ANALYSIS OF MECHANICAL STRUCTURE UNDER VIBRATION USING VIBRATION MEASURING SYSTEM

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ABSTRACT

Vibration is useful in order to realise system alive but beyond a particular value, vibration becomes dangerous for the existence of the system. In the present investigation effort has been made to fabricate and develop a mechanical structure along with a measuring system so that when structure vibrates, behaviour of vibrating structure can be monitored at various frequency of vibration. In order to simplify the fabrication work, the experimental setup was categorized into two, as mechanical structure system and vibration measuring system. Mechanical structure system was further subdivided into three different mechanical systems as, (1) mechanical vibrator, (2) vibration transformation mechanism, and (3) mechanical structure. Dimensions of mechanical vibrator, vibration transformation mechanism and mechanical structure were taken in order to suit the requirement of experimental work. Drawings of structure were developed using AutoCAD for better analysis prior to the fabrication work. As per the drawings, the setup was fabricated using materials, mild steel and aluminium. Potentiometers were used to develop vibration measuring system. The mechanical vibrating system simulates the real vibrating structures and the measuring system records the linear displacement of sensors. In a combination the linear displacement of the sensors indicates mode-I of vibration and for other set of displacement of sensors it indicates mode-II of vibration. The frequency of vibration in each case was observed using tachometer. Using FEM package (ABACUS) the vibrating system was again simulated in order to compare the behaviour and outcomes.

Keywords: Mode-I, Vibrating Structure, Potentiometer, Vibrator.
INTRODUCTION

Vibration is an integral part of any existing live system. Sometimes vibration is desirable and sometimes not. All machines in working condition vibrate and part of input energy dissipates through vibration and part of energy gets transformed into useful work. Efficiency of the system deteriorates with increase in vibration of system through which there is an energy loss. In order to know unwanted vibration we need to monitor vibrating system. This took attention for investigation and therefore decided to develop a system which can be used to measure vibration of any system vibrating. A structure can be defined as a combination of parts fastened together to create a supporting framework, which may be part of a building, machine, and any other mechanical system. Before the Industrial Revolution started, structures usually had a very large mass because heavy timbers, castings and stonework were used in their fabrication; also the vibration excitation sources were small in magnitude so that the dynamic response of structures was extremely low. Furthermore, these constructional methods usually produced a structure with very high inherent damping, which also gave a low structural response to dynamic excitation. The vibration that occurs in most machines, structures and dynamic systems is undesirable, not only because of the resulting unpleasant motions, the noise and the dynamic stresses which may lead to fatigue and failure of the structure or machine, but also because of the energy losses and the reduction in performance that accompany the vibrations. It is therefore essential to carry out a vibration analysis of the proposed structure.

LITERATURE REVIEW

The concept of employing structural control to minimize structural vibration was proposed in the 1970’s [1]. It was proposed that for un-damped linear systems, equations of motion can be given by \( \ddot{u}(t) + ku(t) = F(t) \) [2]. Also, it has been observed that, any mathematical damping model does not give a detailed explanation of the underlying physics [3]. Several mathematical models of physical damping mechanisms in single degree of freedom systems were developed [4]. Banks and Inman have considered four different damping models for a composite beam [5]. This damping behaviour has been studied by many authors [6] in some practical situations. It was recognized that the energy dissipation in a lap joint over a cycle under different clamping pressure is possible [7]. Significant damping can be obtained by suitably choosing the fastening pressure at the interfacial slip in joints [8]. Forced vibration conditions for structural analysis of the systems have been developed as one means in order to minimize the effect of environmental loads [9, 10]. Warburton and Soni have suggested a criterion for such a diagonalization so that the computed response is acceptable [11]. Using the frequency domain approach, Hasselsman proposed a criterion for determining whether the equations of motion might be considered practically decoupled if non-classical damping exists [12]. In order to achieve better protection against vibration even helical springs are used as shock absorbers with fluid dampers as energy dissipaters [13]. Sung Joon Kim and In Hee Hwang worked on the topic, ‘Prediction of fatigue damage for composite laminate using impact response’ and found that an impact response model can be used to compute the fatigue damage [14]. Damage such as an adhesive disband and fatigue damage results in a decrease in structural stiffness, and hence a change in the nature of impact [15]. Adams showed that it is possible to produce a version of the coin-tap test which depends on the measurement of the force input to the test structure during the tap, rather than
on the measurement of the sound produced by the tap [16]. A.N. Damir, A. Elkhatib and G. Nassif worked on the topic, ‘Prediction of fatigue life using modal analysis for grey and ductile cast iron’ to investigate the capability of experimental modal analysis, as a non-destructive tool, to characterize and quantify fatigue behaviour of materials [17]. The modal parameters are, by definition, functions of the physical properties of components (i.e. mass, stiffness or modulus of elasticity) and hence of mechanical properties. This concept was used mainly in the application of modal testing as an acceptance test for castings [18, 19]. The influence of geometric imperfections on the natural frequencies of cylindrical shells was studied [20, 21], and later also their influence on the non-linear vibrations [22, 23]. The effects of boundary conditions and static axial compressive loading on the non-linear vibrations were also investigated [22]. In recent past, a strong interest for the non-linear elastic wave spectroscopy methods applied to non-destructive testing has grown [24]. Different studies of this behaviour have been applied on a large range of materials: harmonic analysis [25], parametric interactions [26], modulation of amplitude [27] and phase [28] and studies of resonance frequency [29, 30]. Mathematical modelling is instrumental in the ongoing optimization of multi-layer designs and characterization techniques for multifunctional hybrid systems and composite structures [31, 32]. The multiple layers of single-purpose materials are replaced in various structures by their multipurpose counterparts. The full advantage of hybrid composites can be realized only when the micro-structural damage is controlled during processing [33], service and repairs.

**THEORETICAL WORK**

It was realised that, in order to observe the effect of damper on the vibration transmitted to the structure, a system has to be developed so that frequency of vibration can be recorded for a particular vibration signature. Here, mode of vibration was found adequate and convenient to observe. Therefore, initially a system was developed using AutoCAD constituting of, a vibrator, vibration transformation system and a structure. Three boxes were joined together using flexible joints to act as a structure. A vibration transformation system was developed so that vibration can be transformed from vibrator to structure in a particular order. Three different vibration transformation systems were developed, each to establish a new experimental condition. The difference between the three was their ability to absorb vibration. A simple mechanical vibrator was also developed as a source of vibration. The need of structure was only to develop a mechanical system to simulate vibration. The idea of structure was initiated from the analysis work done in the previous research work, and was shaped just to fulfil the requirement of experimental work. A vibration measuring system was also developed to record the modes of vibration and frequency when mode-I and mode-II of vibrations are attained.

**DEVELOPMENT OF STRUCTURE USING AUTOCAD**

With the extensive use of software (AutoCAD) the mechanical structure system was developed as shown in the Fig.4. Mechanical vibrator, vibration transformation mechanism, and mechanical structure were also drawn individually to have better understanding of each part to be fabricated. Drawing of mechanical vibrator is as shown in Fig.1, drawing of vibration transformation system is as shown in Fig.2 and drawing of structure is as shown in Fig.3. Recognition of components of vibration measuring system becomes an important part of research work. Vibration measuring system was a method developed to observe modes of vibration of a vibrating structure.
A microcontroller often serves as the “brain” of a mechatronic system. Here, a mini, self-contained computer was designed and programmed to interact with both the hardware of the system and the user. The most basic microcontroller was used to perform simple math operations, control digital outputs, and monitor digital inputs. Potentiometers were used to observe the linear displacement of the spring in order to establish method to record mode-I and mode-II of vibration.

EXPERIMENTAL WORK

A setup was fabricated in order to analyse the vibration affecting the structure and to observe the usefulness of the vibration measuring system designed and developed in order to measure frequency of vibration. Experimental work covers FEM analysis, fabrication of structure, fabrication of vibration transformation mechanism, mechanical vibrator and vibration measuring system.

FEM ANALYSIS

With the extensive use of FEM package (ABACUS) the mechanical viability of the vibrating system was checked by applying different constraints and material condition. Fig.5 describes the deflection of structure at mode-I of vibration.

MATERIAL SELECTION

Using software package it was easy to understand the behaviour of vibrating structure. In order to simplify the construction of complete system the materials were selected accordingly. For structure boxes aluminium was selected. Springs were used to make the joints flexible and the material of spring taken was spring steel. The nuts and bolts used to support the flexible joints and were made of mild steel. The parts of vibration transformation system and vibrator system were fabricated using mild steel plates.
FABRICATION WORK

Boxes were developed with the extensive use of sheet metal work. Three boxes were made and then assembled together. Vibration transformation mechanism system and mechanical vibrator system was fabricated in workshop. The arrangement of cam & follower system was attached to DC motor with regulator in order to control the rpm of motor and in turn vibration. The mechanical vibrator system is as shown in the Fig.6. A vibration transmitting mechanism is then attached with the mechanical vibrator to achieve the vibration on the top plate on which the structure was fixed. Aluminium structure was then fixed over the plate so that the effect of vibration can be observed. By adjusting the motor speed (rpm) frequency of vibration was to be adjusted. To observe the modes of vibration the electronic measuring system was positioned and fixed to the structure as shown in the Fig.7. The readings were observed on the display attached to the system and was governed by four displacement sensors. All the four displacement sensors were fixed, two on the right side and two on the left side in between the flexible joints of two boxes. Experimental work was done to observe the frequency of vibration at Mode-I and Mode-II of vibration for the system and was tabulated. Readings were taken for the three different vibration transformation mechanism systems and used for further analysis.

Fig.5: Structure at mode-I of vibration

Fig.6: Vibration system

Fig.7: Structure with displacement sensors
RESULTS AND DISCUSSIONS

From the tabulated data obtained from the experimental work it was observed that the value of frequency was different as the vibration transformation mechanism changes. The frequency of vibration at mode-I of vibration was 1.7 Hz and the frequency of vibration at mode-II was 2.55 Hz when first vibration transformation mechanism was used.

The mechanism was modified by providing spring support both sides between the fixed plate and the supported plate in order to change the damping capacity of the structure. The second vibration mechanism used for experimental work and the frequency of vibration at mode-I of vibration was 5.3 Hz and the frequency of vibration at mode-II was 9.1 Hz. The mechanism was further modified by providing bolt and a spring support to make a flexible joint at one end between the fixed plate and the supported plate in order to set a different damping capacity of the structure. The third vibration mechanism was used for experimental work and the frequency of vibration at mode-I of vibration observed was 7.12 Hz and at mode-II it was 13.28 Hz. The value of frequency observed for each vibration transformation mechanism at mode-I and at mode-II of vibration was plotted as shown in Fig.8

![Fig.8: Variation in the frequency with the change in mechanism](image)

CONCLUSIONS

It was found that the vibration transformation mechanism plays a vital role in achieving modes of vibration. While performing experimental work the only change made in the experimental setup was the vibration transformation mechanism, as a result of which the frequency for the modes of vibration changes. It was observed that as the damping capacity of vibration transformation mechanism increases the frequency for the modes of vibration increases as shown in the Fig.8. No remarkable change was observed in the maximum deflection of the structure at mode-I of vibration. Therefore it can be concluded that as the damping capacity of vibration transformation mechanism increases the structures are safe and mode-I and mode-II of vibration attained will be observed at higher frequency of vibration.

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