Omega Design and FEA Based Coriolis Mass Flow Sensor (CMFS) Analysis Using Titanium Material

Pravin P. Patil  
Department of Mechanical Engineering, Graphic Era University, Dehradun, India  
E-mail: pravinppatil2004@gmail.com

*Ashwani Kumar  
Department of Technical Education Kanpur, Uttar Pradesh, India  
*E-mail: kumarashwani.geu@gmail.com

Faraz Ahmad  
Department of Mechanical Engineering, Graphic Era University, Dehradun, India  
E-mail: faraz4433@gmail.com

Abstract. The main highlight of this research work is evaluation of resonant frequency for titanium omega type coriolis mass flow sensor. Coriolis mass flow sensor is used for measuring direct mass flow in pipe useful for various industrial applications. It works on the principle of Coriolis effect. Finite Element Analysis (FEA) simulation of omega flow sensor was performed using Ansys 14.5 and Solid Edge, Pro-E was used for modelling of omega tube. Titanium was selected as omega tube material. Experimental setup was prepared for omega tube coriolis flow sensor for performing different test. Experimental setup was used for investigation of different parameters effect on CMFS and validation of simulation results.

Keywords: Omega Tube, CMFS, FEA, Titanium, Coriolis Effect.

1. Introduction

These In practice, Coriolis type sensors are used in continuous process and parallel pipes in plant pipe systems. Coriolis mass flow sensor (CMFS) has various applications in engineering field [1-3]. S.C. Sharma [1] has performed analysis on U type copper tube and checked performance of CMFS. Pravin Patil [2] has performed optimisation of copper omega type CMFS. For optimisation they have used response surface method (RSM). ANFIS advanced tools were also used for performance evaluation of omega tube [3]. 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]. Anklin has performed literature survey of past studies in field of CMFS [5 & 8]. Coupled fluid structure model was studied [6, 7& 10] for advanced development in CMFS. Advanced coriolis mass flow sensors are independent of viscosity and density of flowing fluids.
For performing FEA simulation of omega tube fixed constraint based boundary conditions were developed in Ansys. Ashwani kumar [9 & 11] has performed the constraint based analysis on transmission gearbox using FEA. Many Authors have numerically investigated working method of Coriolis flow sensors. In coriolis flow sensors there are no moving parts only fluid carrying flow tube vibrates with small amplitude [14].

Pravin Patil [15] has investigated material properties effect on Electromechanical Mass flow sensor (EMMFS) using ANFS modelling tool. To determine resonant frequency of coriolis flow tube in meso and micro level FEA simulation was performed [18]. Fixed constraint based studies using FEA simulation is currently used for heavy vehicle dynamics analysis [16, 17 & 19]. 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.

2. FEA and Experimental Setup

Performing modal analysis of the measuring tube subjected to the physical boundary constraints is the first step of the simulation scheme. The only purpose being to ascertain the natural frequency of the tube, as in the Coriolis sensor the tube is to be vibrated in its first mode of vibration. Also, it provides estimation for the experimentation phase to expect Coriolis action generation around the evaluated frequency. Therefore, modal analysis is performed using finite element code ANSYS [12] for all tube configurations and results are tabled. The foundation of test rig was prepared using rubbers pad to provide the passive isolation.

![Model of Omega Configuration (40x40)](image1)
![Mesh model of omega tube](image2)

(a) Model of Omega Configuration (40x40)  (b) Mesh model of omega tube

**Figure 1** Omega tube configuration and FEA meshed model.
The actual photograph of the experimental test rig is shown in figure 2. It consists of the functional elements like, Hydraulic bench, excitation system. An excitation system consists of shaker, CU (control units), Accelerometer and Vibration Sensor. Working fluid (Water) mechanical properties are Density 1000 Kg/m³, Young’s Modulus 1.32e7 Pa, Poisson’s Ratio 0.499, Bulk Modulus 2.2e9 Pa and Shear Modulus 4.4029 e6. Omega titanium tube Properties are Density 4620 Kg/m³, Young’s Modulus 9.6 e10 Pa, Poisson’s Ratio 0.36, Bulk Modulus 1.1429 e11 Pa and Shear Modulus 3.5294 e10.

![Figure 2 Experimental arrangements for CMFS.](image)

### 3. FEA Results

In this study titanium omega tube type flow sensors was designed and analysed using FEA simulation method. Table 1 shows natural frequency variation for Coriolis flow sensor. In modal analysis, first natural frequency is known as fundamental frequency. It is resonance frequency for empty omega tube. The first six-mode shape of vibration under empty condition with fluid is shown in figure 3. Fundamental frequency is 19.882 Hz and highest frequency is 330.56 Hz. Table 1 shows the frequency variation for omega tube Coriolis flow sensor with fluid condition. In comparison, it was found that increased height and width of tube causes higher fundamental frequency. Fundamental frequency increases by 2.5 times in comparison to earlier titanium tube flow sensor (40x40) cm. Figure 4 shows the frequency variation for omega tube with vibration mode.
Table 1 Natural frequency for Omega Tube configuration

| Mode | Frequency (Hz) | Titanium Omega Tube (With Fluid: 40x40) |
|------|----------------|----------------------------------------|
| 1.   | 19.882         |                                        |
| 2.   | 25.443         |                                        |
| 3.   | 40.369         |                                        |
| 4.   | 148.78         |                                        |
| 5.   | 154.74         |                                        |
| 6.   | 176.78         |                                        |

Mode 1 $f_1=19.882$ Hz

Mode 2 $f_2=25.443$ Hz

Mode 3 $f_3=40.369$ Hz

Mode 4 $f_4=148.78$ Hz
Figure 3 Frequency and mode shape variation.

Figure 4 Frequency variation graph.
4. Conclusion

Solid Edge and Pro-E has been used for modelling of omega tube. Ansys has been used for FEA analysis. FEA based modal analysis of titanium omega tube was performed for omega tube to evaluate vibrating frequencies and mode shapes. The resonant frequency was measured in Hz. For titanium omega tube dimension (40x40) c.m. was selected. For this resonant frequency is 19.882 Hz. Others 5 natural frequencies are 25.443 Hz, 40.369 Hz, 148.78 Hz, 154.74 Hz and 176.78 Hz. By evaluating fundamental frequency the first step of this research work has been completed. Next step is to perform experimental simulation corresponding fundamental frequency at 19.882 Hz. In future this research work can be extended for experimental analysis of Coriolis flow sensor under sensor location variation and mass flow rate variation.

Acknowledgment

Authors are thankful to Department of Science and Technology (DST, New Delhi) for necessary funding of this project.

References

[1] S. C. Sharma, P. P. Patil, M. A. Vasudev and S. C. Jain, “Performance evaluation of an indigenously designed copper (u) tube coriolis mass flow sensors,” Measurement, Vol. 43(9), pp. 1165-1172, 2010.

[2] P. P. Patil, S. C. Sharma and S.C. Jain, “Response surface modelling of vibrating omega tube (copper) electromechanical coriolis mass flow sensor,” Expert Systems with Applications, Vol. 39 (4), pp. 4418 – 4426, 2012.

[3] P. P. Patil, S. C. Sharma and S.C. Jain, “Performance evaluation of a copper omega type coriolis mass flow sensor with an aid of ANFIS tool,” Expert Systems with Applications, Vol. 39 (5), pp. 5019-5024, 2012.

[4] R. Cheesewright, A. Belhadj and C. Clark, “Effect of mechanical vibrations on coriolis mass flow meters”, Journal of Dynamic Systems, Measurement, and Control, Vol. 125, pp. 103–113, 2013.

[5] M. Anklin, W. Drahm and A. Rieder, “Coriolis mass flow meters: overview of the current state of the art and latest research,” Flow Measurement and Instrumentation, Vol. 17 (6), pp. 317-23, 2006.

[6] G. Bobovnik, N. Mole, J. Kutina, B. Stok and I. Bajsic, “Coupled finite-volume/finite-element modelling of the straight-tube Coriolis flowmeter,” Journal of Fluids and Structures, Vol. 20, pp. 785–800, 2005.

[7] N. Mole, G. Bobovnik, J. Kutina, B. Stok and I. Bajsic, “An improved three-dimensional coupled fluid–structure model for Coriolis flowmeters,” Journal of Fluids and Structures, Vol. 24, pp. 559–575, 2008.

[8] T. Wang and R. Baker, “Coriolis flowmeters: 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 Vol. 40, pp. 99-123, 2014.

[9] A. Kumar and P.P. Patil, “FEA simulation based performance study of multi speed transmission gearbox,” International Journal of Manufacturing, Materials, and Mechanical, Vol. 6 (1), pp. 51-61, 2016.
[10] L. Rongmo and W. Jian, “Fluid-structure coupling analysis and simulation of viscosity effect on Coriolis mass flowmeter,” APCOM & ISCM 11-14th December, Singapore, 2013.

[11] A. Kumar, A. Dwivedi, H. Jaiswal and P.P. Patil, “Material based vibration characteristic analysis of heavy vehicle transmission gearbox casing using finite element analysis,” Intelligent Computing, Communication and Devices, Vol. 308 of the series Advances in Intelligent systems and Computing pp 527-533, 2015. DOI: 10.1007/978-81-322-0212-1_56.

[12] Ansys R 14.5, Structural Analysis guide 2015.

[13] Pro-E 5.0, Designing manual, 2013.

[14] P. P. Patil, S. C. Sharma, V. Paliwal and A. Kumar, “ANN modelling of Cu type omega vibration based mass flow sensor,” Procedia Technology, 14 (2014), pp. 260-265.

[15] P. P. Patil, S. C. Sharma, H. Jaiswal and A. Kumar, “Modeling influence of tube material on vibration based EMMFS using ANFIS,” Procedia Material Science, 6 (2014), pp. 1097-1103.

[16] A. Kumar, H. Jaiswal, A. Pandey and P.P. Patil, “Free vibration analysis of truck transmission housing based on FEA,” Procedia Materials Science, Vol. 6, pp. 1588-1592, 2014.

[17] A. Kumar and P.P. Patil, “Dynamic vibration analysis of heavy vehicle truck transmission gearbox housing using FEA,” Journal of Engineering Science and Technology Review, Vol. 7 (4), pp. 66-72, 2014.

[18] 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 Vol. 23 pp. 239-242, 2015. DOI: 10.5829/idosi.mejsr.2015.23.ssps.101.

[19] P.P. Patil and A. Kumar, “Dynamic structural and thermal characteristics analysis of oil-lubricated multi speed transmission gearbox: variation of load, rotational speed and convection heat transfer,” Iranian Journal of Science and Technology- Transactions of Mechanical Engineering, doi:10.1007/s40997-016-0063-z, 2016, in press.