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Modal and Spectrum Analysis of Vibration-Free Transportation System Using Finite Element Analysis

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Abstract

The transportation trailer system comprises numerous delicate components that require careful handling throughout transit. During transportation, the system is subjected to vibrations and shock loads resulting from road conditions, trailer acceleration, and deceleration. If these loads are transferred to the system, it could adversely affect many of its elements, particularly at resonance. To mitigate such vibration-induced stress on the system, a vibration isolation system has been designed and analyzed. The transportation system is modelled and analyzed using the finite element method. The Power Spectral Density (PSD) based on ISO-8606 standard for random road profiles is utilized for spectrum analysis computations in the Finite Element Analysis (FEA). Natural frequencies in the transportation system with isolator obtained from the finite element analysis are compared with the mathematically calculated values and any discrepancies are reported as error percentages.

Keywords: Vibration isolation; Spectrum analysis; Random vibration; Road profile.

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1. Introduction

Isolation system plays a vital role in transporting highly sensible elements like many sensible system transportations. The shock and vibration exerted by the vehicle due to the road profiles, acceleration and deceleration of the vehicles are to be effectively isolated by a system. For transporting the system, it is positioned on a trailer using specially designed saddle and an isolating system. The saddle is designed based on the pressure vessel design codes and is analysed using ANSYS [1].

Various type of isolators are commercially available but selection of isolator for heavy transportation depends upon the dynamic behaviour of the system. In a dynamical system driven by an external periodic force, when the frequency of the force is varied, in a typical case, the amplitude of the oscillation decreases and reaches a significantly large value of a frequency and then decreases [2]. As a result of their low frequency, highly damp vibration isolation, ability to isolate in three planes, maintenance-free nature, minimal space

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requirements, and ability to operate under varying temperatures and corrosion environments, metallic wire rope isolators are found to be suitable for this application. A Power Spectral Density (PSD) analysis can determine the maximum energy produced by a vehicle's vibrations, including frequency values that affect drivers' comfort [3]. Mathematical models are used to understand the dynamic behavior of systems with the help of different mathematical methods [4]. Due to the resulting vibrations, people's everyday lives and jobs, building structural safety, and the routine operation of sensitive equipment are at risk, which is why the transportation industry has become increasingly concerned. It is necessary to identify vibration source properties and propagation laws in order to create effective vibration reduction and isolation solutions [5-11].

2. Methods

2.1. *Design of saddle*

Saddle is the support structure which is used for holding the transportation system in the fore end and aft end. Centred web type saddle of mild steel material is selected for this application. The saddle is designed based on pressure vessel hand book [12]. Based on the calculations the base plate of saddle is 12 mm and web, wear, rib plates are 8 mm. The saddle is modelled using CREO software and analysed using ANSYS software.

Assembly model of the saddle and transportation system is shown in Fig. 1. The Von-misses stress observed in FE analysis is compared with stress values obtained by the pressure vessel codes and found that the percentage of error is 7.87 % [13]. Using 3D FEM, it's able to simulate the structure's vibration parameters with good accuracy [14-15].

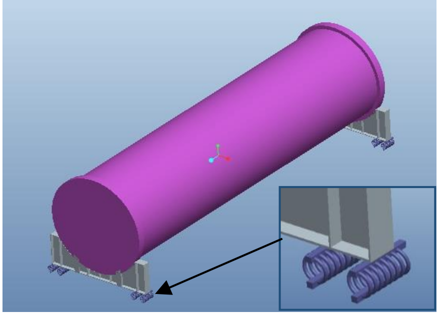

Fig. 1. Full configuration of model.

2.2. *Sizing of wire rope isolator*

The wire rope isolators are sized based on the expected velocity of the vehicle and the static load and acceleration. The fore end and aft end saddles are supported by eight isolators at four locations; each location contains two wire rope isolators as shown in Fig. 1. The wire rope isolator characteristics like Shock stiffness, vibration stiffness and maximum deflection are calculated for different velocities and acceleration. Based on the Centre of

Gravity (CG) offset of the transportation, the reaction loads on fore end and aft end saddles are calculated and used for the sizing of the vibration isolators. The CG location of the transportation system is shown in Fig. 2. The ENIDINE wire rope isolators WR28-400-8 is selected for fore end and WR28-800-8 are selected for aft end.

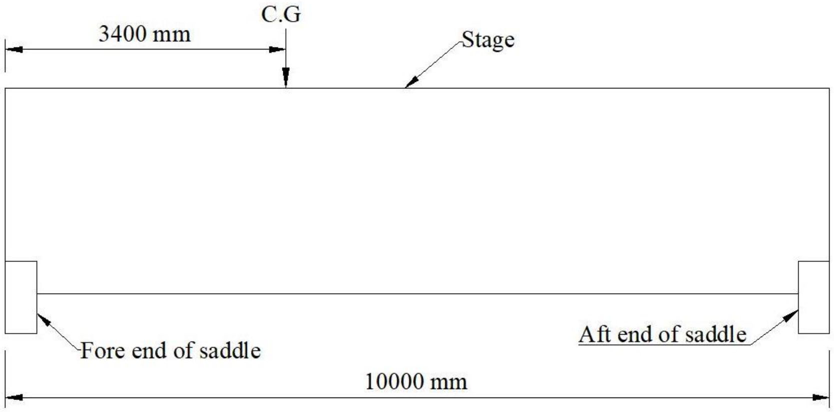

Fig. 2. CG location of transportation system.

2.3. ***Modal analysis***

The Finite element Analysis is applied to obtain numerical solutions of this system [16]. The transportation system is subjected to the modal analysis for finding out the natural frequencies. The finite element model of the total system is shown in Figs. 3 (a) and 3(b). The physical model is converted into the FEA model. To facilitate the purpose of analysis the physical model is converted into the equivalent beam model of the stage and saddle. The system is idealized using beam 188 elements with variable cross section to suit the equivalent profile of the saddle. Contact elements are used between stage and saddle.

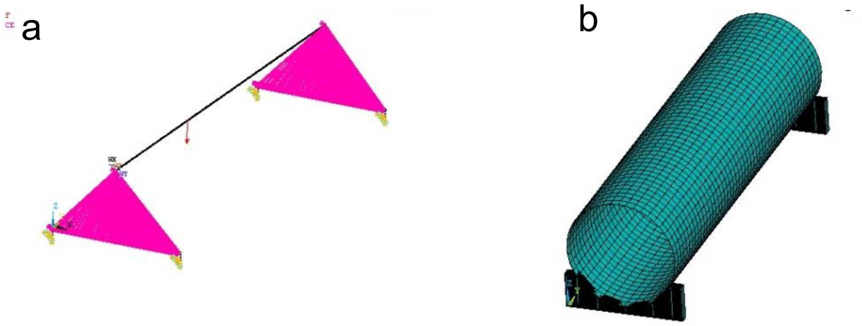

Fig. 3. (a) FE model of the system (b) FE element display model of the system.

The physical model is converted into the spring mass system for analytical calculations. The degree five of freedom spring mass system is considered. In this system saddle mass is 350 kg and the stage mass is 5000 kg. The stiffness of the saddle is 46060 N/mm, stiffness of the stage is 115235 N/mm, stiffness of the WR28-400-08 isolator is 1513 N/mm and stiffness of the WR28-800-08 isolator is 800 N/mm . In the system natural frequencies are determined analytically using spring mass system.

The equation of motion of the spring mass system is

$$m\ddot{x} + kx = 0 \tag{1}$$

To mathematically calculate the natural frequency of the 5DOF spring mass system. Modal analysis is carried out for the FE model and is compared with the analytical calculation for the equivalent spring mass system with isolator for the stage transportation as shown in Fig. 4.

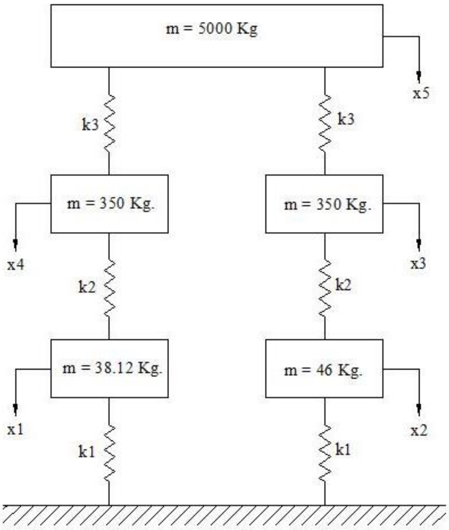

Fig. 4. Spring mass system of transportation system with isolator.

2.4. *Spectrum analysis*

In Fig. 5, the International Organization for Standardization (ISO) 8606 proposes a power spectral density (PSD)-based roughness classification [17]. A-type road profile represents the very good road and H-type represents very poor road. A spectrum analysis is carried for the FE model with and without the isolator to find out displacement variation due to base excitation.

The fairing and the system may be affected by delivery vibrations, which could lead to a system failure. This work, which is based on dynamical analysis with the finite element method, is therefore concerned with the safety assessment of the multi-point isolation system during transportation [18-20]. The analysis carried out for base random excitation for road B-type, D-Type and F type. The trailer platform is considered as base of the transportation system. Base excitation is directly applied on the isolator for the spectrum analysis.

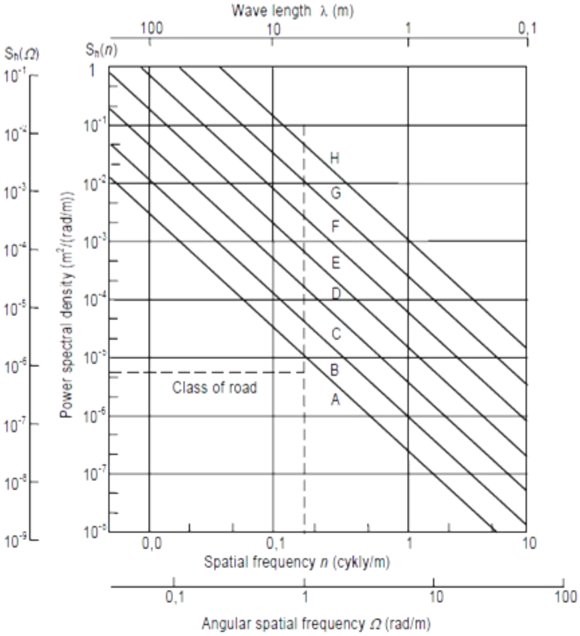

Fig. 5. Road profile classification ISO 8608.

3. Results and Discussion

The natural frequency of the system is calculated by analytical method using equivalent spring mass system and FEA method. It is found that the FEA result is very close to the analytical calculation. The comparisons of the system natural frequencies are shown in the Table 1. The analytical technique and FEA findings are compared to the system's natural frequency for various modes. Natural frequencies in this instance varied slightly among both of the analysis techniques.

Table 1. Natural frequencies of transportation system.

Description	fn_1	fn_2	fn_3	fn_4	fn_5
FEA Results (Hz)	1.322	3.363	3.435	5.673	7.120
Analytical results (Hz)	1.249	3.416	3.507	5.43	7.287

The maximum displacement due to vibration is observed at CG of transportation system. The isolation effectiveness of wire rope isolators is calculated based on the system response by FE method is for the B-type, D-type and F type road are shown in the Fig.6.

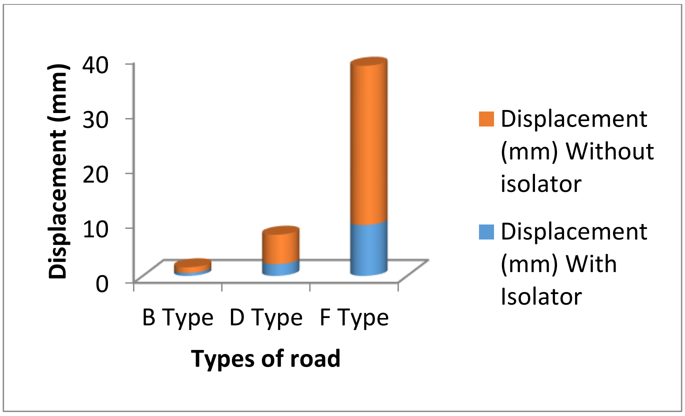

Fig. 6. Displacement values for different road profile.

As a result, the graph demonstrated that the displacement of the transpiration system depends on whether or not an isolator is fixed in the system. Displacement decrease by up to 46 %, 60 %, and 68 % when the isolator was fixed in the system for road profiles with types B, D, and F.

4. Conclusion

The comparison between mathematically calculated natural frequency values and those obtained through Finite Element Analysis reveals a close agreement. This study was conducted to forecast the response of the stage transportation system equipped with wire rope isolators using spectrum analysis via Finite Element Analysis. The research indicates that the wire rope isolators effectively mitigate up to 68 % of road random vibrations, demonstrating their efficacy in vibration isolation for the transportation system.

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