Finite Element Analysis of Omega Type Coriolis Mass Flow Sensor (CMFS)for Evaluation of Fundamental Frequency and Mode Shape

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Abstract - This research article highlights Omega type Coriolis Mass Flow Sensor (CMFS) used for measuring direct mass flow. CMFS works on the principle of Coriolis effect. In this research article omegatype, CMFS has been investigated for evaluatingresonant frequency. Modelling of CMFS can be split into two domains- structural and fluid. The omega shaped tube, forming the structural part and the fluid flowing through it, being modeled as a string and composing the fluid domain.Omega tube is clamped at both ends and vibrates in the x–z plane on its fundamental natural frequency. Large tube deformations are specifically countered to be absent in order to enable convergence of the solution. The measuring characteristic of the mass flow rate is phase shift, which is experienced in the motion of sensing points that are located symmetrically at the two limbs of the tube.Frequency response of omega type CMFS resonant frequency with water and without water was compared. Simulation of CMFS has been done using Ansys 14.5.Geometric properties of the measuring omega shaped tube are its tube height, internal diameter and external diameter.Solid Edge, Pro-E was used for modelling of omega shaped tube. The tube material is taken to be the same of that used in experimentation – commercially available aluminium, copper and mild Steel.Copper is selected as omega tube material and water as working fluid.

Keywords: Omega Tube, CMFS, Resonant Frequency, Excitation, Copper and FEA.

1. Introduction

Artificial Neural Network (ANN) is new field of engineering analysis. Now days it has been applied for different engineering problems[1-3]. In this research article, fluid carrying tube with omega shape has been analysed. Tube vibrates at its fundamental frequency.Flowing fluid inside tube apply forces on tube walls due to this mode shape changes [4]. Advanced coriolis mass flow sensors are independent of viscosity and density of flowing fluids. During flow inside tube generated velocity profile and obtained Reynolds number of the flow does not affect the flow meter as compared to others conventional flow meters based on volume measurements [5]. Coriolis flowmeter is also used for measuring fluid density by measuring change in natural frequency [6].Many Authors have numerically investigated working method of Coriolis flow meters. In coriolis flow meters there are no moving parts only fluid carrying flow tube vibrates with small amplitude [7-11].

Mass flow study is highly nonlinear problem. To simplify the solution, it is assumed that large deformations in fluid tube are absent. Finite Element Analysis (FEA) is an advanced technique used for complex geometry analysis. Artificial Neural Network (ANN) based model was developed for copper type CMFS [14]. The developed model has been found in agreement with experimental setup model. Modelling of CMFS using Adaptive neuro-fuzzy inference system (ANFIS)has been studied [15] to check the influence of material. The input parameters are tube material, drive frequency, sensor location and height of tube. Using various parameters performance of mass flow sensor has been predicted. Material influence is an important criterion to check the structural rigidity and performance. Material based free vibration analysis was performed for transmission system using FEA [16]. [21, 24 & 25] Author has used Fuzzy interference system tools for comparison of texture and CMFS study. Coriolis effect and new straight coriolis flow meter has been investigated by researcher [22 & 23] for further development.

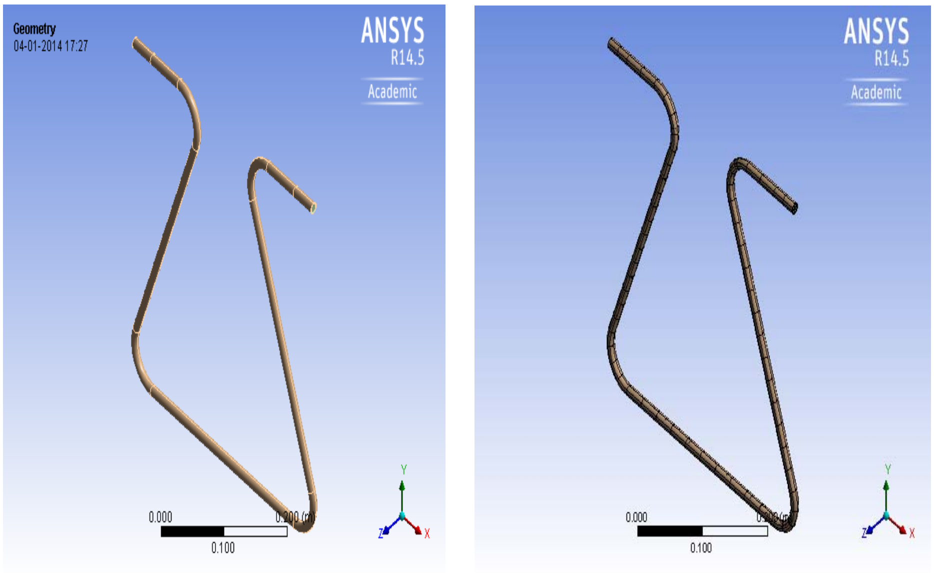
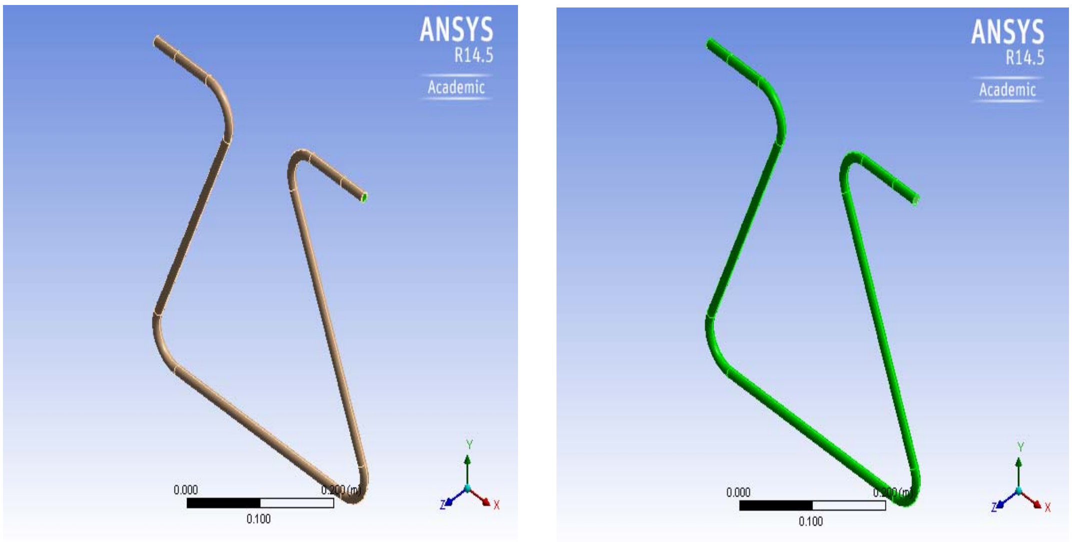


Figure 1Copper Omega tube and FEA meshed model.

2. Simulation Arrangements and Experimental Setup

Simulation and experimental investigation of coriolis mass flow sensor (CMFS) is required for direct mass measurement. Using FEA simulation fundamental frequency was obtained. An experimental test rig is required to conduct the experiments to obtain accurate results. Using theory of Coriolis phenomenon an experimental setup was prepared. Optical displacement sensors and signals processing techniqueswere implemented in setup. Foundation of test rig was prepared using rubbers pad to provide the passive isolation.

The operating test conditions are finalized and listed along with the identification of natural mode shapes for various tube configurations and materials using finite element code ANSYS [12]. Figure 1 shows the geometry and mesh model of omega tube. Geometry of omega tube is prepared using hollow tubes with specific dimensions. FEA meshed model of Cu tube consists of 6497 nodes and 1080 elements.



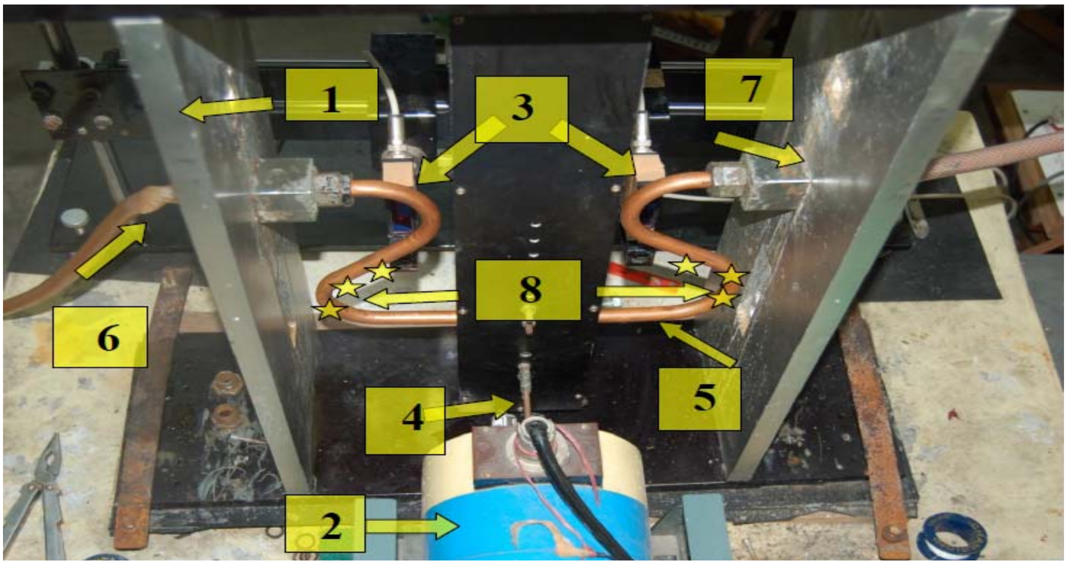


Figure 2FEA simulation arrangements and experimental test rig of Copper omega tube.

Figure 2 (a) shows simulation arrangements where ends of omega tube are constraint and water is selected as working fluid. Designing work of experimental set up was done using Pro-E [13].The actual photographs of the experimental test rig are shown in figure 2 (a). It consist of the functional elements like, Hydraulic bench (It provides continues water supply to flow meter), test bench (supporting element-used for tubes support). Mechanical excitation was provided to the flow meter using excitation system. An excitation system consists of shaker, CU (control units), Accelerometer and Vibration Meter. Optical Sensors were used for motion sensing. It eliminates the surroundings disturbance and humidity, oil. Working fluid (Water) mechanical properties are Density 1000 Kg/$m^{3,}$Young's Modulus 1.32e7 Pa, Poisson's Ratio 0.499, Bulk Modulus 2.2e9 Pa and Shear Modulus 4.4029 e6.

Omega copper tube Properties are Density 8950 Kg/m^3, Young's Modulus 1.1e11 Pa, Poisson's Ratio 0.34, Bulk Modulus 1.145 e11 Pa and Shear Modulus 4.1045 e10. Omega tube of Coriolis mass flow sensors has dual functions that impose conflicting requirements. The first function is material containment. The flow tube must be strong enough to withstand the internal pressure of the flowing material. Second function of flow tube is that it must be flexible enough so that it can readily respond to the generated Coriolis forces. A stiff flow tube that is optimized for high pressure material containment has poor flexibility and poor sensitivity to the measurement of material flow.

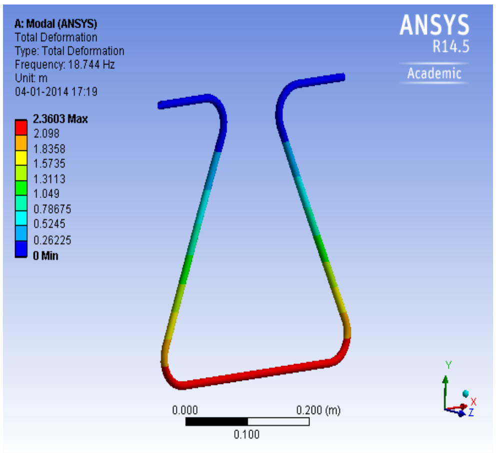
3. FEA Simulation Results and Discussion

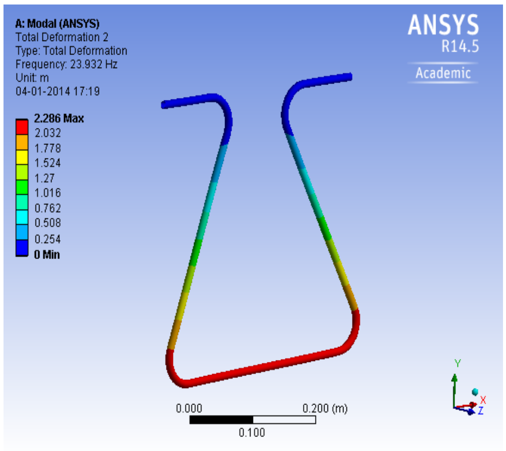
A modal analysis shows the vibration response in term of natural frequencies and mode shapes of any object. In engineering application, it is used for structures and machine components. In this research article Modal analysis serve as starting point for detailed dynamic analysis of CMFS. In dynamic harmonic or transient analysis can be performed on omega type CMFS. The output of Modal analysis is modal frequency (natural frequency) and mode shapes. These two parameters serve as important criteria in design of structure subjected to dynamic loading conditions.Varieties of tube designs are currently available like U tube flow meters. In this research article omega tube type CMFS was designed and analysed. Table 1 shows the frequency variation for omega tube Coriolis mass flow sensor. As the mass of Coriolis flow meter reduces (without water), natural frequency increases. First natural frequency is known as fundamental frequency. Omega tube resonates when it is subjected to excitation at resonance frequency. The first six-mode shape of vibration under excitation condition is shown in figure 3. Fundamental frequency is 18.744 Hz and highest frequency is 165.84 Hz.

Table 1 Natural Frequencies for Omega Tube Configurations

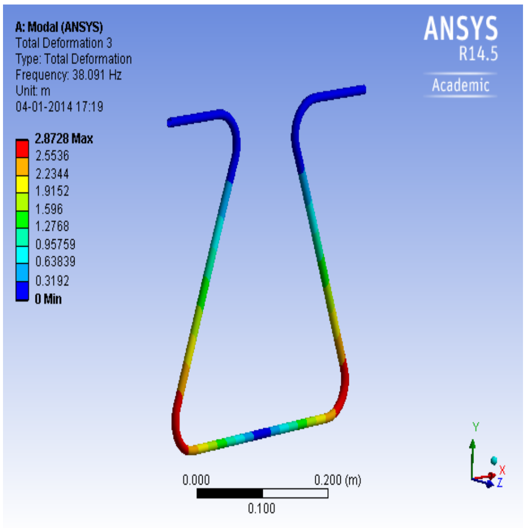
Frequency Variation (Hz)	
Cu Omega Tube(Without Fluid)	Cu Omega Tube(With Fluid)
18.744	16.756
23.932	21.415
38.091	34.055
139.57	124.76
145.32	129.84
165.84	148.19

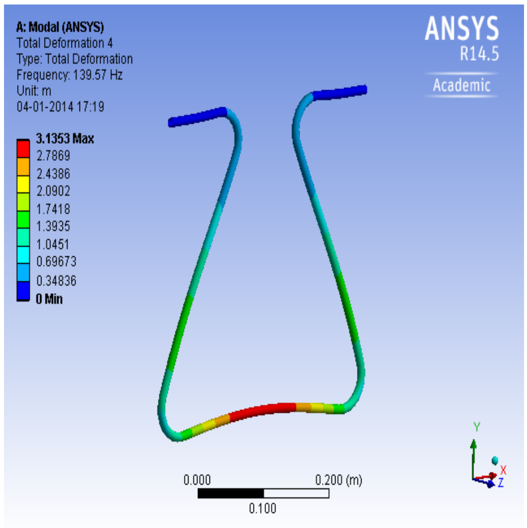
In omega type CMFS study, performing modal analysis is first step to measure physical boundary constraints (resonant frequency) because in Coriolis metering the tube is to be vibrated in its first mode of vibration. Using mode shape, it provides estimation for the experimentation phase to expect Coriolis action generation around the evaluated frequency. Phase shift between two arms of omega tube is measured using displacement sensors and this phase shift is proportional to mass flow rate. In this research article modal analysis was performed using Ansys, finite element code and results are tabled above.



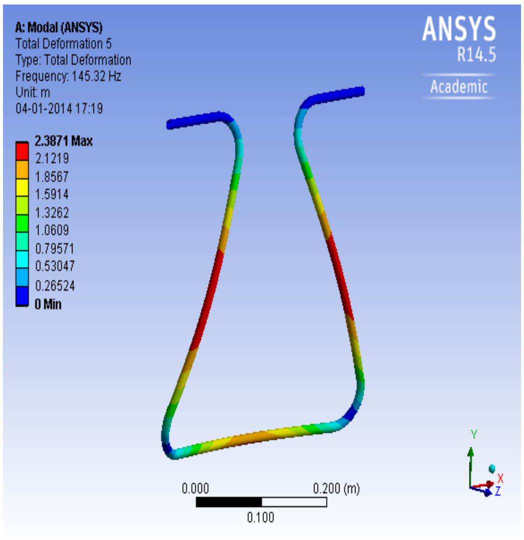


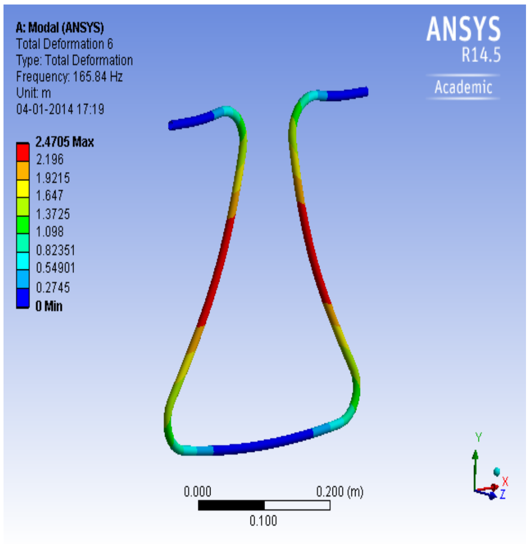
Mode 1 f1=18.744 Hz Mode 2 f2=23.932 Hz





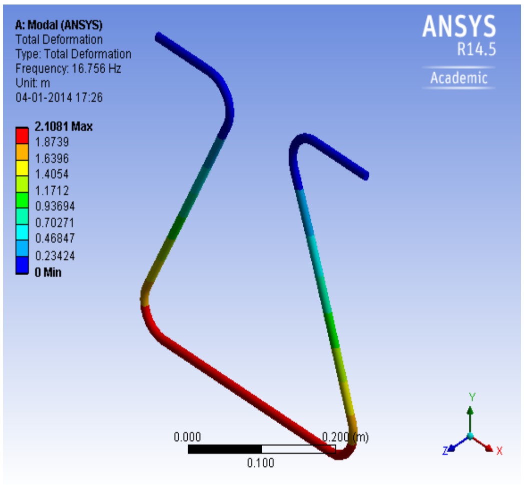
Mode 3 f3 =38.091 Hz Mode 4 f4 =139.57 Hz

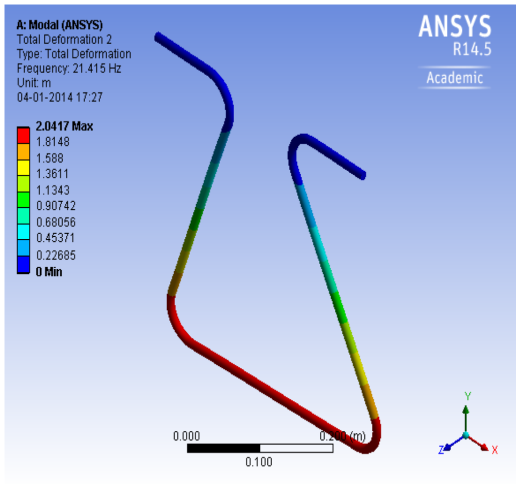




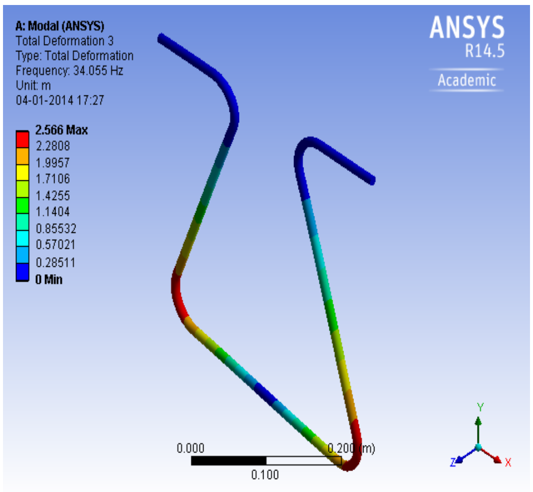
Mode 5 f5=145.32 Hz Mode 6 f6=165.84Hz

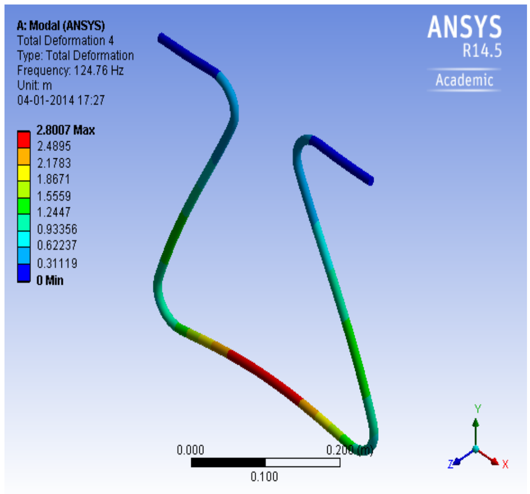
Figure 3 Frequency and mode shape variation for omega type CMFS without fluid.



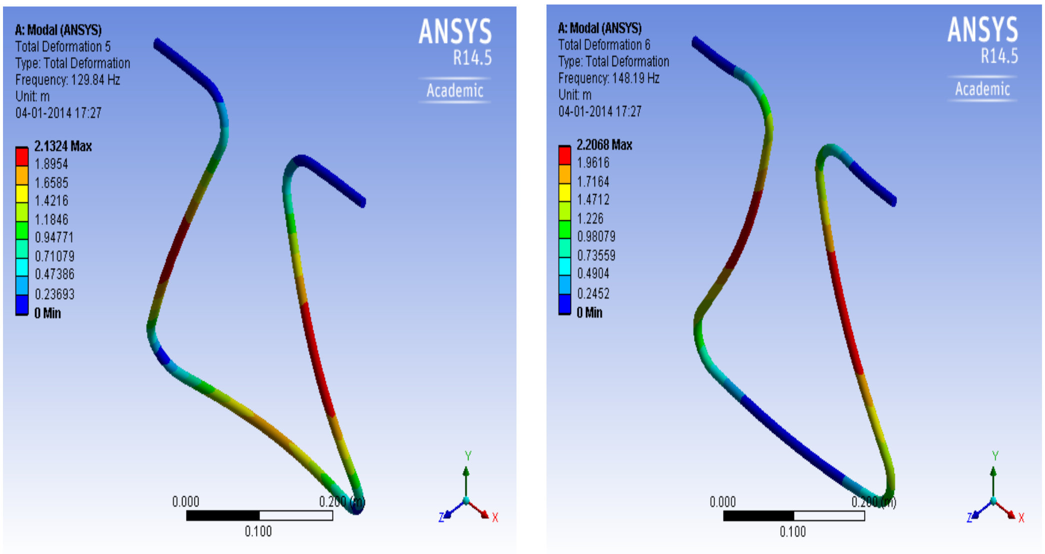


Mode 1 f1=16.756 HzMode 2 f2=21.415 Hz





Mode 3 f3=34.055HzMode 4 f4 =124.76 Hz



Mode 5 f5=129.84 HzMode 6 f6=148.19 Hz

Figure 4 Frequency and mode shape variation for omega type CMFS with fluid.

Table 1 shows the frequency variation for omega tube CMFS with fluid condition. Figure 3 & 4 shows frequency and mode shape representation. Using mode shapes in different condition, deformations level can be predicted. The fundamental frequency is 16.756 Hz that is less than 2 Hz from empty tube condition. As 148.19 is highest frequency obtained from FEA analysis with fluid condition. First natural frequency or fundamental frequency is 18.74 Hz & 16.75 Hz. These fundamental frequencies are applied for excitation and other experimental values are evaluated.

4. Conclusions

FEA based modal analysis of omega type CMFS was performed for fluid and without fluid condition. The aim of the research work has been achieved by measuring resonant frequency in both cases. The resonant frequency was obtained without fluid condition is 18.744 Hz. Others 5 natural frequencies are 23.93 Hz, 38.09 Hz, 139.57 Hz, 145.32 Hz and 165.84 Hz. Under fluid condition fundamental frequency decreases by 2 Hz (16.756 Hz). Other natural frequencies are 21.415 Hz, 34.055 Hz, 124.76 Hz, 129.84 Hz and 148.19 Hz. It shows that as mass of CMFS increases natural frequency decreases. Obtained fundamental frequency will be used for excitation of CMFS. In future this research work can be extended for experimental analysis of vibration pattern for omega type Coriolis mass flow sensor under resonant frequency.

Acknowledgment

Authors are thankful to Department of Science and Technology New Delhi for necessary funding of this research project.

References

[1] Sharma Satish C. , Pravin P. Patil , Major Ashish Vasudev, S. C. Jain, Performance Evaluation of an Indigenously Designed Copper (U)tube Coriolis Mass flow sensors, Measurement, 43(9) (2010) pp. 1165-1172.
[2] Pravin PPatil, Satish C. Sharma, S.C. Jain, Response surface modelling of vibrating omega tube (Copper) Electromechanical Coriolis mass flow sensor, Expert Systems With Applications , 39 (4) (2012) pp. 4418 – 4426.
[3] Pravin PPatil, Satish C. Sharma, S.C. Jain, Performance evaluation of a Copper omega type Coriolis Mass Flow Sensor with an aid of ANFIS tool, Expert Systems with Applications, 39 (5) (2012), pp. 5019-5024.
[4] R. Cheesewright, A. Belhadj and C. Clark, “Effect of mechanical vibrations on Coriolis mass flow meters”, Journal of Dynamic Systems, Measurement, and Control, 125 (2003), pp. 103–113.
[5] Anklin M, Drahm W, Rieder A., Coriolis mass flow meters: Overview of the current state of the art and latest research, Flow Measurementand Instrumentation, 17 (6) (2006), pp. 317-23.
[6] G. Bobovnik,N. Mole, J. Kutina, B. Stok, I. Bajsic, Coupled finite-volume/finite-element modellingof the straight-tube Coriolis flowmeter, Journal of Fluids and Structures 20 (2005), pp. 785–800.
[7] N. Mole , G. Bobovnik,J. Kutina, B. Stok, I. Bajsic, An improved three-dimensional coupled fluid–structure model for Coriolis flowmeters, Journal of Fluids and Structures 24 (2008), pp. 559–575.
[8] Tao Wang, Roger Baker, Coriolis flowmwters: A review of developments over the past 20 years and an assessment of the state of the art and likely future directions, Flow Measurement and Instrumentation 40 (2014),pp. 99-123.
[9] R.M. Saravanan, Christ W. Raj and M. Shanmugavalli, Design and Simulation of Coriolis Flow Tube in Meso and Micro Level to Determine Its Resonant Frequency, Middle-East Journal of Scientific Research 23 (Sensing, Signal Processing and Security): 23 (2015) pp. 239-242,ISSN 1990-9233. DOI: 10.5829/idosi.mejsr.2015.23.ssps.101.
[10] LuoRongmo, Wu Jian, Fluid-structure coupling analysis and simulation of viscosity effecton Coriolis mass flowmeter, APCOM & ISCM11-14th December, 2013, Singapore.

[11] SiavashHooshmandzadeh, Simulation a disposable mass flow meter by an advanced FSI modeling and finite element analysis, Master's Degree Thesis, ISRN: BTH-AMT-EX--2015/D02—SE, Department of Mechanical EngineeringBlekinge Institute of TechnologyKarlskrona, Sweden2015.
[12] Ansys R 14.5, Structural Analysis guide 2015.
[13] Pro-E 5.0, Designing manual, 2013.
[14] Pravin PPatil, Satish C. Sharma, Vipul Paliwal, Ashwani Kumar,ANN Modelling of Cu Type Omega Vibration Based Mass Flow Sensor, Procedia Technology, 14 (2014), pp. 260-265.
[15] Pravin PPatil, Satish C. Sharma, Himanshu Jaiswal, Ashwani Kumar,Modeling Influence of Tube material on vibration Based EMMFS using ANFIS, Procedia Material Science, 6 (2014), pp. 1097-1103.
[16] Ashwani kumar, Arpit Dwivedi, Himanshu Jaiswal, Pravin P Patil, Material based Vibration Characteristic Analysis of Heavy Vehicle Transmission Gearbox Casing using Finite Element Analysis, Advances in Intelligent Systems and Computing, 308 (2015), pp. 527–533. Doi:10.1007/978-81-322-2012-1_56.
[17] Chester M. Neural networks—a tutorial. Englewood Cliffs, NJ: Prentice Hall, 1993.
[18] Rumelhart D, Hinton G, Williams R. Parallel distributed processing. Cambridge, MA: MIT Press, 1986.
[19] Richard W. Miller, “Flow Measurement Engineering Handbook”, third ed., McGraw-Hill International Edition, 1996.
[20] Neural Network Toolbox User’s Guide of MATLAB 8.0, The Math Works Company, Natick, MA, 2010.
[21] E. Avci,. Comparison of wavelet families for texture classification by using wavelet packet entropy adaptive network based fuzzy inferencesystem. Applied Soft Computing, 8 (2008), pp. 225–231.
[22] F. Cascetta, SD Valle, AR Guido, S. Pagano, P. Vigo. A new straight-pipe Coriolis mass flow meter: The mathematical model.Measurement 9 (1991), 115-23.
[23] H. Raszillier, F. Durst. Coriolis effect in mass flow metering. Archive of Applied Mechanics 61 (1991), pp. 192-214.
[24] L.C. Ying, M.C. Pan. Using adaptive network based fuzzy inference system to forecast regional electricity loads. Energy Conversationand Management 49 (2008), pp. 205–211.
[25] J.S.R Jang. ANFIS: Adaptive Network-Based Fuzzy Inference System. IEEE Trans. Syst. Man Cybern23 (1993), pp. 665–685.