density measurement using the Coriolis mass flow meter is discussed in [6] and it gives an idea about how density measurement becomes critical due to material properties of the device changing with the temperature. [7] gives a mathematical design approach for the Coriolis mass flowmeter considering various error analysis like uneven flow rate, vibration effects, effect of inner pressure and temperature. The physical model for the CMF to be used in custody

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transfer of liquid hydrocarbons is briefly explain in [8]. The resonant frequency analysis on the dual mass based Parallel-Plate Electrostatic actuators is given in [9] and it shows when there is a dual mass involved the amplitude of the output signal generally becomes higher than those of that in single mass. Precision electrostatic frequency tuning in a dual-mass gyroscope is demonstrated in [10]. [11] talks about finite element method (FEM) based analysis is pursued and simulations are carried out for the examination of distinct frequency modes and frequency response of dual mass micro gyroscope modelling in ANSYS. [12] gives about the dual mass accelerometer with a better read out circuit which increases the mechanical and electrical sensitivity. Integrated design of piezo-actuated 2-DOF submillimeter-range super-resolution (SR) platform with self-sensing unit offers large-scale travel within a compact platform size with fast response times and self-sensing capabilities which can be used for actuation of the tube is given in [12]. [13] is about how Piezo actuation can be used with a better resolution and high linearity in output signal.
ANSYS is a Computer Aided Design software for modeling and testing Engineering designs in a virtual instance. It is also a Mechanical finite element analysis software which is used to simulate computer models of structures, electronics, or machine components for analyzing strength, toughness, elasticity, temperature distribution, electromagnetism, fluid flow, and other attributes. Various online tutorials and support is provided from Ansys.com to get familiarize with the ANSYS -Workbench environment [14]. [15] gives the methodology in ANSYS with which the resonant frequency can be determined for the CMF model. The CFD analysis of butterfly valve type flowmeter is done in [16]. Performance of the perforated plate flowmeter for liquid hydrogen was analyzed with the help of ANSYS in [17]. Simulations of the air flow in a circular pipe with multiport averaging Pitot tube and the effect of the shape of this probe to the permanent pressure loss in FLUENT module ANSYS is shown in [18]. Deviation induced by bubble and resonance effect were modelled. The corrected model with known gas-liquid ratio was modelled. The deviation of density and mass flow are significantly lower than those before [19]. U-Tube modelling for a low-frequency mode is shown in [20].
Section 2 gives a brief about the Split mass design compared with Non-Split mass types. Modelling of the Coriolis mass flow meter tubes all the three different designs in ANSYS are discussed in Section 3. The Section 4 is about the various analysis that are done on the three different models of the Coriolis mass flow meter tube.

II. SPLIT MASS CORIOLIS MASS FLOW METER

To understand what Split mass type flow meter is we should first have an over view of what are the designs that are most commonly used and are available for the Coriolis mass flow meter. Generally, there are two basic design of Coriolis mass flow meter which are Single tube and Dual tube design. single tube designs are often preferred since they offer the best cleanability and the most careful fluid handling. However, it is challenging to find a balancing mechanism for such flowmeters. Nevertheless, there are single straight or fairly straight tube Coriolis mass flowmeters, which offer a similar performance to dual tube flowmeters. In this paper the following design of Single U-Tube Coriolis mass flow meter is used to do the analysis as shown in the Figure: 1 which shows the design of Small mass Coriolis mass flow meter and the Figure: 2 shows the Big mass type Tube design of the CMF.

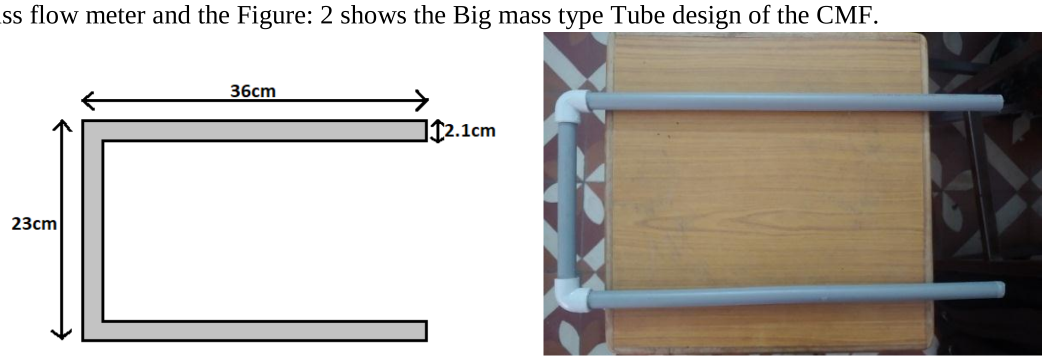

Figure: 1 Small mass Single U-Tube design of the Coriolis mass flow meter.

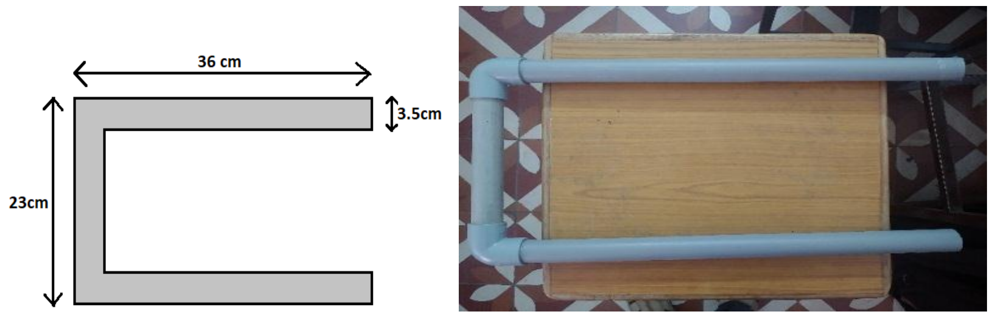

Figure: Big mass Single U-Tube design of the Coriolis mass flow meter.

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From both the figures one thing is pretty clear that the dimensions are almost same except the diameter of the pipes which in casts more flow in case of Big mass and Less flow in case of Small mass design. The Split mass is a kind of hybrid type made out of these two as shown in Figure: 3 and the dimensions are kept the same in contrast with the non-Split mass type CMF.

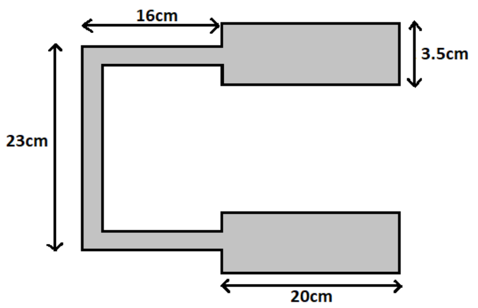

Figure: 3 The Split mass design of the Coriolis mass flow meter.

The material for construction of all the three types is Poly Vinyl Chloride (PVC) pipes with the same dimensions as shown in the above figures and it is the same material with which the analysis is going to be done in ANSYS.

III. MODELLING OF SPLIT MASS CORIOLIS MASS FLOW METER TUBE IN ANSYS

The modal analysis aids in determining the natural frequencies and the related mode shapes of the structure. It also serves as the basis and initial point for the other comprehensive dynamic analysis, like harmonic response analysis. The natural frequencies and the related mode shapes are of central importance while designing the structure for dynamic loading conditions. All the three different types are modelled in ANSYS as shown in the figure: 4 which reflects the Geometry build based upon the dimensions shown in Table:1.

Table: 1 Dimensions of the Coriolis mass flow meter tubes for simulation purpose in ANSYS.

Parameters	Small mass tube	Big mass tube	Split mass tube
Inlet Diameter	1.5 cm	3 cm	3 cm
Thickness	0.6 cm	0.5 cm	0.5 cm
Vertical cross section	36 cm	36 cm	20 cm (Big mass) + 16 cm (small mass)
Horizontal cross section	23 cm	23 cm	23 cm
Type of Material	PVC	PVC	PVC
Elastic module	1.5 Mpa	1.5 Mpa	1.5 Mpa
Poisson Ratio	0.4	0.4	0.4
Density	1.39 g/cm^3	1.39 g/cm^3	1.39 g/cm^3

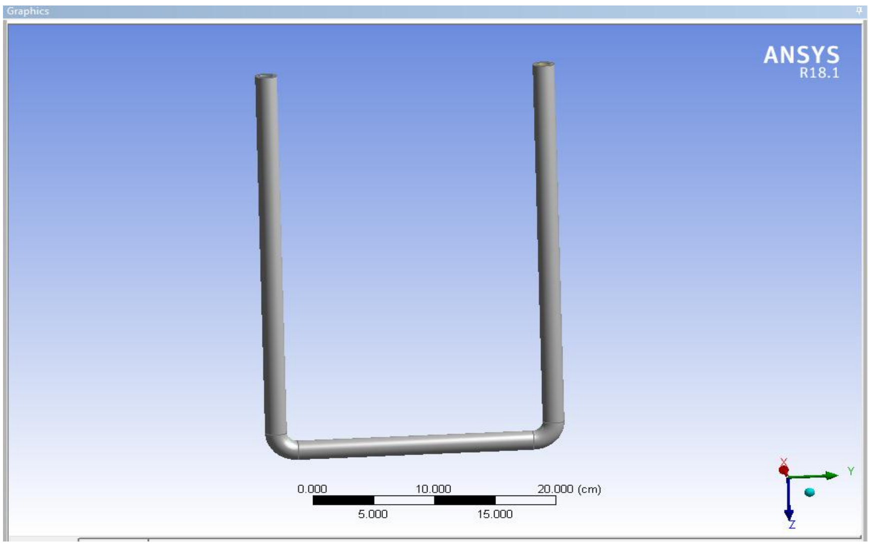

Figure:4. a Small mass Coriolis mass flow meter tube

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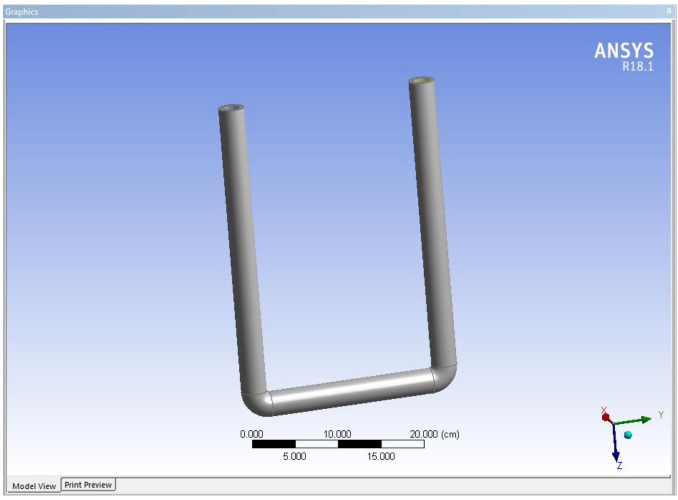

Figure:4.b Big mass Coriolis mass flow meter tube

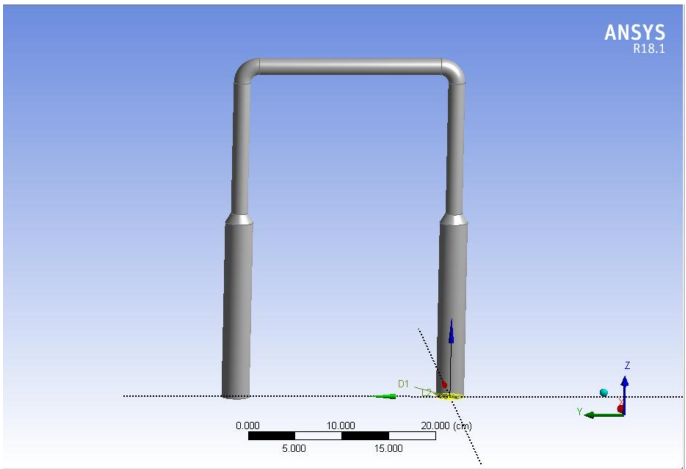

Figure:4.c Split mass Coriolis mass flow meter tube

Figure: 4 The three different Coriolis mass flow meter tube geometries in ANSYS.

To create the Non-Split mass type flow tube, the Geometry is modelled as follows. The global axis set in XY plane and the unit for dimension is set as centimeter (cm). Using Draw options in the menu, a circle is drawn and extruded for 36 cm. A mirror image of the same structure is done in the same XY plane at the distance of 23 cm. Two circles of inner diameter 1.5 cm and 3 cm is drawn at YZ plane and is extruded for 36 cm. Thus, the mirror image is created but a certain gap left to be filled in order to get the complete structure. To bring the curves at the edges Fillet function is used which is available in draw menu. The structure created is meshed using Auto mesh. The edges of U-Tube are fixed to run the analysis.

For the Split mass type similar approach is adopted but with some minor adjustments. First a circular tube denoting Small mass is created using the above-mentioned steps. Whose parameters are 16 cm vertical cross section with inlet diameter of 1.5 cm and thickness of 0.6 cm. A mirror image is created and the remaining curved edges are filled using the Fillet function. Now Big mass tube is modelled at a distance of 18 cm out of its 20cm total in the same manner as described above. The 2cm gap is kept for intersecting the small and big mass tube using Fillet function by selecting two edges using 2 surfaces selection option. Thus, the structure is generated and meshed using Auto mesh for further analysis.

IV. ANALYSIS OF THE CORIOLIS MASS FLOW METER TUBES

The three different types are analyzed on various aspects like pressure, velocity and the most vital one the frequency analysis. First pressure and velocity analysis are carried out. The pressure at the inlet is kept at 1 Pa initially for all the three types and Velocity as 0.01 m/s and the fluid is set as Water. The results are tabulated in Table: 2 and the respective ANSYS simulated models are shown in Figure: 5 to Figure: 7 which gives a clear indication of the effect of pressure and velocity on the structures.

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Table 2: Pressure and Velocity effect on the Coriolis mass flow meter tube designs.

Analysis parameters	Location	Small mass	Big mass	Split mass
Pressure (Pa)	INLET	3.423e-002	9.864e-003	1.584e-002
	OUTLET	2.746e-002	1.973e-003	1.554e-003
Velocity (m/s)	INLET	1.253e-002	1.280e-003	1.062e-002
	OUTLET	1.241e-002	1.228e-003	1.055e-002

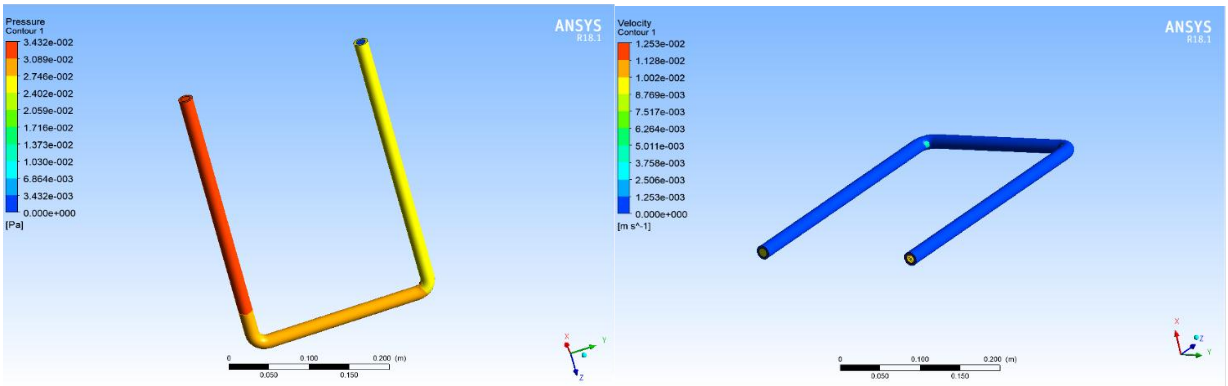

Figure: 5 Small mass tube Pressure and Velocity analysis

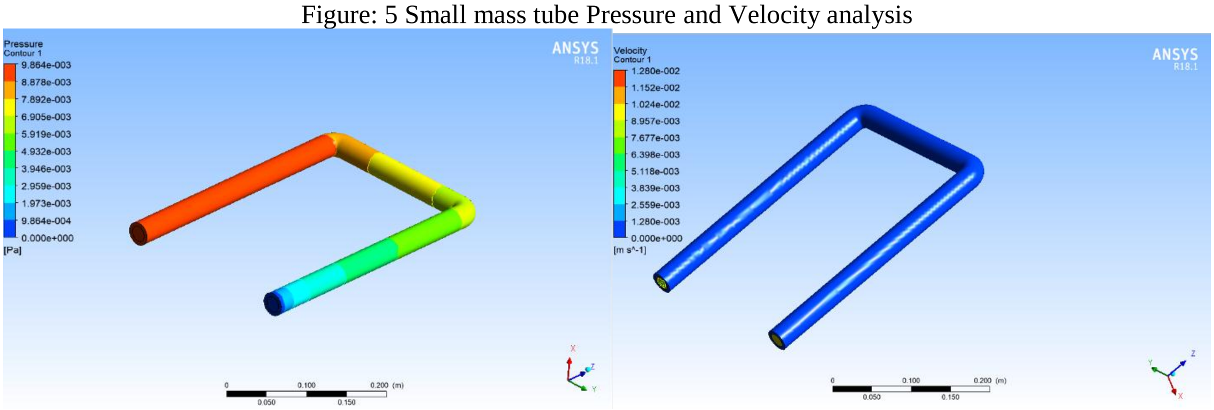

Figure: 6 Big mass tube Pressure and Velocity analysis

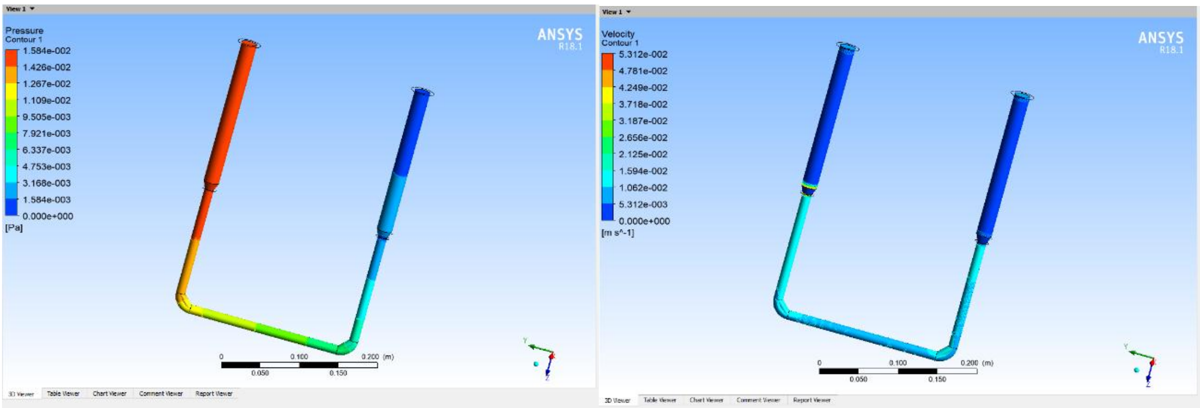

Figure: 7 Split mass tube Pressure and Velocity analysis

After carrying out the Pressure and Frequency analysis for the three different Coriolis mass flow meter tube designs now the vital analysis of determining first six mode of natural frequency is done. The harmonic analysis of the same geometries is used to determine the natural frequency of the tube models. Table: 3 gives all the first six mode of resonance for the three different types of CMF tubes and from Figure: 8 till Figure:16 shows the first three modes of resonance simulated model using ANSYS. The first mode of resonance is always advisable to be used for oscillating the tubes. If the oscillation is not enough to get the phase shift accurately then any resonant frequency from the first six modes can be used.

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Table: 3 First SIX mode of resonance for the Coriolis mass flow meter tube models.

SMALL MASS TUBE						
Mode of Resonance	1	2	3	4	5	6
Frequency (Hz)	80.36	108.58	202.24	475.74	495.82	641.87
BIG MASS TUBE						
Mode of Resonance	1	2	3	4	5	6
Frequency (Hz)	114.81	178.78	283.77	770.4	776.69	1044.3
SPLIT MASS TUBE						
Mode of Resonance	1	2	3	4	5	6
Frequency (Hz)	162.46	207.09	304.63	579.74	598.54	760.84

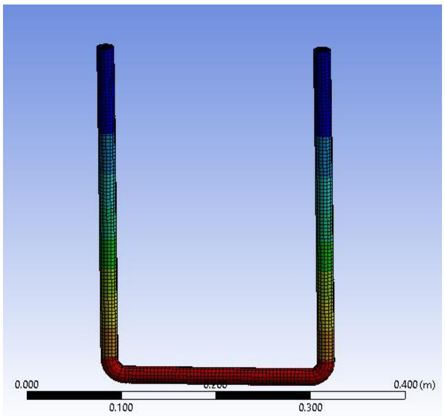

Figure: 8 1st mode of resonance of the Small mass tube at 80.36 Hz.

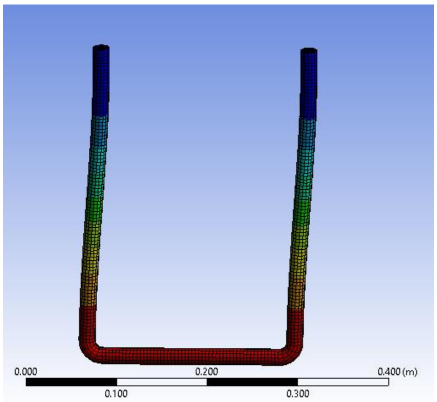

Figure: 9 2nd mode of resonance of the Small mass tube at 108.58 Hz.

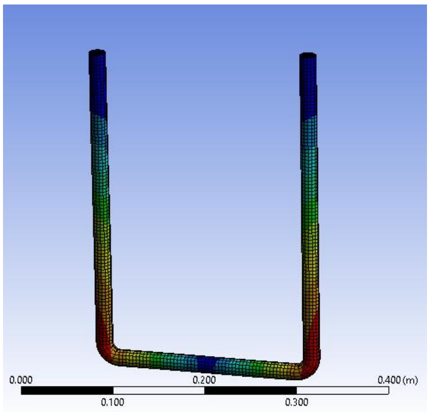

Figure:10 3rd mode of resonance of the Small mass tube at 202.24 Hz.

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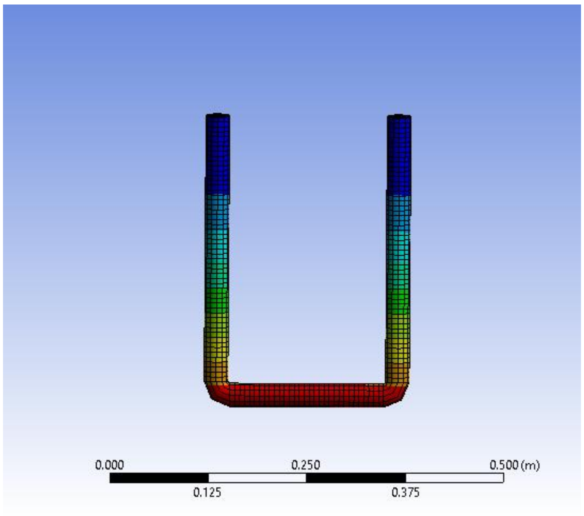

Figure:11 1st mode of resonance of the Big mass tube at 114.81 Hz.

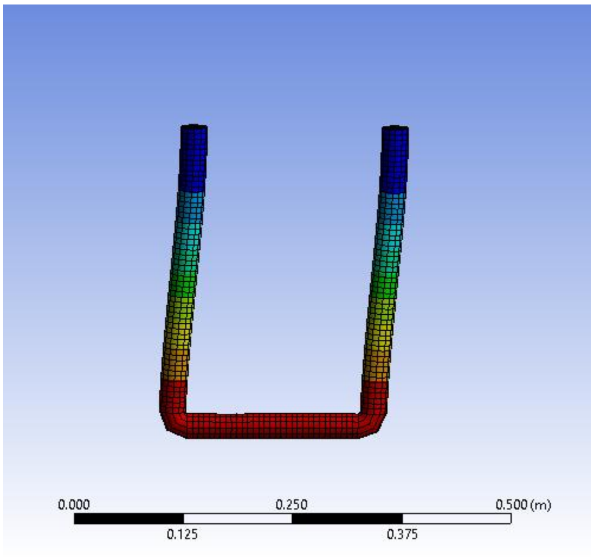

Figure:12 2nd mode of resonance of the Big mass tube at 178.78 Hz.

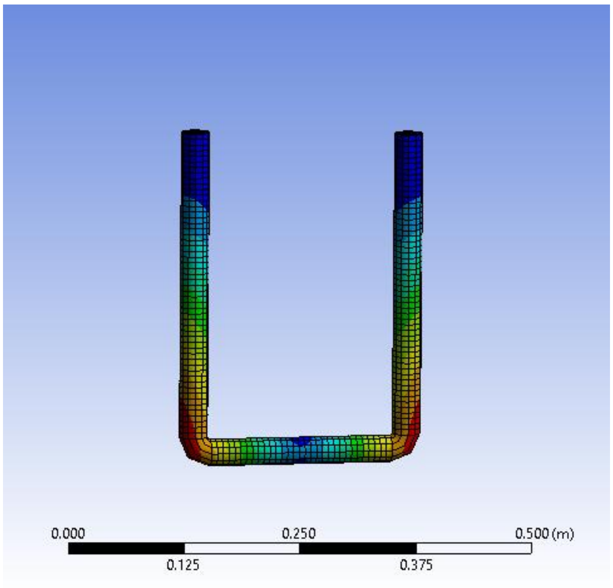

Figure:13 3rd mode of resonance of the Big mass tube at 283.77 Hz.

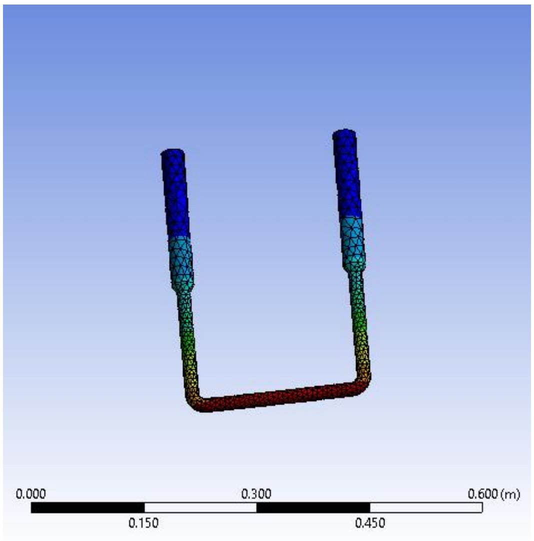

Figure:14 1st mode of resonance of the Split mass tube at 162.46 Hz.

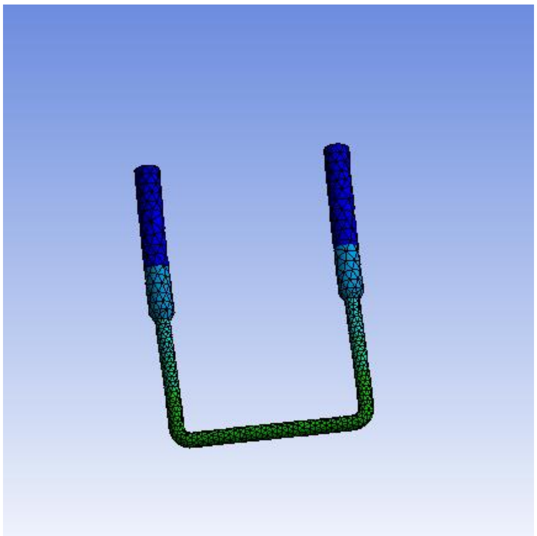

Figure:15 2nd mode of resonance of the Split mass tube at 207.09 Hz.

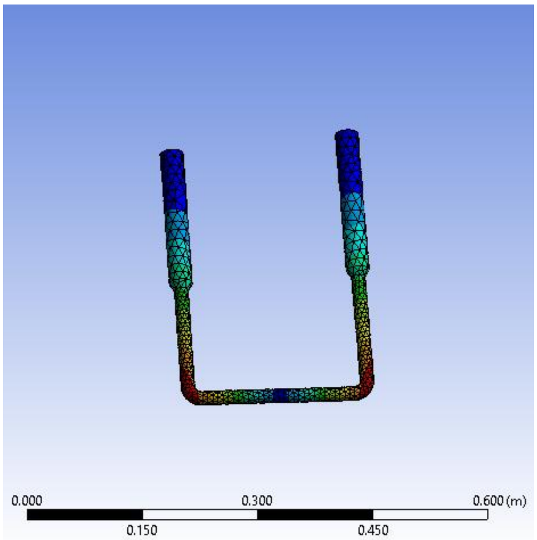

Figure:16 3rd mode of resonance of the Split mass tube at 304.63 H

V. CONCLUSION

The simulated models show the first SIX modes of resonance for all the three types of the Coriolis mass flow meter tube. It is recommended that always first mode of resonance should be opted as it will give higher amplitude of the output signal. The discussed three different models that is Small mass, Big mass and Split mass can be effectively used for the experimentation purposes to have a better understanding of the Coriolis mass flow meter technology. The Split mass type Coriolis mass flow meter as discussed earlier is under development and has a better scope because of its higher resolution and sensitivity which makes it a better choice than the convectional design approaches of the Coriolis mass flow meter tubes.

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