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Application of Numerical and Experimental Simulations for the Vibrating Systems with Three Degrees of Freedom

J.O.Kiran[1] and D.Shivalingappa[2]
[1]*Associate Professor, Department of Mechanical Engineering, S.T.J Institute of Technology, Ranebennur, Karnataka, India,*
[2]*Professor, Department of Mechanical Engineering, Adhiyamaan College of Engineering, Hosur, Tamilnadu, India,*

Abstract:- In this work,there may be some requirements of finding out the coupling loss factors of system component.It becomes difficult to exactly know the coupling loss factor by looking at the behavior of the system. For this purpose, the numerical solution developed in this work. Initially, one need to extract the displacement, velocity and energy profiles of the system which has got the components installed for which the coupling loss factor need to be determined. Then the numerical simulations can be run for different coupling loss factor of the vibrating system and the coupling loss factor can be found when the simulation results match with the experimental measurements. In this paper the experimentation is carried out i for the model a)Pre-design application of the work developed. b) Post design application of the work developed. The numerical results converge very well towards the experimental results as the coupling loss factor in simulation is varied towards the actual value. Similarly, for the second approach the experimental results converge towards the simulation results of 0.15 as the coupling loss factor of the damper that is installed on the system is varied towards 0.15.

Keywords:- *Coupling Loss Factor, Damper, Transient excitation,*

I. INTRODUCTION

The theory of vibration deals with the systematic analysis of vibratory motions of the body and the forces involved in it. Vibration is a repetitive, periodic, or oscillatory response of a mechanical system.Vibration or oscillation may be defined as any structural deformation that repeats itself periodically [1-2].The kinetic energy is stored due to the mass of the structure, potential energy is stored due stiffness and the energy is dissipated due to damping. If the damping is insufficient, the structure that is vibrating at a resonant frequency tends to result in high amplitudes which radiates sound and might ultimately lead to structural failure. Hence it is essential to calculate or predict the resonant frequencies and prevent the structure from high amplitude vibrations by providing sufficient structural damping [3] inside the structure.

There are two types of damping that are inherently present in any structure [4], namely, internal damping of the structure and structural damping at the joints in the structure.

Due to the presence of dynamic loads, the visco-elastic material dissipates energy in the form of heat energy by disrupting the bonds of its long-chain molecules [5].In vibration analysis, physical system can be represented in the form of mathematical model and it is important for analysis to translate mathematical equations and formulations into real conclusions [6].Most engineering systems are continuous and have an infinite number of degrees of freedom. The vibration analysis of continuous systems requires the solution of partial differential equations, which is quite difficult [7].Using the two approaches, one can determine the coupling loss factor of a component that is already present in the design and also one can manufacture a component for a desired coupling loss factor. The first approach can be used in post-design phase and the second one can be used in pre-design phases.

- Variation of numerical results with experimental results of a damper already installed in the system.
- Change of dampers in the physical system until experimental results match numerical

II. ANALYTICAL MODEL

The analytical model ofThree degrees of freedom system is developed and the governing equations are derived and they are represented in the matrix form. By solving the governing equations, the energy stored in the form of kinetic energy and potential energy in the model can be estimated.

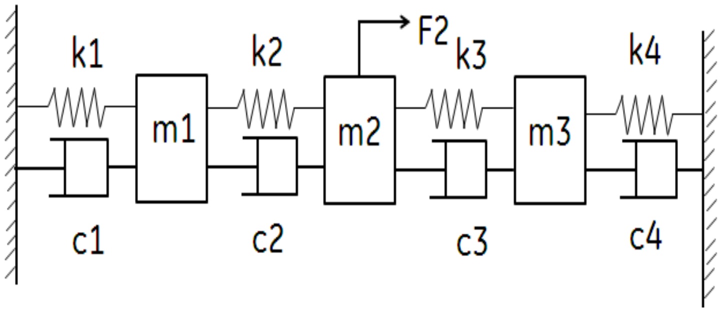


Fig. 1 Mathematical Model for Coupling Loss Factor Estimation

Fig.1 shows the spring mass damper system with three degrees of freedom for model respectively. Let m_1, m_2 and m_3 represent masses which are connected to four springs of stiffnesses represented by k_1, k_2, k_3 and k_4. The force F_2 acts on mass m_2 and the energy is transferred to other masses through the springs and a part of the energy is absorbed by dampers. Springs k_1 and k_4 dampers c_1 and c_4 are attached to rigid surfaces. The spring mass damper system is represented by the following equations.

$$m_1\ddot{x}_1 + (c_1 + c_2)\dot{x}_1 - c_2\dot{x}_2 + (k_1 + k_2)x_1 - k_2x_2 = 0 \quad (1.0)$$

$$m_2\ddot{x}_2 + (c_2 + c_3)\dot{x}_2 - c_2\dot{x}_1 - c_3\dot{x}_3 + (k_2 + k_3)x_2 - k_2x_1 - k_3x_3 = F_2 \quad (1.1)$$

$$m_3\ddot{x}_3 + (c_3 + c_4)\dot{x}_3 - c_3\dot{x}_2 + (k_3 + k_4)x_3 - k_3x_2 = 0 \quad (1.2)$$

The above three governing equations can be represented in matrix form as

$$M = \begin{pmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{pmatrix} \quad (1.3)$$

$$C = \begin{pmatrix} c_1 + c_2 & -c_2 & 0 \\ -c_2 & c_2 + c_3 & -c_3 \\ 0 & -c_3 & c_3 + c_4 \end{pmatrix} \quad (1.4)$$

$$K = \begin{pmatrix} k_1 + k_2 & -k_2 & 0 \\ -k_2 & k_2 + k_3 & -k_3 \\ 0 & -k_3 & k_3 + k_4 \end{pmatrix} \quad (1.5)$$

$$F = \begin{Bmatrix} 0 \\ F_2 \\ 0 \end{Bmatrix} \quad (1.6)$$

$$M\ddot{x} + C\dot{x} + Kx = F \quad (1.7)$$

$$\begin{pmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{pmatrix}\begin{Bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \\ \ddot{x}_3 \end{Bmatrix} + \begin{pmatrix} c_1 + c_2 & -c_2 & 0 \\ -c_2 & c_2 + c_3 & -c_3 \\ 0 & -c_3 & c_3 + c_4 \end{pmatrix}\begin{Bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{Bmatrix} + \begin{pmatrix} k_1 + k_2 & -k_2 & 0 \\ -k_2 & k_2 + k_3 & -k_3 \\ 0 & -k_3 & k_3 + k_4 \end{pmatrix}\begin{Bmatrix} x_1 \\ x_2 \\ x_3 \end{Bmatrix} = \begin{Bmatrix} 0 \\ F_2.e^{-\omega t} \\ 0 \end{Bmatrix} \quad (1.8)$$

III. EXPERIMENTAL SETUP FOR TRANSIENT EXCITATION FOR PRE-DESIGN APPLICATION

The transient excitation is one of the simple excitation method and the structure is vibrated by hammer impact. The three plate system is used for the transient excitation and the experimental setup is shown in Fig.2. The number of measurement samples was taken at each time intravels at different positions of the accelerometer. The hammer excitation made at different positions,the measurements and the excitation points are shown in Fig. 3.

3.1 DETAILS OF EXPERIMENTAL SETUP

The experimental setup consists of a three plates which are connected with bolt and nuts. One bolt each consists of one contact point, the plates are joined by a spacer of 20mm thick having outside diameters of spacer is 40mm and inside diameter is 20mm the thickness is 20mm. Eight spacers are used made up of aluminum material. The spacers are replaced with the dampers for different cases,during the experimentation for different models. All the four edges of the plates are free.The four connecting locations are away from the edges. The details of the three plate system are shown in Fig.2. In this configuration three plates connected at discrete points using bolts with a small gap between them.

The three plates are identical and they are numbered as 1,2& 3. Plate 2 are inner plate and plate 1&3 are outer plates. It is to be noted that plate 2 is not connected to plate1 or 3.The plate 1 and plate 3 are fixed to the frame through the bolts, but they are coupled through the spacers.

Each plate has dimensions of 1100mm x 900mm.the thickness of each plate is 2mm.the plate used is aluminum material. The young's modulus of the material is 7.0x 10^{10}N/m^2 and the Poisson's ratio is 0.3. The density of material is 2800 Kg/m^3.

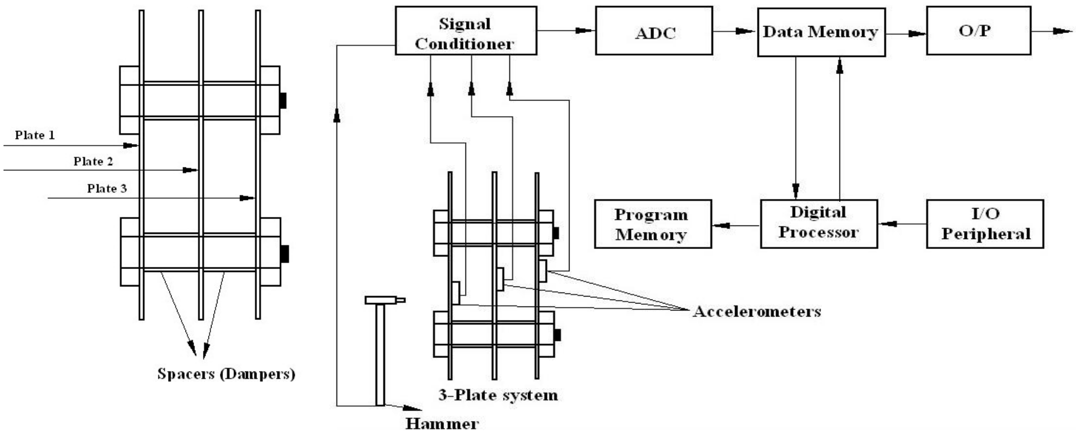


Fig 2 Experimental Setup for transient excitation for pre-design Application

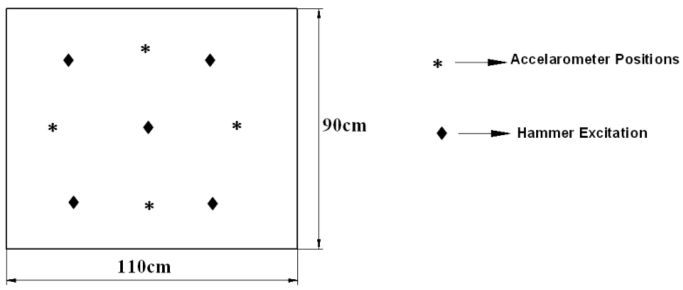


Fig.3 Measurement and excitation points for hammer excitation

3.2 Post-design application

In the present setup, researcher is given a component for installation as damper and the measurements were taken for the associated energies. The component that was installed has a coupling loss factor of 0.075 and it is not known to the researcher. The Researcher was asked to determine the coupling loss factor of the dampers. Measurements were taken for the energies.

The total energy transferred ie, kinetic energy and the potential energy of the different oscillators are simulated with the different coupling loss factor because of limitation in the measurement of coupling loss factor measurement for analyising the high frequency of vibration in power input method the coupling loss factor is in the range of 0.001 to 0.5[44]. The simulation results are plotted for the different coupling loss factors shown in Fig.4 for different oscillators. The experimentation is carried out for the coupling loss factor 0.075 to check the validity of the simulation results

3.3 Experimental results ofPost-design application:

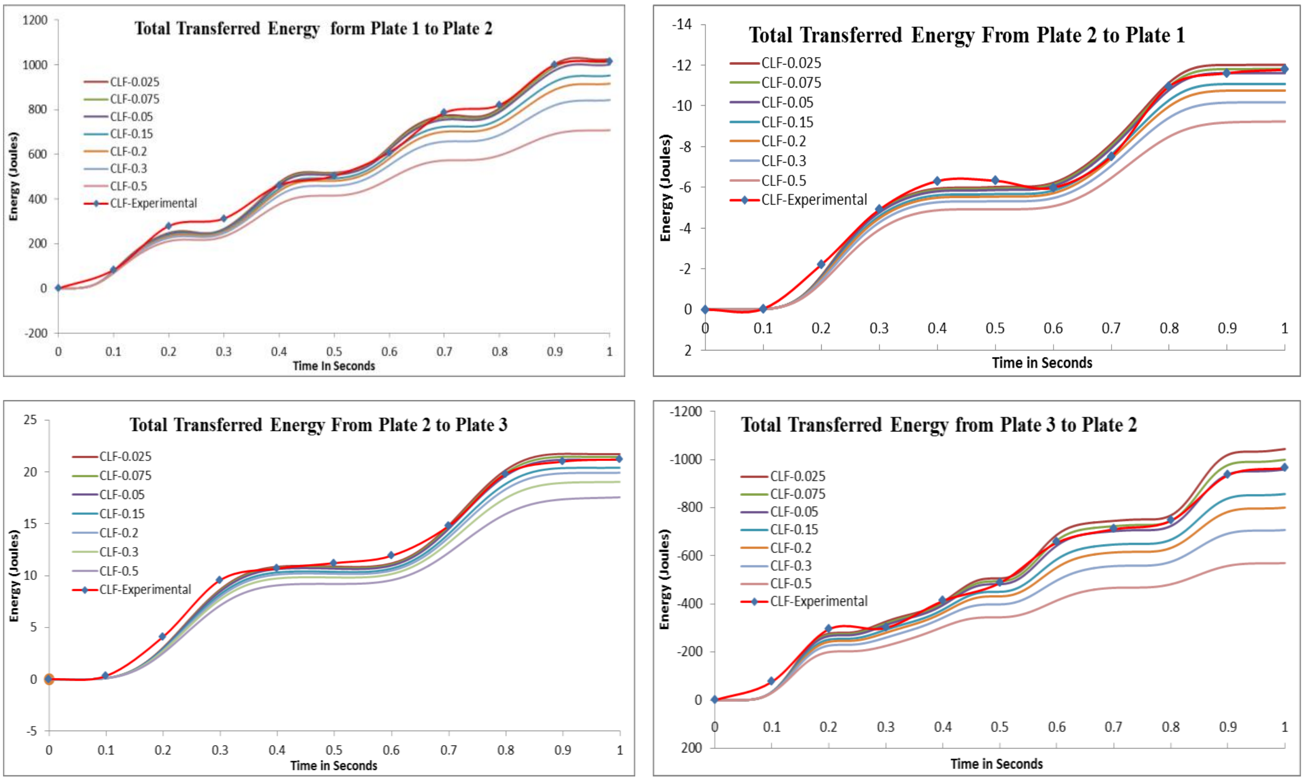
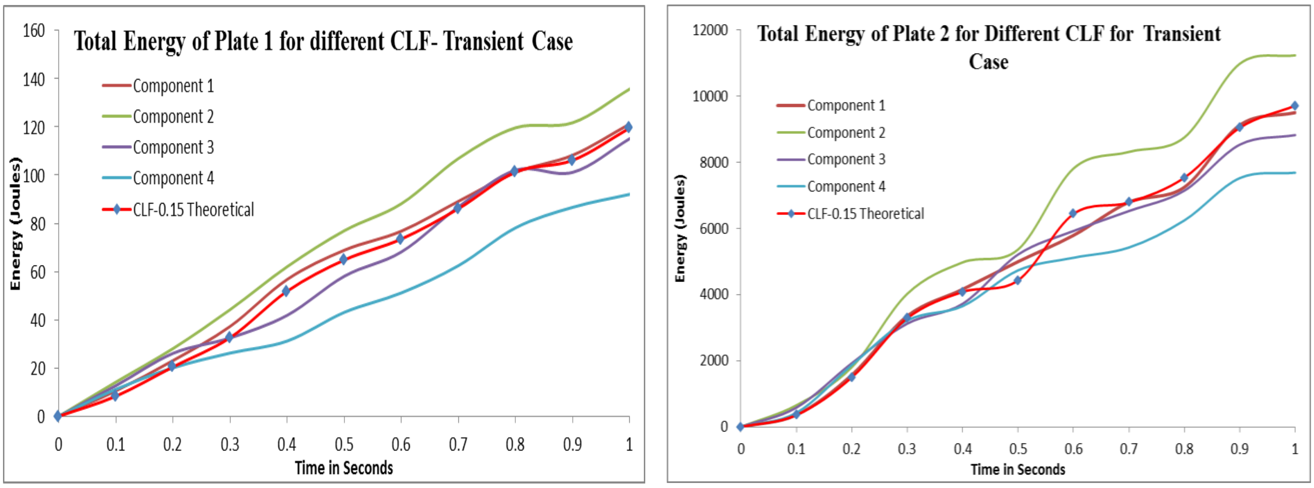


Fig.4 Energy transfer from plates for different CLF with Experimental CLF of 0.075

Initially the experimental measurements were made for a component installed on the vibrating system. The values are plotted in Fig.4 for different plates(Oscillators) on Coupling Loss Factor experimental. The numerical simulation were run starting from CLF 0.50 and ended at a CLF of 0.025. By observing the comparisons made in the Fig.4 it is concluded that the experimental measurements matches very well with a simulation case of CLF 0.075.Hence this CLF of the components is 0.075.

3.4. Pre-design application:

In some of the applications of the design, one needs to simulate the vibration levels of the system and at certain desired vibration behavior, the parameters of the design are frozen. Based on the design needs the components of the vibration system need to be manufactured. It is difficult to manufacture the components to exactly match with the design requirements. For this purpose, several components can be manufactured and are experimentally verified to match with the desired numerical results. The following results describe the procedure adopted.



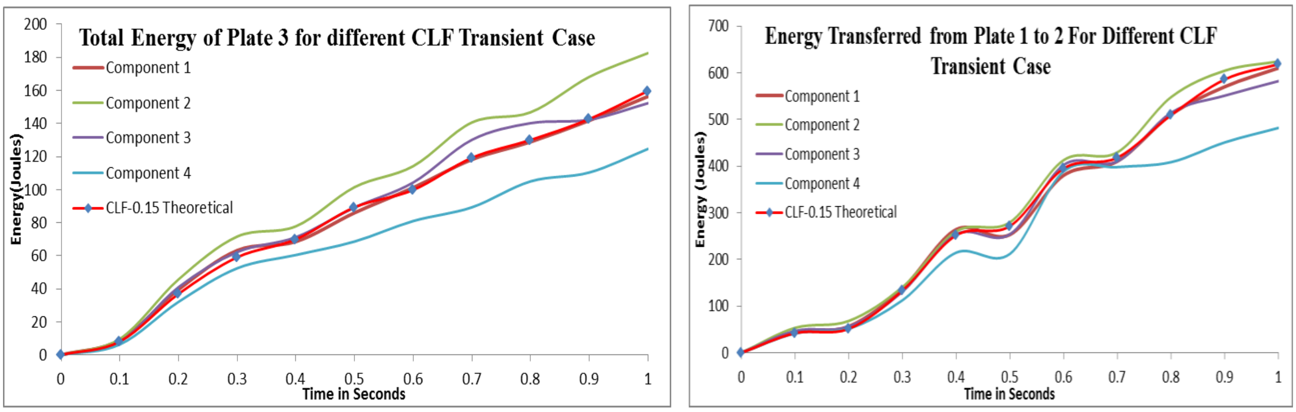


Fig.5 Energy transferred from plates for different Coupling Loss Factorwith theoretical fixed CLF-0.15

IV. CONCLUSIONS

In the first approach, the energies stored in the plates or oscillators are experimentally determined. The simulations are run for various cases of coupling loss factors from 0.025 to 0.5. The energies stored in as well as energies transferred out of the three plates are extracted for the time up to 1 Sec and is compared with that of the numerical results. The experimental and numerical results match well for the case of the coupling loss factor of 0.075. In order to verify this approach, the damper with a known coupling loss factor was installed on the vibrating system, without providing the knowledge about this to the researcher. The numerical results converge very well towards the experimental results as the coupling loss factor in simulation is varied towards the actual value.

Similarly, for the second approach, numerical results are taken from the MATLAB for a case of coupling loss factor of 0.15 and are verified against the experimental results for different dampers that are installed one after the other on the system. In this case also, the experimental results converge towards the simulation results of 0.15 as the coupling loss factor of the damper that is installed on the system is varied towards 0.15.

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BIOGRAPHIES

J.O. Kiranis having total twelve years of experience in teaching Mechanical and Machine Design Engineering subjects. He is working in the area of vibration analysis and design engineering. He has industrial experience in the field of Hydraulics. He has supervised 16 undergraduate projects and 03 post graduate projects. He has presented many research papers in the international and national conference and journals.

Dr. D. Shivalingappa received Ph.D degree from IIT Roorkee India. He is working in the area of Vibration Analysis, Design Engineering Composite Materials. He has supervised 9 postgraduate projects and 29 undergraduate projects. Currently he is supervising 3 Ph.D projects and 4 postgraduate projects. He has published 21 research papers in journal/ conferences of national and international repute.