Six degree of freedom active vibration isolation using quasi-zero stiffness magnetic levitation

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Abstract

Vibration is recognised as one of the most significant disturbances to the operation of mechanical systems. Many traditional vibration isolator designs suffer from the trade-off between load capacity and isolation performance. Furthermore, in providing sufficient stiffness in the vertical direction to meet payload weight requirements, isolators are generally overly stiff in the remaining five degrees of freedom (DOF). In order to address the limitations of traditional isolator designs, this thesis details the development of a 6-DOF active vibration isolation approach. The proposed solution is based on a magnetic levitation system, which provides quasi-zero stiffness payload support in the vertical direction, and inherent zero stiffness in the other five DOFs. The introduced maglev isolator also allows the static force and moment inputs from the payload to be adaptive-passively balanced using permanent magnets.

In this thesis, the theoretical background of the proposed maglev vibration isolation method is presented, which demonstrates the ability of the maglev system to achieve the intended vertical payload support and stiffness in the six degrees of freedom. Numerical models for calculating the forces and torques in the proposed maglev system are derived, and the analysis of the cross-coupling effects between the orthogonal DOFs of the isolator is also presented based on the developed system models. A mechanism is introduced by which the cross-coupling effects can be exploited to achieve load balancing for static inputs using permanent magnet forces alone.

Following the development of the theoretical model, the mechanical design of the maglev isolator is presented. The designs of the various control systems that are necessary to enable the operation of the maglev isolator are explained. The presented control algorithms achieve three functions: stabilisation of the inherently unstable maglev system, adaptive-passive support of the payload using the cross-coupling effects introduced previously, and autonomous magnet position tuning for online system performance optimisation.

Abstract

Following the discussion of the controller design, a 6-DOF skyhook damping system is presented. The active damping system creates an artificial damping effect in the isolation system to reduce the vibration transmissibility around the resonance frequency of the system. The vibration transmissibilities of the developed maglev isolator were measured in 6-DOF, and results are presented for various combinations of controller settings and damping gains. Through comparisons between the measured performance of the physical system and the predicted performance from theory, the developed maglev vibration isolator demonstrated its practical ability to achieve high performance vibration isolation in six degrees of freedom.

Statement of Originality

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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