Exploring Mass Effects on the Dynamic Behavior of Spring-Mass-Damper Systems through Finite Element Analysis

A Comprehensive Study Using ANSYS Mechanical APDL to Analyze Natural Frequencies with Varied Mass Parameters

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***Abstract*—It is imperative in mechanical engineering to comprehensively examine the dynamic behavior of spring-mass-damper systems. This study employs finite element analysis with ANSYS Mechanical APDL, focusing on the systematic variation of mass while keeping spring stiffness and damper coefficients constant. The investigation analyzes resulting changes in natural frequencies and mode shapes, yielding essential insights into the influence of mass on the overall behavior of such systems. The findings contribute valuable knowledge for engineering and design applications.**

Keywords—Dynamic Behavior, Spring-Mass-Damper System, Finite Element Analysis, ANSYS Mechanical APDL, Mass Variation, Natural Frequency, Steady state,

I. Introduction

In the realm of mechanical engineering, the dynamic behavior of spring-mass-damper systems stands as a fundamental aspect crucial for engineering and design applications. Spring-mass-damper systems find application in wide areas within engineering including analysis of suspension bridges where a similar study was done and it was found that In the realm of mechanical engineering, the dynamic behavior of spring-mass-damper systems stands as a fundamental aspect crucial for engineering and design applications [1]. This paper explores the details of such systems through the lens of finite element analysis, leveraging the capabilities of ANSYS Mechanical APDL. The primary focus is on systematically manipulating the mass parameter while holding spring stiffness and damper coefficients constant. This paper explores the details of such systems through the lens of finite element analysis, leveraging the capabilities of ANSYS Mechanical APDL. The primary focus is on systematically manipulating the mass parameter while holding spring stiffness and damper coefficients constant.

The significance of understanding the dynamic response of these systems is underscored by their ubiquitous presence in engineering applications. In parallel to the investigation, the report sheds light on the computational aspect of this exploration. Employing ANSYS Mechanical, a potent finite element analysis tool, the study adds depth to the understanding by introducing specific parameters - spring stiffness (500 N/m), damper coefficient (2 Ns/m), and an applied force of 800 N to initiate vibrations.

Together, these endeavors aim to unravel the interplay of mass variations with the overall behavior of spring-mass-damper systems. Through computational simulations and analysis of resulting changes in natural frequencies, this report contributes essential knowledge, fostering a deeper comprehension of the dynamic behaviors vital for engineering and design practices.

II. Literature review

A. *Overview*

The literature review delves into existing research concerning the dynamic behavior of spring-mass-damper systems. Previous studies have explored similar topics, often utilizing computational tools such as ANSYS Mechanical APDL. These investigations contribute to the broader understanding of mechanical systems, emphasizing the significance of comprehending the interplay between mass variations and system response. This section aims to contextualize the current study within the existing body of knowledge while identifying gaps or areas where further exploration is warranted.

B. *Tuned Mass Dampers*

Research by [2] explored the impact of tuned mass dampers (TMD) on transmission towers during seismic events. Shaking table tests on a scaled model revealed that TMD effectively controlled tower vibrations, with performance varying based on earthquake characteristics. The study emphasized TMD's role in enhancing the resilience of transmission towers in seismic regions, offering valuable insights for design and performance evaluation under dynamic loading conditions.

C. *Torsional Vibration Dampers*

A study on torsional found out that the torsional stiffness of a leaf spring vibration damper significantly influences its natural frequency and compatibility with a diesel engine [3]. Using a validated mechanical model with nonlinear characteristics, the study explored design parameter impacts. Findings revealed that the arc radius of the clamping groove and leaf spring length crucially affect torsional stiffness and nonlinear traits. The research established a gap in that it recommended that future damper designs should consider these dynamic parameters comprehensively for optimal performance.

D. *Dynamic Beam-MSD Interaction*

[4] Presented an efficient semi-analytical method for assessing the dynamic response of a Euler-Bernoulli beam with general boundary conditions intersected by a mass-spring-damper (MSD) system. Using a dynamic substructuring technique, the non-classically damped beam subsystem is coupled with the MSD system through a generalized corresponding assumption, emphasizing equal displacements at contact points. An application example emphasized the importance of explicitly considering the beam-MSD interaction for accurate response prediction compared to a less expensive static axle loads approach.

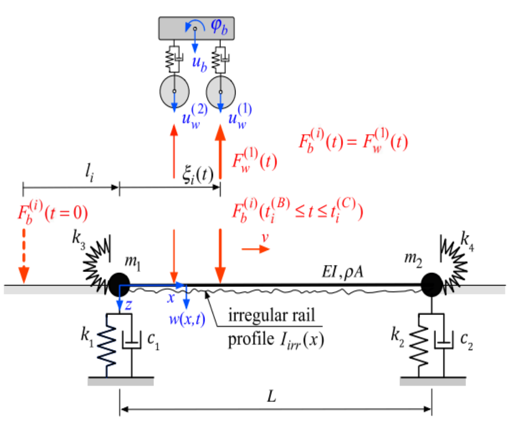

Figure 1. Illustration for Euler-Bernoulli beam with planar mass-spring-damper model [4].

III. Methology

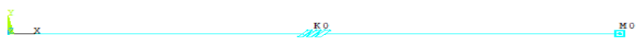

Figure 2. Mechanical APDL illustration for the spring-mass-damper system

The masses were applied to the system at varying magnitudes starting from a mass of 2kgs up to 8kgs with an increment of 2kgs for every iteration.

Procedure

1. Opening ANSYS Mechanical APDL and setting "Structural" preferences in "Job Preferences."
2. Defining element types (Structural mass) under "Element Type" in the "Preprocessor" menu.
3. Setting spring-mass-damper parameters using elements like COMBIN14 for springs and damper and MASS21 for mass.
4. Creating an appropriate mesh and assembling system components.
5. Applying boundary conditions and loads as needed.
6. Selecting the analysis type (harmonic) and defining controls in the "Solution" menu.
7. Executing the analysis by clicking "Solve."
8. post-processing the results in the "Postprocessing" environment, using plots and tools for visualization and interpretation.

Figure 3. Setup illustrating constraints applied to the degrees of freedom.

A. *Case I*

Spring-stiffness and damper coefficient was held at a constant value of 500 N/m and 2 Ns/m respectively. Mass of 2 kgs was applied and the following graph was produced.

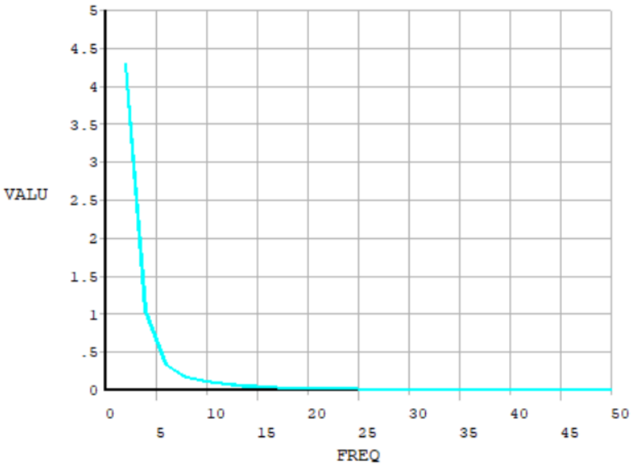

Figure 4. Illustration of the response when a mass of 2 kgs is applied.

B. Case II

Applying a mass of 4 kgs led to the graph below.

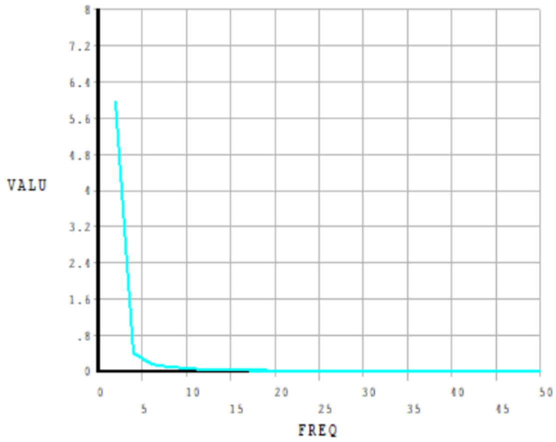

Figure 5. Illustration of the response when a mass of 4 kgs is applied.

C. Case III

Application of 6 kgs to the system.

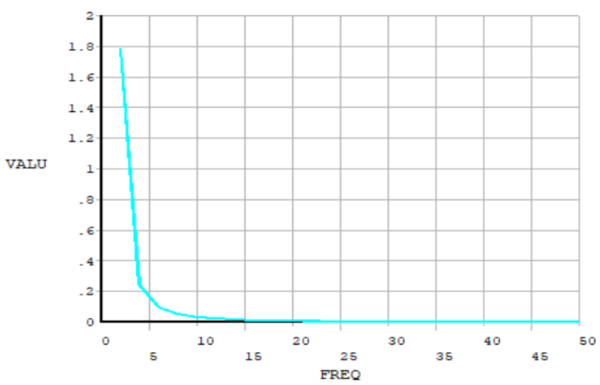

Figure 6. Illustration of the response when a mass of 6kgs is applied.

D. Case IV

Application of 8kgs to the system yields the following graph.

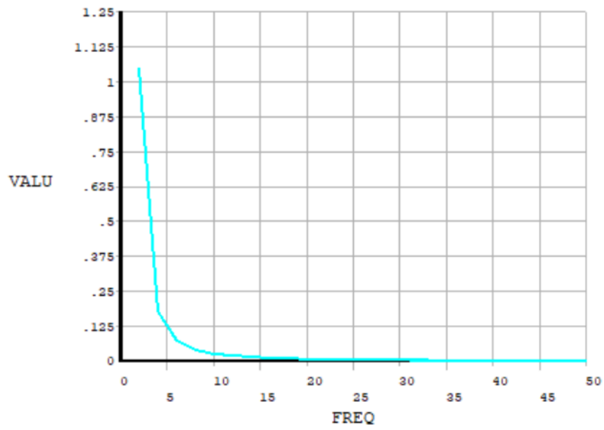

Figure 7. Illustration of the response when a mass of 8kgs is applied.

III. Observation

Throughout the simulation runs, it was consistently observed that as the mass of the spring-mass-damper system increased, the peak amplitudes of the system's response decreased, while maintaining constant spring stiffness and damping coefficients. However, it was also observed that when a mass of 4kgs was applied, the peak amplitude of vibrations achieved the highest value surpassing all the other values for a mass 2kgs and every other mass within the test range i.e. 2kgs up to 9kgs. Over time, after the 4 kg peak amplitude, the amplitudes exhibited a decreasing trend, eventually stabilizing to a steady state of approximately zero.

IV. Discussion

The reduction in peak amplitudes with an increase in mass can be attributed to the fundamental dynamics of the spring-mass-damper system. A higher mass results in a lower natural frequency of the system, which, in turn, affects the response amplitude. According to the principles of dynamic systems, the natural frequency is inversely proportional to the square root of the mass. Therefore, as mass increases, the natural frequency decreases, leading to a decrease in peak amplitudes. The amplitude at 4 kg became highest among the test masses because of a possible resonance frequency to the system. This is attributed to the fact that at resonant frequency the steady state amplitude of a system approaches infinity. The frequency of the system, at a mass of 4 kg, was close enough to the resonant frequency compared to the other three test masses.

The observed trend of amplitudes decreasing to a steady state around zero as time progresses is indicative of the system's response to external forces or initial disturbances. The damping coefficient plays a crucial role in governing this behavior. The damping effect gradually dissipates energy from the system, resulting in the attenuation of vibrations over time. As the system reaches a steady state, the damping forces balance the applied forces, and the system remains in equilibrium.

III. Conclusion

These findings emphasize the significance of considering the mass parameter when designing spring-mass-damper systems, as it directly impacts the dynamic response of systems. Furthermore, the role of damping in controlling oscillations and ensuring system stability is highlighted. Engineers and designers can use these insights to optimize system performance by adjusting mass, spring stiffness, and damping coefficients to meet specific requirements while minimizing undesired vibrations.

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