An Overview of Disarray in Analysis of Vibration Isolator Subjected to Harmonic Excitation with Nonlinear Parameters.

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Abstract

A vibration isolator in its most elementary form may be considered as a resilient member connecting the equipment and foundation. The function of an isolator is to reduce the magnitude of motion transmitted from a vibrating foundation to the equipment or to reduce the magnitude of force transmitted from the equipment to its foundation. This paper tries to give an idea about the previous researches & their finding about study of vibration isolator with non-linear parameters by considering quarter car model.

KEYWORDS – Vibration isolator, Resilient member, Non-linear parameters

I Introduction

Inserting the vibration isolator between the source of vibration and the vibration receiver is one of the fundamental ways to reduce the unwanted vibrations and to protect the equipment's from disturbance. The basic concept of the vibration isolator is that, when the frequency of excitation is larger than $\sqrt{2}\omega n$, where ωn is the un-damped natural frequency of the isolator, the transmitted force, Ft (or the transmitted displacement, Xt) reaches a value less than the excitation force, Fi (or the excitation displacement, Xi). The ratio Ft/Fi and Xt/Xi are denoted as force transmissibility and displacement transmissibility respectively. There is a well-known dilemma associated with linear viscous damping systems is that when the linear damping coefficient is increased, the force transmissibility under both base excitation and force excitation when excitation frequency less than $\sqrt{2}\omega n$ is further reduced, but the performance when excitation frequency greater than $\sqrt{2}\omega n$ is contrarily deteriorated. In order to over-come this dilemma, isolators with nonlinear stiffness and nonlinear damping have been studied by many authors in exploring the potential nonlinear benefits in vibration control. Another reason of the study on nonlinear stiffness and nonlinear damping is that almost all the isolators in practical vibration systems are inherently nonlinear.

Spring-mass-damper systems are well-known in studies of mechanical vibrations. The Duffing equation is used to model different spring- mass-damper systems. The Duffing equation may exhibit complex patterns of periodic, sub-harmonic and chaotic oscillations. Parameters of multiple non-linear mass dampers can be optimized based on numerical simulation of transient wave propagation through a linear spring mass carrier structure. Topology optimization is used to obtain optimized distributions of damper mass ratio, natural frequency, damping ratio and non-linear stiffness coefficient. By considering all above facts, this paper tries to cover literature which deals with vibration isolator with non-linear parameters by considering quarter car model.

II The Transmissibility of Vibration Isolators With Cubic Nonlinear Damping Under Both Force and Base Excitations

Zhenlong Xiao et al. [1] carried a work on the Transmissibility of Vibration Isolators with Cubic Nonlinear Damping under both Force and Base Excitations. The influence of a nonlinear damping which is a function of both the velocity and displacement is investigated for a single degree of freedom (SDoF) isolator. The analytical relationships between the force or displacement transmissibility and the nonlinear damping coefficient are developed in the frequency domain for the isolator systems subjected to both force and base excitation. It is theoretically shown that the cubic order nonlinear damping can produce much better isolation performance, i.e., obvious peak suppression at resonant frequency and very close transmissibility to system linear damping-over non-resonant frequencies under both force and base displacement excitations. Moreover, when only the pure cubic order nonlinear damping is used without linear damping, the force or displacement transmissibility is even better. The results are compared with the other nonlinear damping terms previously studied in the literature. Numerical studies are presented to illustrate the results.

III Theoretical Study of the Effects of Nonlinear Viscous Damping on Vibration Isolation of SDoF Systems

Z. Q. Lang et al. [2] carried a work on Theoretical Study of the Effects of Nonlinear Viscous Damping on Vibration Isolation of SDoF Systems. The present study is concerned with the theoretical analysis of the effects of nonlinear viscous damping on vibration isolation of single degree of freedom (SDoF) systems. The theoretical analysis reveals that the cubic nonlinear viscous damping can produce an ideal vibration isolation such that only the resonant region is modified by the damping and the non-resonant regions remain unaffected, regardless of the levels of damping applied to the system. Simulation study results demonstrate the validity and engineering significance of the analysis. This research work has significant implications for the analysis and design of viscously damped vibration isolators for a wide range of practical applications. The analysis indicates that a nonlinear viscous damper with a positive cubic damping term has no detrimental effects in the isolation region but adds considerable damping around the isolator's natural frequency so as to achieve an ideal transmissibility characteristic over the whole frequency range.

IV Damping System Designs using Nonlinear Frequency Analysis Approach

Pengfei Guo [3] submitted a thesis on Damping System Designs using Nonlinear Frequency Analysis Approach. The main purpose of this thesis focuses on the investigation of the frequency domain analysis and design approaches for nonlinear damping systems. With the development of modern mechanical and civil engineering structures, the vibration control has become a more and more important problem for the structural system protection. Traditional frequency domain design methods for linear damping devices have been widely studied by engineers and applied in engineering practice, where the system output frequency response is equal to the input spectrum multiplied by the system frequency response function.

Based on the Ritz-Galerkin method, a new method for the evaluation of the transmissibility of nonlinear SDoF viscously damped vibration systems under general harmonic excitations is derived. The effects of damping characteristic parameters on the system transmissibility are investigated. The results reveal that properly designed nonlinear fluid viscous dampers can produce more ideal vibration control over a wide frequency range.

V A Tunable High-Static–Low-Dynamic Stiffness Vibration Isolator

N. Zhou et al. [4] carried a work on a Tunable High-Static–Low-Dynamic Stiffness Vibration Isolator. In this study, a novel vibration isolator is developed. The developed isolator possesses the characteristics of high-static–low-dynamic stiffness (HSLDS) and can act passively or semi-actively. The HSLDS property of the isolator is obtained by connecting a mechanical spring, in parallel with a magnetic spring that is constructed by a pair of electromagnets and a permanent magnet. Using the stiffness models, the design optimization issues are investigated. In the experimental study, the effectiveness of the isolator for vibration isolation is tested. The analytical natural frequencies of the isolator are validated experimentally. The relationships between the displacement transmissibility and the exciting frequency are measured both under the passive mode and under the semi-active mode. The on-line tuning capability of the isolator is investigated.

VI Vibration Isolation Theory and Practice

Christine Connolly [5] published a paper on Vibration Isolation Theory and Practice. The purpose of this paper is to review the different method of isolating sensitive equipment from the effects of vibrations. The passive mechanisms of springs and dampers, air tables and negative stiffness are explained and practical examples are given. Descriptions of various active systems in which actuators respond in real time to feedback from motion sensors. Ingenious mechanical design allows passive systems to work with frequencies of the order of 1 HZ. Modern accelerometers detect absolute motion and allow disconnection from vibrations of the floor. Applications include the stabilization of inter-ferometric gravitational wave detectors.

VII Dynamics and Control for Vibration Isolation Design

Dino Sciulli [6] submitted a thesis on Dynamics and Control for Vibration Isolation Design. The single-degree-of-freedom (SDoF) system is the most widely used model for vibration isolation systems. The SDoF system is a simple but worthy model because it quantifies many results of an isolation system. For instance, a SDoF model predicts that the high frequency transmissibility increases when the isolator has passive damping although this does not occur for an isolator implementing active damping. Current literature has not fully explored the choice of mount frequency or actuator placement for flexible systems either. It is commonly suggested that isolators should be designed with a low-frequency mount. That is, the isolator frequency should be much lower than any of the system frequencies. A higher-order model such as a two-degree-of-freedom (2DoF) can be used in place of the SDoF model which gives flexibility in system, however increase in accuracy does come at a price.

VIII Modelling and Control Techniques of an Active Vibration Isolation System

Thorsten M¨uller et al. [7] published a paper on Modelling and Control Techniques of an Active Vibration Isolation System. In the field of high-resolution measurement and manufacturing, effective anti-vibration measures are required to obtain precise and repeatable results. In the active vibration isolation system examined, signals are acquired by extremely sensitive vibration detectors, and the vibration is reduced using either local analog feedback control or digital model-based control to drive electro-dynamic actuators. This papers deals with the modelling and control techniques of such an active vibration isolation system. The modelling, parameter identification, and model updating procedure are described. The experimental setup for testing such an anti-vibration system is described. An active anti-vibration system has been investigated both theoretically and experimentally. Control performance demonstrates that the multichannel active isolation system can effectively reduce the vibration of the equipment structure over a wide frequency range.

IX Vibration Isolation with Nonlinear Damping

Jerome E. Ruzicka et al. [8] published a paper on Vibration Isolation with Nonlinear Damping. The present paper discusses the performance characteristics of single degree-of-freedom vibration isolation systems in which the isolator damping force is proportional to the relative velocity across the isolator raised to an arbitrary power. The concept of equivalent viscous damping is employed to develop a general equation for the equivalent viscous damping ratio which is used to determine approximate isolation system response parameters. A range of isolator damping nonlinearity is studied by varying the relative velocity exponent between 0.5 and 5 for a fixed value of damping. Detailed results for parametric variations in damping are presented for specific values of the relative velocity exponent that correspond to Coulomb, viscous, quadratic, and cubic damping mechanisms.

X Large Time Dynamics of a Nonlinear Spring–Mass–Damper Model

Marta Pellicer [9] published a paper on Large Time Dynamics of a Nonlinear Spring–Mass–Damper Model. In this paper we consider a nonlinear strongly damped wave equation as a model for a controlled spring–mass–damper system and give some results concerning its large time behaviour. It can be seen that the infinite dimensional system admits a two dimensional attracting manifold where the equation is well represented by a classical nonlinear oscillations ordinary differential equation (ODE), which can be exhibited explicitly. In contrast to other papers, this one applies Invariant Manifold Theory to a problem whose linear part is not self-adjoint.

XI Analysis and Comparison of Vehicle Dynamic System with Nonlinear Parameters Subjected to Actual Random Road Excitations

Prof. S. H. Sawant and Dr. J. A. Tamboli [10] published a paper on Analysis and Comparison of Vehicle Dynamic System with Nonlinear Parameters Subjected to Actual Random Road Excitations. In this paper, nonlinearity in mass, spring and viscous damper are considered and compared for their individual and relative significance. Also, it is studied how nonlinearity affects the response compared to linear system. The theories of non-linear dynamics are applied to study non-linear model and to reveal its non-linear vibration characteristics. Thus this paper deals with comparison between simulation results obtained for passive and semi-active linear systems with nonlinear mass, spring and damper controller. Thus, the emphasis is to study the nonlinearities in mass, spring and damper for passive suspension system performance and compare the relative significance.

XII Combined Control Strategy Base Isolation and Tuned Mass Damper

M.De Iuliis et al. [11] published a paper on Combined Control Strategy Base Isolation and Tuned Mass Damper. Base isolation is nowadays widely considered as an effective strategy to protect structures subject to seismic excitations. Observing that the response of base-isolated (BI) systems is dominated by the first-modal contribution and that Tuned Mass Damping (TMD) is able to reduce the fundamental vibration mode, a new idea of combining both properties into a unique system (BI&TMD) was proposed and investigated by Palazzo and Petti. A benchmark structure in which the non-linear response of isolation devices (elastomeric and friction pendulum) is explicitly considered has been recently defined. By using this model, this paper aims to investigate the non-linear behaviour of the benchmark isolated structure when a mass damping system is applied on the isolation layer, in order to study the effectiveness of this strategy in reducing the seismic response of the isolation layer.

XIII Optimization of Non-Linear Mass Damper Parameters for Transient Response

Jakob S. Jensen et al. [12] published a paper on Optimization of Non-linear Mass Damper Parameters for Transient Response. The paper is concerned to optimize the parameters of multiple non-linear mass dampers based on numerical simulation of transient wave propagation through a linear mass-spring carrier structure. Topology optimization is used to obtain optimized distributions of damper mass ratio, natural frequency, damping ratio and nonlinear stiffness coefficient. A large improvement in performance is obtained with optimized parameters and it is shown that non-linear mass dampers can be more effective for wave attenuation than linear mass dampers. It was shown also that including non-linear stiffness was beneficial compared to having only a linear oscillator.

XIV Conclusion

By the literature review it is seen that vibration isolator designed with non-linear parameters is better because most vibrations phenomenon are non-linear in nature. In earlier researches vibration isolator with linear parameters were considered but in practice the vibrations phenomenon behaves nonlinear characteristic. So it is important to consider the nonlinearities of vibration isolator while designing the vibration isolator system. This behavior of vibration isolator system is studied with quarter car model.

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