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Material Selection of Compliant Mechanism for Vibration Isolation

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The flexible material is always absorbing some energy and reflects it. This concept was adopted from complaint mechanism principle and it was developed with the help of topology optimization technique. An innovative idea is used these principles to create a new design to absorb the vibration in the machine shop, through an innovative design model and analysis ware discussed. This paper gives a different material selection for design of compliant mechanism and also outline about the complaint mechanisms principle and shows how it is useful in mechanical field. Recently this technique is developed with the help of advanced design and also combination of some other technique. A study has been made in this for different materials.

Keywords: Compliant Mechanism, topology optimization, Harmonic analysis, isolation, material selection.

1. Introduction

1.1. *Compliant mechanism*

A compliant mechanism [6] is the mechanism that relies on its own elastic deformation to transfer or transform motion or force. Common compliant mechanisms function under the application of force at certain location (input) and generate desired force or deflection at another location (output), but uses flexible members instead of joints or links like that of a rigid–body since the deformations of flexible members provide the mobility of the mechanism. The comparison between the rigid–body mechanism and compliant mechanism is illustrated in Fig. 1. The paper proposes compliant mechanisms as a means to provide efficient and low cost vibration isolation [18]. Due to their monolithic (joint less) construction, compliant transmissions offer many inherent benefits including low cost, zero backlash, ease of manufacture, and scalability. Although leaf springs and cantilever beams employed in previous research are in effect of "Compliant mechanisms", the motion amplification mechanism proposed in this research offers a more effective solution. Analysis and design of compliant mechanisms require due attention to kinematics and mechanics of elastic deformations [6]. Different methods have emerged in the last two decades. One, known as the pseudo–rigid–body model approach [7, 8], models elastic effects using a lumped torsional spring at a revolute joint and uses the well–established principles of kinematic analysis and design with appropriate changes as necessary. It has been applied to a number of practical applications and is also extended beyond planar applications to spatial [14] and spherical linkages [9]. Newer approaches are now emerging where in building blocks are used to develop compliant designs [4, 11].

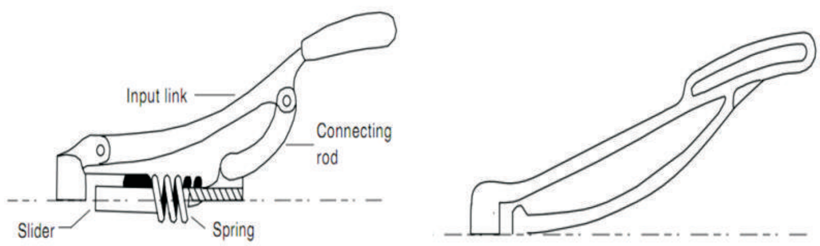

Figure 1 The comparison of rigid–body crimping mechanism (left) and compliant crimping mechanism (right)

1.2. *Topology optimization*

In this homogenization design method is adopted. Homogenization based topology optimization [1, 2, 12] is the basis for the design technique proposed in this research. Topology and size optimization methods are used to design compliant mechanisms the design procedure followed are size optimization of the beam–element abstraction derived from the continuum topology solution. The topology optimization problem is formulated as a problem of finding the optimal distribution of materials [10, 17] in an extended fixed domain where some structural cost function is maximized. This work of topology optimization is carried out by using ANSYS [5, 3] by this the optimum material distribution is obtained [8]. These elements are arranged in such a manner that to reduce the amount of force transmitted by using trial and approximation method. Stability analysis in compliant mechanism [13, 15] design is of utmost importance. From a practical point of view, a compliant mechanism is unstable of no significance. A stable system is defined as a system with a bounded system response. That is, if the system is subjected to a bounded input or disturbance and the response is bounded in magnitude, then the system is said to be stable.

1.3. *Vibration isolation*

Vibrations are produced in machines having unbalanced masses. These vibrations will be transmitted to the foundation upon which the machines are installed. This is usually undesirable, to diminish the transmitted forces, machines are usually mounted on springs or dampers (Fig. 2), or on some other vibration isolation material. Vibration Isolation reduces the level of vibration transmitted to or from a machine, building or structure from another source.

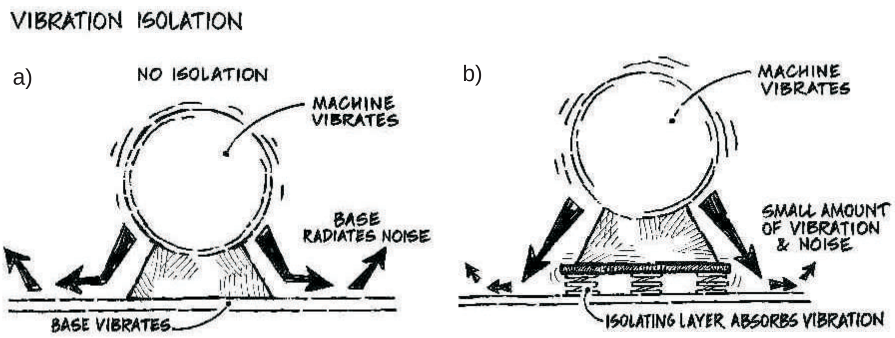

Figure 2 a) Directly mounted, b) Mounted through isolators

For damped system transmissibility:

$$T = \sqrt{\frac{1 + R^2/Q^2}{(1 - R^2)^2 + R^2/Q^2}} \tag{1}$$

$$Q = \frac{1}{2C/C_C} \tag{2}$$

The level of isolation achieved depends on the ratio:

$$R = \frac{f_e}{f_u} \tag{3}$$

where:

f_e – frequency of disturbing vibration,

f_u – natural frequency of isolator.

Transmissibility:

> 1 – increased transmitted vibration,

$= 1$ – no vibration isolation,

< 1 – vibration isolation.

If no damping is present in isolators i.e. C/Cc = 0.

Vibration Control involves the correct use of a resilient mounting or material in order to provide a degree of isolation between a machine and its supporting construction. A condition should be achieved where the amount of vibration transmitted from the machine or to the machine is at an acceptable level.

To achieve efficient vibration isolation is necessary to use a flexible support with sufficient elasticity. So that the natural frequency fn of the isolated machine is substantially lower that the disturbing frequency fe of vibration. The relation fe / fn should be better than 1.4 and ideally better than 2 to 3 in order to achieve a significant level of vibration isolation.

2. Design of compliant mechanism using topology optimization

By using the topology optimization the compliant mechanism is designed. The topology optimization predicts the optimal distribution of the material in the design domain. It is very promising for systematic design of compliant mechanism because topological design is automated by the given prescribed boundary conditions. Its success relies very much on the problem formulation. The topological design of compliant mechanism is solved as a problem of material distribution using the optimality criteria method.

2.1. *Topology optimization for vibration isolator using FEA*

Topological optimization is a form of ”shape” optimization sometimes referred to as ”layout” optimization. The goal of topological optimization is to minimize/maximize the criteria selected (minimize the energy of structural compliance, maximize the fundamental natural frequency, etc.) while satisfying the constraints specified (volume reduction, etc.).

The problem is defined for linear elastic analysis. Then define material properties (Young's modulus, Poisson's ratio, and possibly the material density). Then select the element 2D plane 2 types for topological optimizations generate a finite element model.

Fig. 3 illustrates based on volume constraints for the specific load of 85kN and the force transfer path is identified for structural size of 500mm width and 165mm height. The optimized path for the transfer of maximum force is obtained using topology optimization.

2.2. *Numerical experiments for topology optimization problem*

In this example the boundary condition specified as all the corners of the design domain is fixed and a point load is applied at the middle of the bottom face. The material property and the design variable and domain dimension are given below in Tab. 1.

Table 1 Specifications for topology optimization

Design domain	500 mm × 305 mm × 165 mm
Young's modulus	200 GPa
Poisson's ratio	0.29
Input force	85 kN
Upper limit of design variable	10 mm^2
Lower limit of design variable	0.1 mm^2
Output displacement at output port	25 mm

3. Proposed approach of compliant mechanisms and passive vibration isolation

We propose compliant mechanisms as a means to provide efficient and low cost vibration isolation. Due to their monolithic (joint less) construction, compliant transmissions offer many inherent benefits including low cost, zero backlash, ease of manufacture, and scalability. Although leaf springs and cantilever beams employed in previous research are in effect of "Compliant mechanisms", the motion amplification mechanism proposed in this paper offers a more effective solution. Fig. 4 illustrates how a compliant mechanism can be integrated into a vibration isolation system.

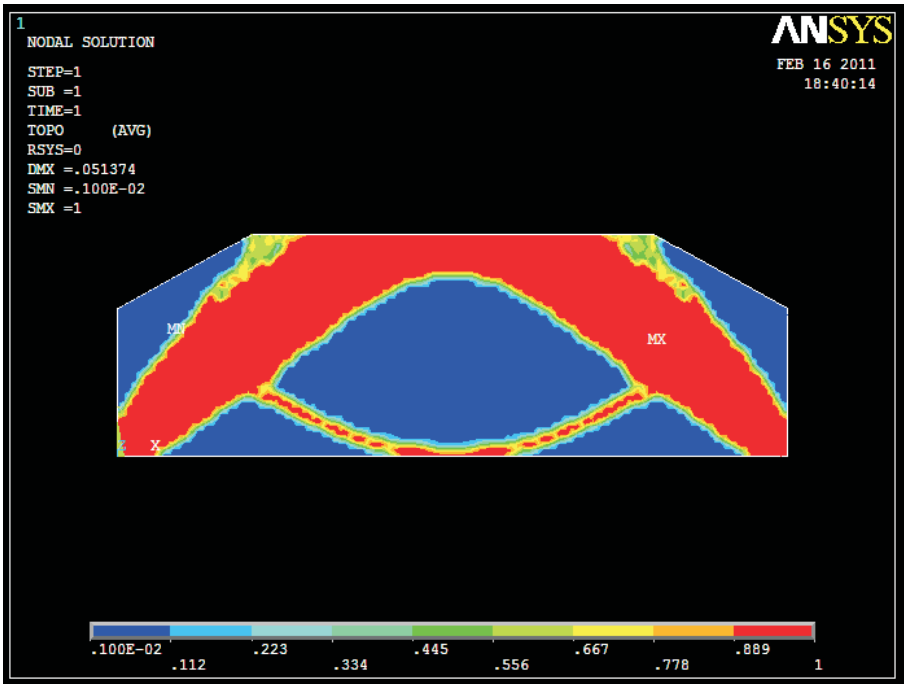

Figure 3 After 50% of volume reduction

The scope of this study is limited to low frequency isolation because the use of compliant mechanisms in active vibration isolation systems has the greatest advantage in the low frequency range. Since many passive systems are effective and sufficient for high frequency isolation, the need of active systems for high frequency isolation is less than that for low frequency isolation. We also focus on understanding the effects of the compliant design parameters and attempt to solve problems systematically. The preliminary results of FEA from ANSYS demonstrate that a compliant mechanism can be effectively used to reduce the amount of force transmitted to the surface.

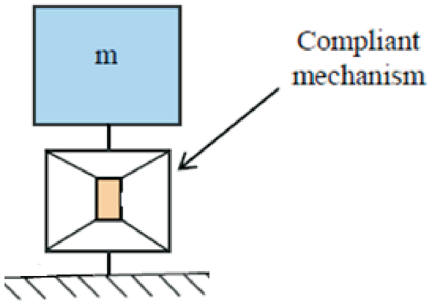

Figure 4 Models illustrating the concept of using a compliant mechanism in passive vibration isolation

4. Material selection for compliant mechanism

Material for this compliant mechanism is selected based (equation 4, 5, 6, 7) on the Young's modulus which includes natural frequency and area moment of inertia and mass and also cross sectional area of compliant beam. Following equations are used for material selection.
Natural frequency of compliant mechanism:

$$\omega_n = \sqrt{\frac{k}{m}} \tag{4}$$

Material constant:

$$k = \frac{192EI}{l^3} = m\omega_n^2 \tag{5}$$

Young's modulus of the material is:

$$E = \frac{m\omega_n^2 l^3}{192I} \tag{6}$$

Area moment of interia:

$$I = \frac{bh^3}{12} \tag{7}$$

Size of the designed isolator is – 500 mm × 305 mm × 165 mm.
Loads acting on the designed isolators:
Maximum load on the isolators – 85 kN,
Minimum load on the isolators – 28 kN.
Spring rate:
Maximum load – 3.4 kN/mm,
Minimum load – 1.12 kN/mm,
Isolator height:
Free height – 165 mm,
Height at Maximum load – 140 mm,
Height at Minimum load – 157 mm.

From the given maximum load of 85 kN the maximum mass acting on the isolator is m = 8500 kg and material constant k = 3400 N. By varying the dimension of width and height of the isolator using area moment of inertia thickness of the compliant beams are determined. In this the width of the isolator is 305 mm. The Tab. 2 shows the selection of material using different young's modulus.

Table 2 Selection of material using Young's modulus

S. No	Dimension mm	Young's modulus E N/m^2
1	305 × 3	278×10^9
2	305 × 4	209×10^9
3	305 × 5	107×10^9
4	305 × 6	60×10^9
5	305 × 7	35×10^9

Here the optimum range of dimension is 305 mm × 4 mm which is having a young's modulus of 209 × 109 N/m^2. The required range of E value is around 200 GPa. The Fig. 5 and Fig. 6 shows the two dimensional and three dimensional respectively for the suggested optimum range of dimensions.

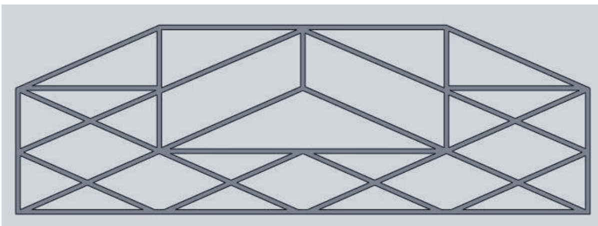

Figure 5 2D–compliant isolator design

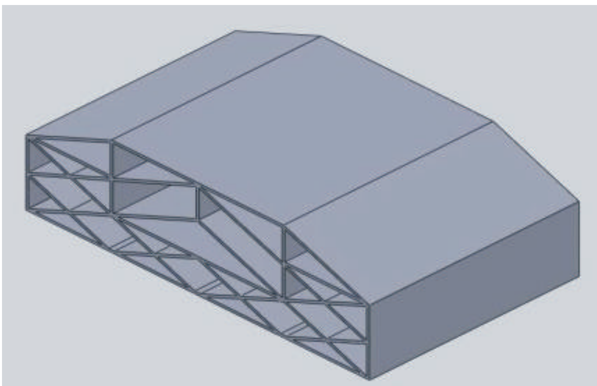

Figure 6 3D–compliant isolator design

5. Different material selections for compliant mechanism

The interaction between function, material, shape, process lies at the heart of the material selection process.

Function: for what purpose we are using the material we should understand that clearly.

Material: has the ability to change property and also high precision accuracy of geometrical tolerance preferable.

Process: means what way we produce the structure of the required shape in our project we prefer casting.

Shape: for what shape we need to produce.

According to this parameter we took some materials and did harmonic analysis, that results shows the response of the material, that data will help to choose the correct material are as follows: Aluminum, Brass, Bronze, Cast iron, Copper, Monel, Steel c15, Steel c35, Titanium & Zirconium.

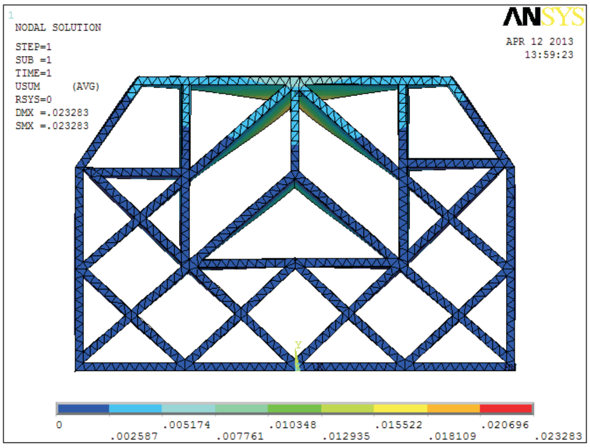

Figure 7 Steel C60 model displacement

From Fig. 9 the graph clearly understand the material behavior under the certain load, from this data we concluded stainless steel because of its displacement is low, normally the insulation materials are rubber, plastic, and wood but due to the industrial growth we are in need to find some new type of materials, springs replace the problem, stainless steel is suitable for springs, because it rigidity level is high. In that case we select the stainless steel for our project, using this material to manufacture our machine bed.

Natural frequency of compliant mechanism:

$$\omega_n = \sqrt{\frac{k}{m}} \tag{8}$$

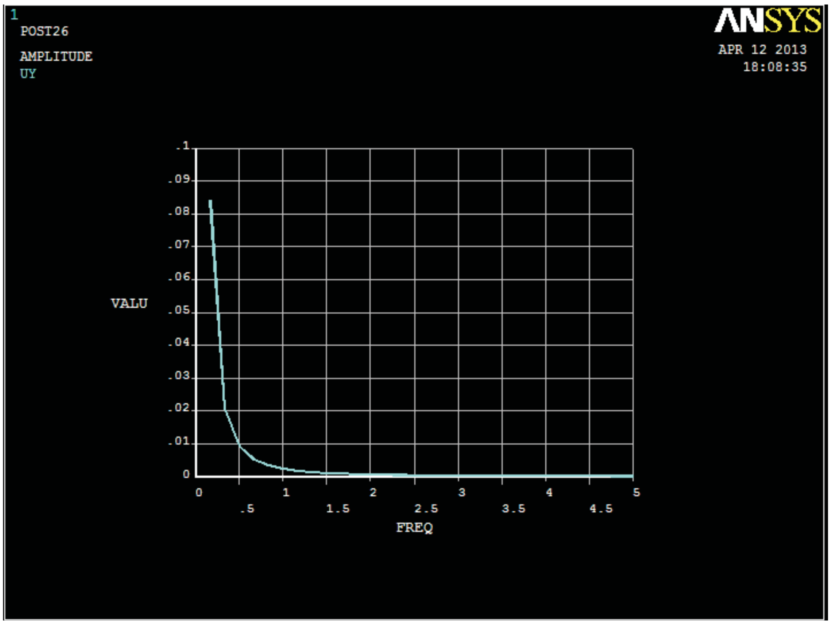

Figure 8 Frequency and amplitude value of nodal displacement for Steel C60

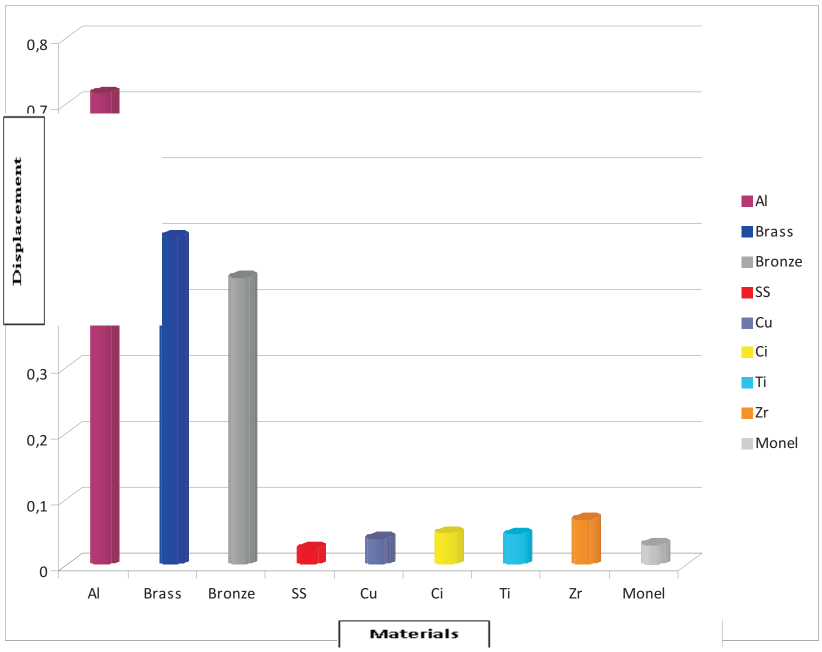

Figure 9 Different materials Vs displacement graph

Material constant:

$$k = \frac{192EI}{l^3} = m\omega_n^2 \tag{9}$$

Young's modulus of the material is:

$$E = \frac{m\omega_n^2 l^3}{192I} \tag{10}$$

Area moment of interia:

$$I = \frac{bh^3}{12} \tag{11}$$

Size of the designed isolator is – 500 mm × 305 mm × 165 mm.

6. Results and discussion

6.1. *Natural frequency*

Natural frequency is the frequency at which a system tends to oscillate in the absence of any driving or damping force. Free vibrations of any elastic body are called natural vibration and happen at a frequency called natural frequency. Natural vibrations are different from forced vibration which happens at frequency of applied force (forced frequency). If forced frequency is equal to the natural frequency, the amplitude of vibration increases manifold. This phenomenon is known as resonance.

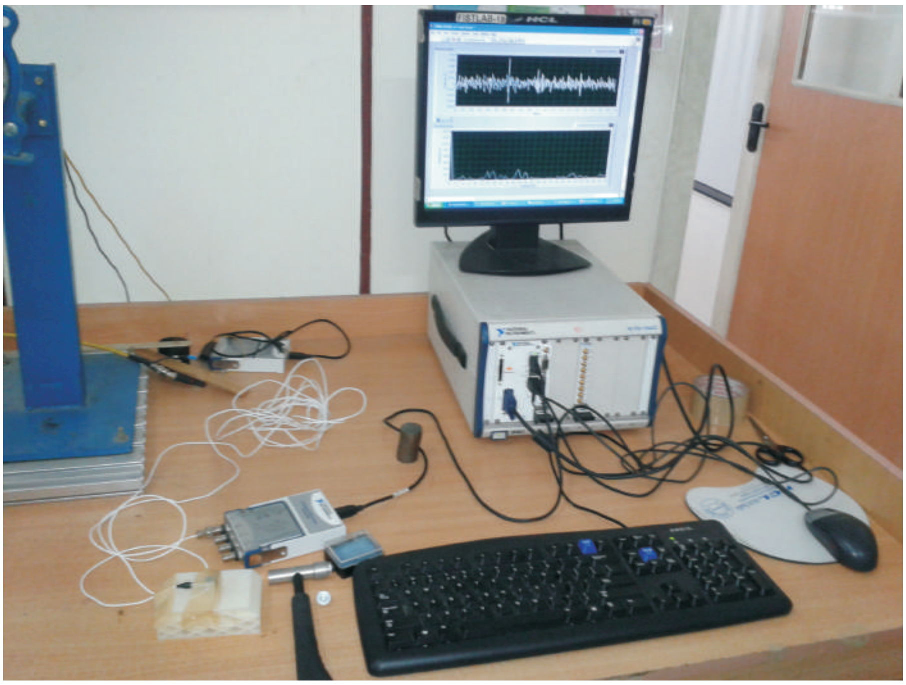

Figure 10 Experimental analysis of natural frequency by using LabView Software

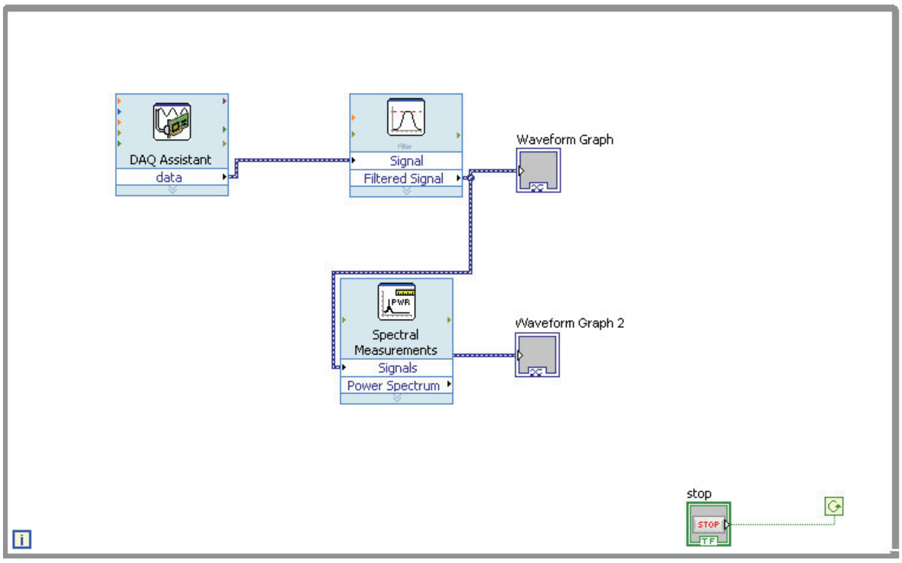

Figure 11 Block diagram of Lab View Software for finding natural frequency

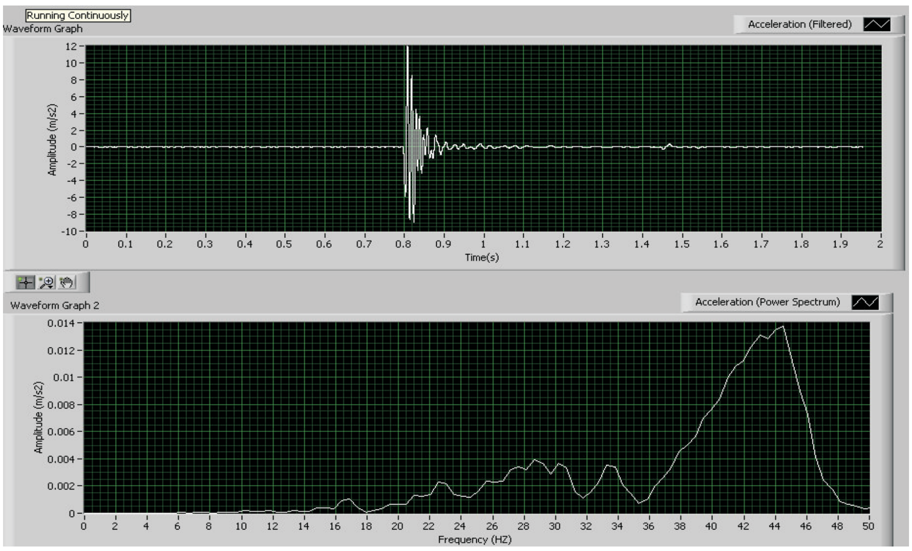

Figure 12 Natural frequency using aluminium tip

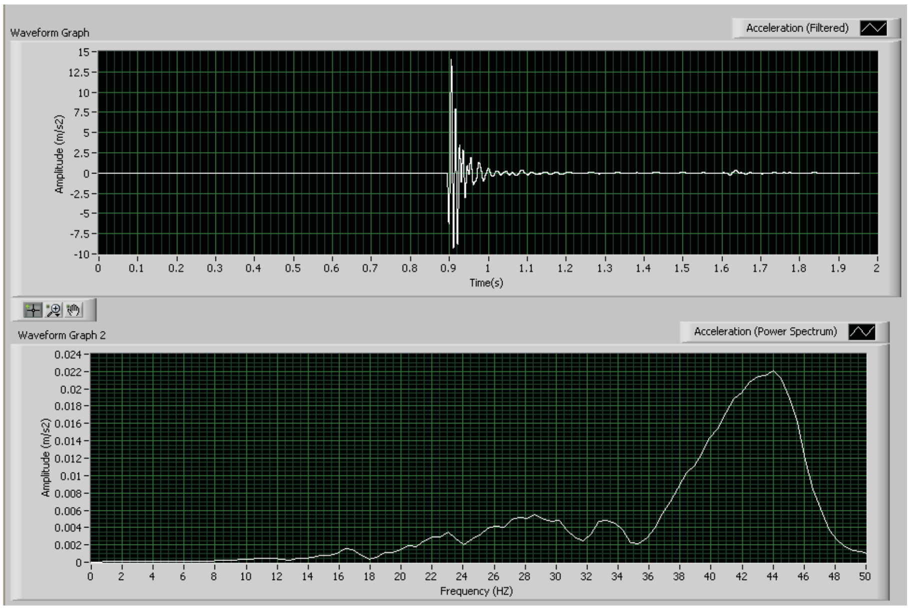

Figure 13 Natural frequency using plastic tip

6.2. *Process*

- DAQ Assistant converts the mechanical energy into electrical energy.
- Accelerometer filters the noise waves and converts the wave to time vs amplitude and gives waveform graph 1 in Fig. 12 and 13.
- Fast Fourier transform (FFT) converts waveform graph 1 to frequency vs amplitude and gives wave graph 2 in Fig. 12 and 13.

When the component is hit with aluminium tip by manual means using a hammer the frequency obtained is 45 Hz.

When the component is hit with aluminium tip by manual means using a hammer the frequency obtained is 44 Hz.

7. Conclusions

Compliant mechanisms which are proposed to provide cost effective and high performance vibration isolation systems. Their function is to transmit the force for various displacement amplitude of corresponding frequency ratios. The preliminary results from FEA using ANSYS show that a compliant mechanism can provide effective vibration isolation from a sinusoidal disturbance with known frequency ratios. Stainless steel the displacement is low, normally the insulation materials are rubber, plastic, and wood but due to the industrial growth we are in need to find some new type of materials, springs replace the problem, stainless steel is suitable for springs, because it rigidity level is high. In that case we select the stainless steel for our project, using this material to manufacture our machine bed.

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