DESIGN OF SIMULATION SYSTEM FOR STRUCTURAL DYNAMIC OPTIMIZATION OF MECHANICAL STRUCTURES

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Abstract

Various structures used in aerospace, automotive, naval and other industrial applications will experience vibration during their service mount condition. Response of a structure to the input vibration will be dictated by three dynamic parameters namely mass (M), stiffness (K) and damping (C). Proper combination of these critical parameters needs to be chosen while configuring particular structure otherwise input vibration energy gets amplified to a greater extent and drives the structure towards catastrophic failure. As of now no practical means are available to evolve optimal combination of above mentioned dynamic parameters. This paper proposes design of a dynamic simulation system which offers a promising solution to have various combinations of mass, stiffness and damping over a specified range. Further intended device can be excited with desired frequency and amplitude by mounting it on a vibrator and response of the device can be measured and quantified for a specified input. With the proposed simulator optimal combination of dynamic parameters can be evolved which becomes input to conFig. The design of a particular structure. To begin with base line configuration of the proposed simulation system is worked out for the purpose of conceptual demonstration and also to identify the subsystems. Subsequently sizing of all these subsystems is arrived at using design calculations. Assembled configuration of the system is worked out using 3D CAD modeling software.

Keywords: *mass (M), stiffness (K) and damping (C), 3D CAD modeling software.*

1. INTRODUCTION

Structural elements designed for any application like automotive, aerospace and industrial will possesses three basic dynamic characteristics like stiffness (k), mass (m) and damping (c). Under the influence of dynamic loading the response of the structure is dictated by these three parameters. Hence designer needs to optimize these key parameters while configuring any structure. Finite Element Method (FEM) is in general used as a tool to evaluate the effectiveness of the optimization with respect to dynamic response of the structure. However accuracy of response predicted by FEM is always questionable as it is considered to be an approximate method. Other way of doing it is to realize the hardware and test so as to obtain the dynamic response. But later one calls for cost implication and if the first fabricated hardware doesn't meet the requirement design needs to be fine-tuned and new hardware has to be realized and so on. To overcome this via media between FEM and hardware realization is proposed in form of dynamic simulation system in this work.

Computer Aided Design (CAD) was introduced to refer to a technique which employs the computer in the design process in order to increase the efficiency with which a designer is able to design. Whilst a computer is incapable of creativity, it is efficient in analysis, robust in repetitive tasks, fast in processing information and capable of storing a large amount of data. As design is an iterative process, it is necessary to update the drawing constantly and often requires a small modification. It can therefore be a cumbersome and time-consuming task to reproduce the drawings for every modification and the use of computers can be very effective [1]. A Genetic Programming formulation is presented, using design modification operators as modular "programmes", and shown to be capable of synthesizing a range of novel, optimally-directed designs. The method developed consistently finds the global optimum for a small 2D planar test problem, generates high-performance designs for larger scale tasks and shows the potential to generate designs meeting user-defined aesthetic requirements [2]. Current engineering analyses rely on running expensive and complex computer codes. Statistical techniques are widely used in engineering design to construct approximate models of these costly analysis codes. These models referred as metamodels, are then used in place of the actual analysis codes to reduce the computational burden of engineering analyses [3]. Multidisciplinary design optimization (MDO) can be used as an effective tool to improve the design of automotive structures. Large-scale MDO problems typically involve several groups who must work concurrently and autonomously for reasons of efficiency. When performing MDO, a large number of designs need to be rated. Detailed simulation models used to assess automotive design proposals are often computationally expensive to evaluate. A useful MDO process must distribute work to the groups involved and be computationally efficient [4]. There is a need for an efficient numerical optimization tool that can explore and generate several design alternatives in the preliminary design phase which can lead to a more desirable final design. Details of a tool that can be very useful in preliminary design optimization - finite element modeling, design optimization, translating design code requirements into components of the FE and design optimization models, and pre-and post-processing to verify the veracity of the model are presented [5]. A common finite element model for the whole aircraft was used for the static and aeroelastic optimization and analysis purposes. A detailed design model in the order of thousands of design variables was constructed. Most of these tools were developed in close coordination with the MSC Software [6]. Software combining parametric geometric modeling with a version of the harmony search method, modified to support multimodal structural optimization is described. Researchers have recognized the potential of population-based optimization methods, such as genetic algorithms, to support multimodal optimization: that is, generating a diverse range of good alternative solutions, rather than a single best solution [7]. Structural optimization as a discipline has developed almost in parallel with the advancement of structural analysis (e.g., based on the finite element method). Formulating a design problem in a mathematically rigorous way allows for finding optimal solutions using semi-automatic and algorithmic solutions. The use of these methods has increased manifold with the decrease in the cost of computational resources and has opened up new ways of designing structures and systems [8]. As can be seen, all the research focus on design with the aid of FEM.

Based on the limitations brought out as an outcome of literature review it is observed that a great need exists for design of a dynamic simulation system which offers a promising solution to have various combinations of mass, stiffness and damping over a specified range.

2. DESIGN PHILOSOPHY

Features will be incorporated during design such that after fabrication following parameters can be fine-tuned with simple mechanical adjustment

- Spring stiffness
- Damping coefficient of damper
- Motorized mass

By fine tuning the above said parameters the proposed system can be made suited to any desired design configuration. Any oscillating member is required to simulate the stiffness. Close coiled helical spring is such element which satisfies this requirement. Hence spring is chosen for stiffness. A mechanism with nut is planned to manipulate the number of active turns of the spring by which its stiffness can be changed. It is planned to simulate the damping of the system with the help of hydraulic cylinder. Different damping rates can be obtained by accommodating different oils in cylinder with different viscosities. Similarly to have varying mass, moving mass with the motion lead screw is planned. By altering the position of mass, effective mass on the system changes. Same system can be used for any design configuration just by tuning few parameters with which different variants can be evolved with single system. Proposed design with all subsystems is shown in Fig. 1.

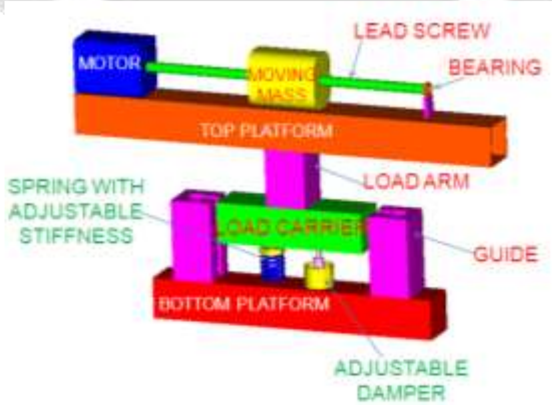

Fig. 1. Proposed design with all subsystems

From the above Fig. the following components are identified for which detailed design is carried out.

- Lead screw
- Motor
- Bearing for lead screw
- Top platform
- Load arm
- Load carrier
- Spring
- Damper
- Bottom platform

3. DESIGN CONFIGURATION

Following are the constraints for design.

- Minimum desired factor of safety is 1.5.
- There should be a provision to vary stiffness, damping and mass of the system.

Outcome of design is summarized in Table 1.

Table 1: Design parameters

Sl. No.	Design Parameter	Value
Lead screw		
1.	Size	35 mm
2.	Torque	2.06 Nm
Lead screw bearing		
1.	Outer diameter	62 mm
2.	Width	14 mm
3.	Designation	6007
Top platform, Load arm & Load carrier		
1.	Cross section	Box
2.	Size	140x140x5 mm
Spring		
1.	Wire diameter	12 mm
2.	Mean coil diameter	72 mm
3.	Free length	90 mm
Damper		
1.	Bore	90 mm
2.	Stroke	71 mm

4. STRUCTURAL ANALYSIS

Structural analysis of simulation system is carried out using Finite Element Method (FEM) in ANSYS software in order to assess the design adequacy against the functional load. Maximum Von Misses stress thus obtained is compared with allowable stress and obtained the available factor of safety.

To begin with geometric model of the intended design is built in 3D CAD software from its dimensions. However load bearing members are only considered for analysis. Then geometric model is converted into FE model by discretizing all the members with shell (SHELL63) elements, except mass with lumped mass (MASS21) elements. As the simulation system is made of steel its material properties are considered for the analysis. FE model of the assembly is constrained in all DOF on either side of suspension base. FE model with boundary conditions is shown in Fig. 2.

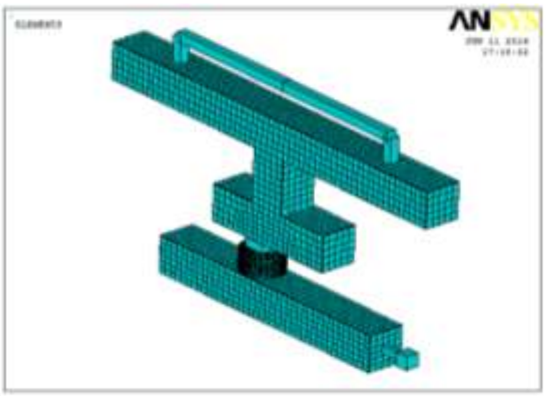

Fig. 2. FEM model of the total system

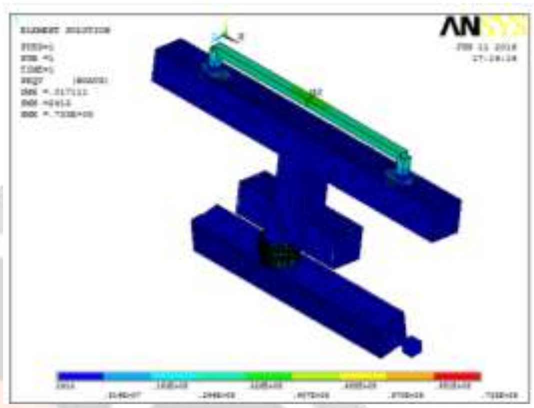

Fig. 3. Stress plot

Static analysis was carried out and the corresponding Von Misses stress plot is shown in Fig. 3.

Then dynamic (Modal) analysis was also carried out. Modal analysis is the study of the dynamic properties of structures under vibration excitation. In structural engineering, modal analysis uses a structure's overall mass and stiffness to find the various periods that it will naturally resonate at. A modal analysis calculates the undamped natural modes of a system. These modes are given in decreasing order of period and are numbered starting from 1. Mode shape plot corresponding to first natural frequency is shown in Fig. 4.

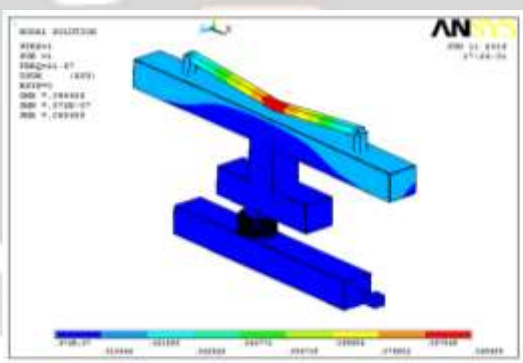

Fig. 4. Mode shape plot

5. RESULTS AND DISCUSSION

Outcome of analyses is summarized in Table 2.

Table 2: Analyses results

Sl. No.	Result	Maximum Value	Allowable value	Factor of safety
<u>**Static**</u>				

1.	Von Misses stress	73 MPa	250 MPa	3.4
Modal				
2.	First natural frequency	21 Hz	--	--

- Maximum Von Misses stress is observed to be 73 MPa.
- Available factor of safety is observed to be 3.4 which is more than minimum desired factor of safety (1.5). Hence the design is safe.
- Frequency of the intended system corresponding to first bending mode is found to be 21 Hz..

6. CONCLUSION

A dynamic simulation system has been designed which offers a promising solution to have various combinations of mass, stiffness and damping over a specified range. This device can be excited with desired frequency and amplitude by mounting it on a vibrator and response of the device can be measured and quantified for a specified input. With the proposed simulator optimal combination of dynamic parameters can be evolved which becomes input to configure the design of a particular structure.

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