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OPTIMIZATION AND MEASUREMENT OF EDDY CURRENT DAMPING IN A TUNED MASS DAMPER

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Abstract. This paper describes the optimization of the eddy current damping, applied in a tuned mass damper. A semi-analytical model based on scalar potential formulation is extended for different permanent magnet topologies. Optimal design variables are acquired by particle swarm optimization. Measurements are performed for validating the semi-analytical model and optimization routine.

Keywords: eddy current damping, tuned mass damper

INTRODUCTION

Over the last decades, the accuracy of high-precision positioning systems is increased to nanometer-scale. Parasitic vibrations in these positioning systems negatively affect its accuracy. These vibrations are often excited by uncontrollable sources, such as airflow or mechanical forces due to, for instance, rotating machines. It is complex to remove or suppress the excitation source. Therefore, the vibrations should be damped by active or passive devices.

Passive devices, such as Tuned Mass Dampers (TMDs), are capable of compensating frequencies above 100 [Hz], but only damp a single resonance mode and have limited bandwidth in which they work effectively [1]. The TMD splits a single resonance mode into two resonance modes, which have a lower amplitude compared to the original, single, resonance mode. Adding damping to the TMD further reduces the amplitude of the vibration by converting kinetic energy into heat.

Damping technologies applied in tuned mass dampers are, for instance, viscoelastic material damping, liquid/gas damping or electromagnetic damping, based on eddy currents. The damping in TMDs is commonly provided by liquid dampers. However, the liquid may leak over time and changing the damping ratio is complex or expensive after the damper is equipped in the TMD [2]. Electromagnetic damping on the other hand, has the advantage of no mechanical contact with the moving mass of the TMD and the damping ratio can easily be adjusted after the TMD is installed [3]. Electromagnetic damping originates from a time-varying magnetic field experienced by conductive materials, which induces eddy currents in the conductive material and opposes the changing magnetic field. The eddy currents, in conjunction with the magnetic field, create a damping force.

SEMI-ANALYTICAL MODEL

A simplified topology of eddy current damping in a TMD, as shown in Figure 1a and 1b, is modeled using the scalar potential model. In the scalar potential model, the permanent magnet is modeled based on a charge model. A field solution is obtained by solving the Maxwell equations for a single permanent magnet, and a conductive plate which is infinite in both *x*- and *y*-direction. The obtained field solution is magnetostatic, since the charge model assumes that the magnetic field is irrotational. Therefore, skin effect in the conductive plate and the counteracting magnetic reaction field, produced by the eddy currents themselves, is not taken into account by the scalar potential model. Skin effect has been included by assuming an exponential distribution of eddy current density along the height of the conductive plate. Multiple permanent magnets, magnetized in *z*-direction, can be modeled using superposition.

In the derivation of the semi-analytical model, it is assumed that the conductive plate is infinite in the *x*- and *y*-direction, whereas the conductive plate in Figure 1a and 1b has finite dimensions. To account for the finiteness of the conductive plate, a 2D-mirroring algorithm is applied [4].

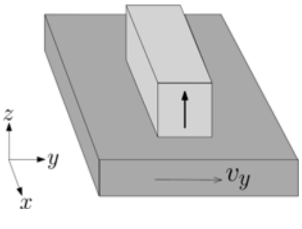

Figure 1a. The simplified topology of an eddy current damper

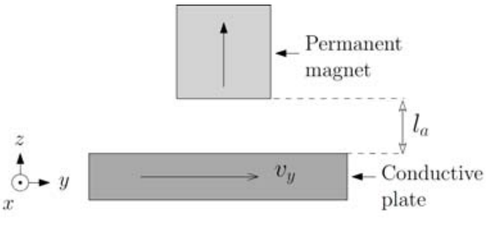

Figure 1b. The sideview of the simplified topology

DESIGN OPTIMIZATION AND MEASUREMENTS

A design optimization and measurements are performed for the inverse polarized topology to validate the semi-analytical model and increase the damping coefficient of a TMD. The inverse polarized topology consists of 2 permanent magnets which are reversely magnetized, on each side of the conductive plate (i.e. magnetized in the +*z* and -*z* direction).

A test assembly, as shown in Figure 2, is created to measure the damping force resulting from a moving conductive plate between permanent magnets. The permanent magnets are mounted on the magnet mount of the setup. Each side of the magnet mount is composed of two permanent magnets, magnetized in the +*z* and –*z* direction. The load cell is mounted on a linear mover to acquire the damping force. On top of the load cell, a conductive plate is mounted which experiences a time-varying magnetic field by moving through a static magnetic field, created by the permanent magnets. In Figure 3, the measured and modeled damping coefficient of the inverse polarized topology is shown for various heights of the conductive plate,z_{plate}, and gap between the magnets,d. The results are obtained for a constant velocity,v_y, of 0.3 [m/s] and a fixed airgap length,l_a, of 1 [mm].

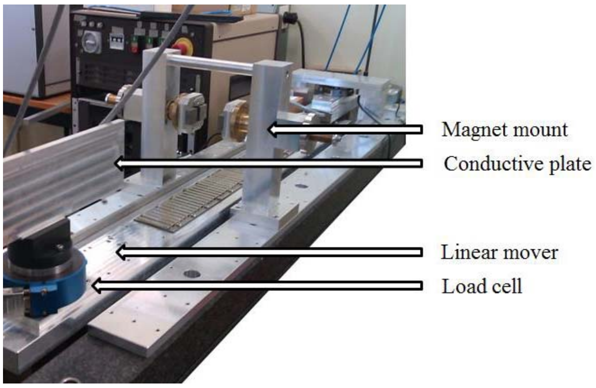

Figure 2. The sideview of the inverse polarized topology

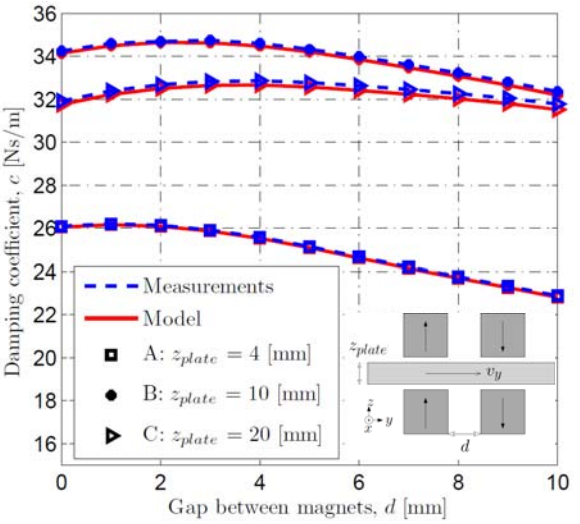

Figure 3. The modeled and measured damping coefficients for different conductive plates as function of the gap between the permanent magnets

The results of the semi-analytical model are obtained with 1 layer of mirrors. The average difference between the measurements and the semi-analytical model is below 5 [%].

Optimal design variables, such as the height of the conductive plate, are obtained by an optimization algorithm, based on Particle Swarm Optimization (PSO). Design variables are optimized such that the resulting damping coefficient is maximized. The results of the optimization algorithm are in good agreement with the optimal design variables found by measurements. Optimal dimensions of different permanent magnet topologies are obtained with the optimization algorithm for a TMD.

CONCLUSIONS

In this paper, a semi-analytical model, based on the scalar potential method, presents the damping force due to a, finite, rectangular, conductive plate moving in a magnetic field, induced by cuboidal permanent magnets. The maximum difference of the damping coefficient between the semi-analytical model and measurements is below 5[%]. Optimal design variables are acquired by an optimization algorithm, based on particle swarm optimization. The results of the optimization algorithm have been experimentally verified and are in good agreement with the results of the optimization. The final paper will include test results of optimized permanent magnet topologies in a TMD.

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