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Modelling And Simulation Of A Bolted Joint Test Rig Under Dynamic Conditions

V Achwal[1], S Dravid[2] , R Lodha[3]
[1.]Research Scholar, Mechanical Engineering Department, Mewar University, Chittorgarh, Raj., India
[2] Associate Professor, Mechanical Engineering Department, SDBCT, Indore, M.P, India.
3 Associate Professor, Faculty of Engineering and Technology, Mewar University, Chittorgarh, Raj., India
Corresponding Author: V Achwal

ABSTRACT:*This paper includes modal analysis and harmonic analysis studies for a bolted joint test rig. Machinery vibration problems, e.g. bolt loosening, may get more severe if the operational frequency of the systems matches with any of the natural frequencies of the system. Such problems can be controlled by carrying out modal and harmonic analysis of the system. The test rig considered in this work is a multibody system (MBS) and includes eight components in it. Various components of the system have been modelled in the CAD environment. These components are then assembled to get the overall CAD model of the experimental bolted joint test rig. Modal analysis of flexible components of the system has been carried out. This is followed by modal and harmonic analysis of the CAD model of the experimental test rig. Modal analysis helps in identifying resonance regions. Such primary analysis of system plays important role in studying loosening of bolted joints as well as in finding out fatigue strength of the dynamic systems.*

KEY WORDS: *Bolted Joints, Natural Frequency, Modal Analysis, Harmonic Analysis.*

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I. INTRODUCTION

Bolted joints are commonly used in fastening various machine components. All these components together form a system, which is termed as multibody system. Bolted joints in machines are subjected to dynamic loading, which may cause them to loose or fail in fatigue. This paper aims to carry out modal analysis and harmonic analysis of a specially developed bolted joint test rig.

Study of dynamics of a machine includes various types of analysis e.g. modal analysis, harmonic analysis, transient analysis etc. Modal analysis is generally considered as the primary analysis, which needs to be carried out before carrying out more advanced analysis of the system.

Modal analysis is used to find out modal characteristics of a system. These characteristics include natural frequencies, modal damping factors and mode shapes [1]. Mode shapes give spatial displacement pattern of the system in a particular mode. Modal analysis helps in dynamic design of the systems and gives ideas to prevent resonant conditions in a machine or structure [2]. Modal analysis is classified into theoretical and experimental modal analysis. In experimental modal analysis, the system is excited with known excitation and the vibration response is measured. In this way, Frequency Response Functions are recorded, which are further used to extract the modal parameters of the system. Experimentally extracted modal parameters can be useful for analytical model validation, structural design modification, response simulation for optimum design, force prediction, structural monitoring or damage detection [3]. Theoretical modal analysis generally uses analytical approach or finite element method for the modal characterization of the system. In this work, theoretical modal analysis of a bolted joint test rig has been attempted.

Multibody dynamics (MBD) covers a system of many bodies linked together via kinematic constraints. .Numerous computer programs have been developed in many engineering fields, and they are jointly used with multibody dynamics programs. Multibody systems can range from very simple to highly complex. In fact, motion characteristics of a large number of engineering fields can be studied kinematically and dynamically with the help of analysis of multibody structures [4].There is no doubt that multibody systems are ubiquitous in engineering and research activities, such as robotics, automobile vehicles. Hwan et. al. [5] has investigated the modal characteristics of constrained multibody systems undergoing rotational motion by employing relative co-ordinates to derive the equations of motion.

Several computational methods were introduced since early 1960s to obtain the response of a constrained complex system. Suleman [6] studied the thermo-structural modelling and interaction effects on the system modal spectrum using system modes in large flexible space structures. Using these methods, kinematic, dynamic, and static equilibrium analyses of constrained multibody systems can be performed. Chant et al. used [7] used CAE Models to predict the dynamic behaviour of interconnected rigid or flexible bodies, each of which may undergo large translational, rotational or complex spatial displacements. There is a difference between a single component and a machine. A whole machine tool structure is composed of many components connected with many joint interfaces. The whole machine tool structure is an integrated system. The various types of joint interfaces in a structure have significant effect on the static and dynamic behaviours of the structure [8].

Dynamic analysis of multibody system may be more involving and time consuming when compared with single body system, as the former involves many machine components and joints. The bolted joint test rig, as modelled in this work, includes 08components in all. These components have been modelled in Creo 2.0. Some of the components find their use multiple times. These components include 44 joints among them. Hyperworks software has been used in this work for the dynamic analysis of the system, as it has efficient meshing capabilities in its Hyperworks module [9].

Bolt loosening often causes catastrophic failure in machines. Bolted joints are generally tested for their reliability using cyclic tests in specially designed machines. Dravid et al.[11]designed a special purpose test set-up to study bolt loosening behaviour for different types of bolts with plain and spring washers. The set-up is capable of applying amplified forces at the bolt to study the loosening behaviour under cyclic loading condition. Both the force and the frequency of excitation play important role in loosening behaviour of bolted joints [12].The frequency of excitation in any system is governed mainly by the operational frequency of the system. Bolt loosening may be more severe, if the operational frequency of the machine comes within the region of resonance of the system [13]. In view of this, modal analysis and harmonic analysis of the dynamic systems becomes crucial. Modal analysis helps in identifying resonance regions, whereas harmonic analysis helps in getting peak amplitudes at the points of resonance in the system.

It is found that modal analysis studies have been found for multi body systems. However studies relating modal analysis of individual components with modal analysis of multi body systems are not found many in the available literature. Hence this work attempts firstly attempts modal analysis of individual components of a bolted joint test rig, which is followed by modal analysis of the overall system and related correlation. Finite element method is a commonly used tool for machinery numerical simulation [14].This work uses first modelling of various components of rig and then it is followed by finite element modal analysis of the system.

II. FINITE ELEMENT ANALYSIS

Finite element analysis is a commonly used method for structural analysis. Different types of elements, e.g. one dimensional, two dimensional and three dimensional elements may be employed to carry out the analysis. Various computer codes can be used for the purpose. However, this work employs Hyperworks 13.0 for the dynamic analysis. It has been noted that in order to accurately predict the physical behaviour of the structure with many parts, a detailed three-dimensional model is desirable. However, for a large complex structure a detailed modelling of the joint is difficult because of restriction of the problem size and computational cost to analyse the entire structure. Complex machine models can be developed accurately using the finite element method [14-17].

2.1 Modelling the Bolted Joint Test Rig

A bolted joint test rig has been considered after following the experimental test rig as given in the work by Dravid et al. [18] .It may be noted that the bolt loosening may not be only affected by the force but also by the frequency of excitation.

Bolted joint testing machine has been designed and constructed for checking the performance of loosening of threaded fasteners. Unlike a single structure or a component, a whole machine tool structure is composed of many component connected with many joints interfaces. The whole machine structure is an integrated system. Therefore, the structure is a very complex one. Bolt joint testing rig has been designed and constructed for checking the performance of loosening of threaded fasteners. In this set up, an unbalanced mass is used to produce dynamic force in the system. This unbalanced mass is mounted on a pulley which is driven by a motor through a v-belt. An external motor is used to provide rotation to the belt which connects the motor to the pulley. The pulley further is mounted on a bell crank lever. Thus, the forces produced by the unbalanced mass are transferred to the bell crank lever. So, the bell crank lever goes under vibrations

The schematic of the bolted joint test rig has been shown in Figure 1 where all the component shown in previous figure is assembeled with each other .

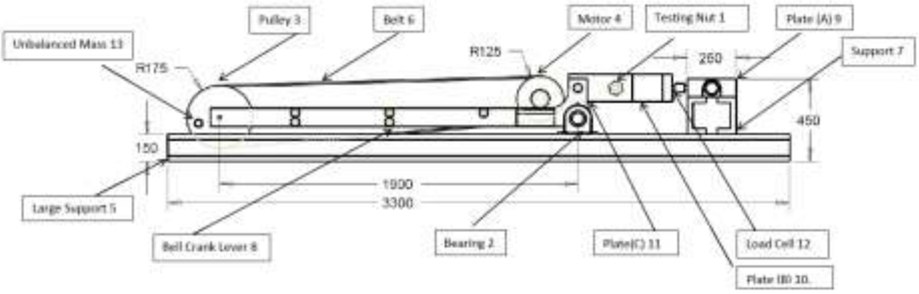

Figure 1 Set- up of bolted joint test rig

Various components also been modelled using the CRE-O software.The CRE-O model of the assembly is shown in Figure 2.

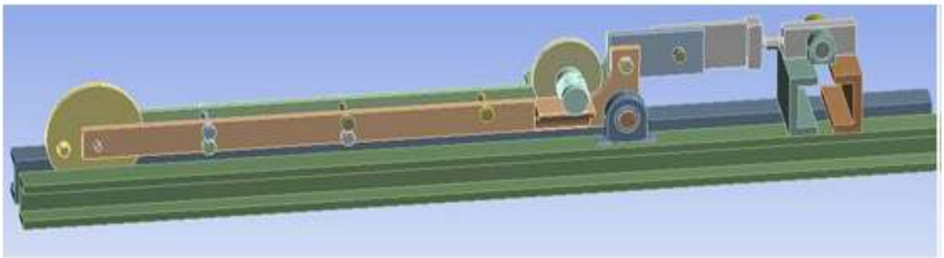

Figure 2 CRE- O model of bolted joint testing rig for Shear Attachment

2.2 Modal Analysis of the System

Firstly modal analysis of individual components has been attempted. The shape in which structure vibrates at its natural frequency us called its mode shapes. Hypemesh was used for the modal analysis of individual component and the rig. The model was built in Creo 2.0. After assembly & converting the model into .igs format this model is imported into Hyperworks. After importing the model, contact and constraints are defined according to the real conditions of the rig. A default mesh is automatically generated during initiation of the solution. The user can generate the mesh prior to solving to verify mesh control settings. A finer mesh produces more precise answers but also increases CPU time and memory requirements. Natural frequency of Pulley, crank lever and test rig is done and comparative study is done to analyse the system. Table 1 shows the first six natural frequencies of the plate. Fig. 3(a) to Fig. 3(f) shows the various mode shapes of the pulley.

Table 1 Natural Frequencies of the pulley

Mode No.	1	2	3	4	5	6
Natural Frequency (Hz)	12.61	14.25	44.23	55.7	65.6	70.26

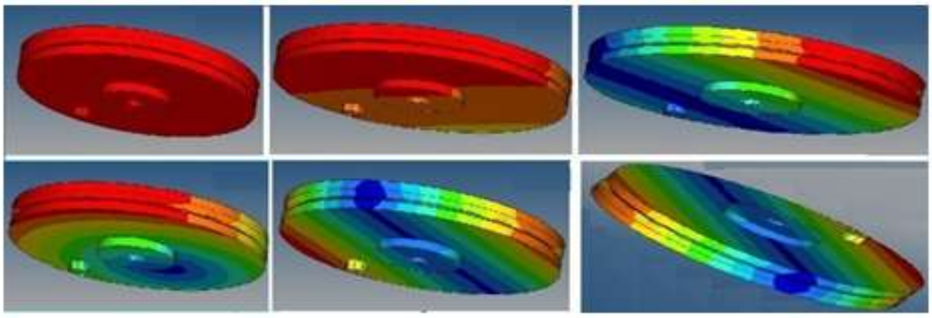

Figure 3 Mode Shape of Pulley (a) 1st mode at 12.61 Hz; (b) 2nd mode at 14.25 Hz; (c) 3rd mode at 44.23 Hz; (d)4th mode at 55.7 Hz: (e)5th mode at 65.6 Hz: (f) 6th mode at 70.26 Hz

Table 2 list the first four natural frequencies of crank lever. Figure 4(a) to 4(d) show the mode shapes for the respective modes.

Table2 Natural Frequencies of the crank lever

Modes	1	2	3	4
Natural Frequency (Hz)	57.89	62.42	73.52	102.56

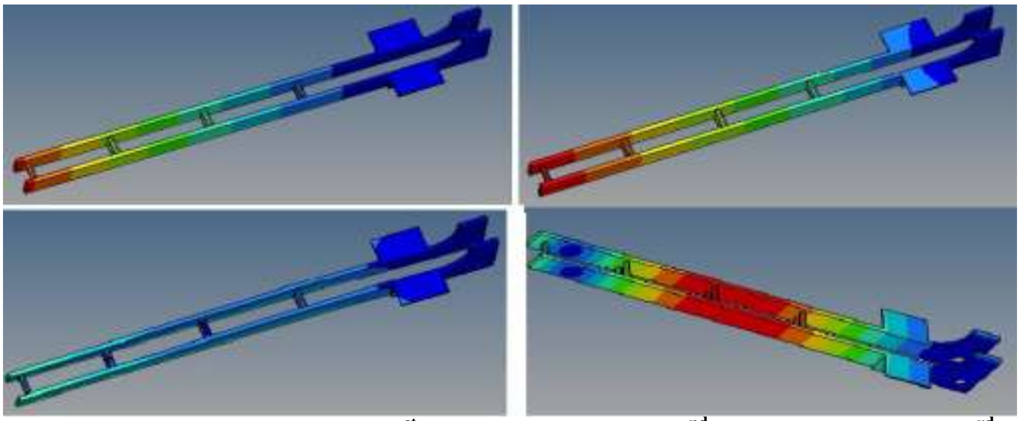

Figure 4 Mode shape of Crank Lever (a) 1st mode at 57.89 Hz; (b) 2nd mode at 62.42 Hz; (c) 3rd mode at 73.52 Hz; (d) 4th mode at 102.56 Hz.

Modal analysis of the test rig is done between 1 to 150 Hz. Table 3 lists the first six natural frequencies of test rig. Figure 5(a) to 5(f) show the mode shapes for the respective modes, where lateral, longitudinal and torsional Modes were obtained for 6 natural frequencies.

Table 3 Natural Frequency of the rig with shear force Attachment

Modes	1	2	3	4	5	6
Natural Frequency (Hz)	12.71	14.32	57.95	60.73	70.51	102.20

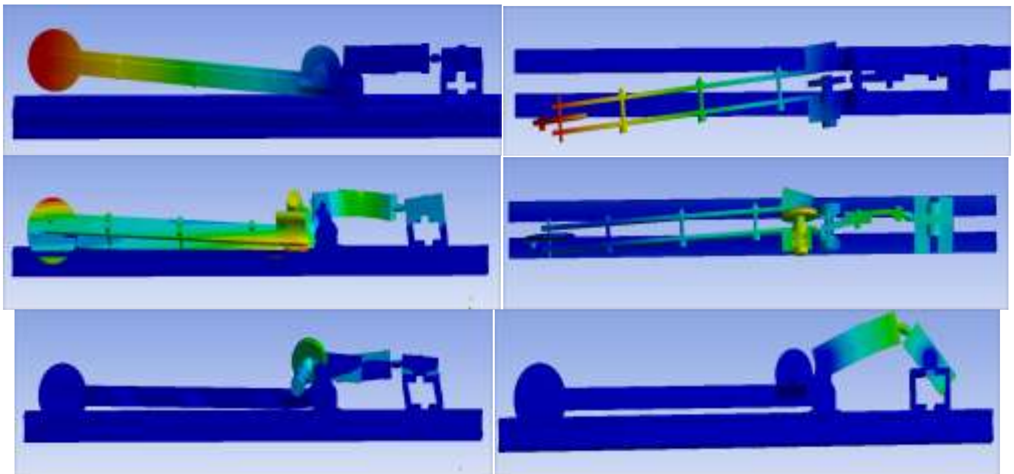

Figure 5 Mode Shape of Test Rig (a) 1st mode at 12.71 Hz; (b) 2nd mode at 14.32 Hz; (c) 3rd mode at 57.95 Hz; (d) 4th mode at 60.73 Hz: (e)5th mode at 70.51 Hz: (f) 6th mode at 102.20 Hz

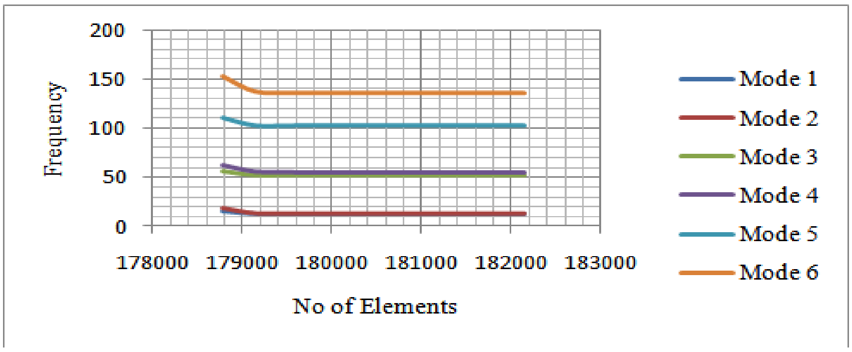

Figure 6 Convergence Graph for All the Modes against Natural frequency and No of element

These results were obtained when structural steel is assigned as the material for the rig.As the no of element increase the natural frequencty of the system unchanged.

III. CONCLUSION

This was an attempt to build a CAE environment for a bolted joint test rig complex structure. This type of CAE environment can be developed for any machine of which analytical analysis is very tough. Use of software to find the modal results by using proper constraints & contacts between parts was shown. The modal analysis of bolt test rig has the convergence in all the modes and it is also compared with the individual components which also give the same pattern. This shows that the results are accurate and convergent also. Further analysis of other attachment in the same test rig and different bolts can be performed. For this purpose, designer is liable to provide a table so that manufacturer & industrialist can study it and choose the range for their product. Developing mathematical model for such types of structure is very time consuming and requires deep knowledge which is only available in expert system. Element stresses results are analyzed and verified in further harmonic analysis.

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