Integrated Adaptive Absorber for Vibration Damping in Printed Circuit Boards

Peter P. Pott, Axel Jäger, Helmut F. Schlaak

Institut für Eelektromechanische Konstruktionen,

Technische Universität Darmstadt, Deutschland, Email: p.pott@emk.tu-darmstadt.de

Introduction

Today's mobile machinery like cars, trucks, railways, construction machines and other equipment heavily rely on electronic subsystems. Engine- and chassis-induced vibrations can occur and cause fatigue effects in this electronic equipment. For dependable functionality, these devices usually are covered in rugged cases or casted in epoxy resin. However, for electronic circuits that require frequent maintenance or are subject to heat production this approach cannot be used.

Vibrations of large PCBs could be reduced by a directly integrated tuned vibration absorber device. Also, it is desirable to build small adaptive tuned vibration absorbers directly in the same process in which the main PCB is assembled and soldered. The work presented in this paper describes the design and the functionality of a PCB-integrated tuned vibration absorber.

System Design

In conventional absorbers, a passive spring-mass system is initially tuned to the dominant exciting frequency and thus introduces a damping force at its base point that reduces the amplitude of this particular vibration [1] [2]. In an environment with variable excitation frequencies, a suboptimal performance can be the result. In case of a rather large difference between the natural frequency of the absorber and the excitation an amplification of the amplitude can occur. This problem can be solved by the use of larger masses or by introducing adaptive absorbers, which track the disturbance frequency and provide a constant amount of vibration reduction while avoiding a high amount of additional mass.

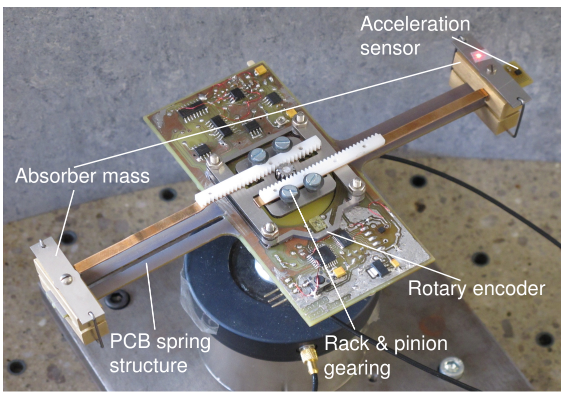

Figure 1: Adaptive vibration absorber on its test rig on an electrodynamic shaker. The bright dot on the right absorber mass indicates the use of a laser vibrometer.

The presented device basically is a two-mass adaptive modular tuned vibration absorber that consists of masses movable along spring elements. So, the natural frequency of the device can be tuned a specific frequency affecting the main PCB. Several sub-systems characterise the device:

Vibration System

The most important part in the tuned mass absorber is the spring element. In the presented case the PCB material itself is used to provide this functionality. PCB material consists of a glass-fibre reinforced epoxy resin with a flame retardant (FR4) and provides reliable mechanical properties in terms of its Young's modulus as well as breaking strain and strength. It is thus well suitable for the fabricating of spring structures. These are designed as bending beams. The masses are guided by a slot guide and a sliding bearing. By setting the masses to a specific position the Eigenfrequency of the tuned mass absorber is defined.

Actuation System

The movement of the absorber masses is achieved by a PCB-integrated piezoelectric travelling wave actuator (PCBmotor ApS, Hillerod, Denmark) that consists of a number small piezoelectric elements soldered to a ring structure that is directly milled out of the PCB material. The motor is driven by a two-phase alternating voltage of 40 kHz at 100 to 200 V. Thus, the actuator can be directly integrated into the PCB.

The masses are driven by a rack and pinion gearing that allows precise and play-free performance with little backlash. The guidance of the gearing is achieved by a monolithic pre-tension structure that is made from a single sheet of steel.

Sensor System

Two MEMS acceleration sensors (type BMA220, Robert Bosch GmbH, Gerlingen-Schillerhoehe, Germany) are mounted to the end of one of the bending beams and the base, respectively. So the frequency as well as the phase shift between the base and mass vibration can be determined by the micro controller. An optical encoder (AEDR-8300-1W1, Avago, San José, CA, USA) is used to determine the rotation angle of the PCBmotor rotor. In a later stage of the project a correlation between Eigenfrequency and mass position can thus be determined and a look-up table could be established. So, the tuned mass absorber could be externally set to a specific frequency that is not defined by the device itself.

Control System

A micro controller sets the phase-shift between the vibration of the mass and the base to 90° thus achieving a maximum amplitude reduction [3]. The algorithm uses a stepwise approach. In each cycle the phase-shift is compared to 90° and the an angular step of the size s of the PCBmotor in the according direction is initated as the actuator cannot be speed controlled. The movement is stopped when the actual phase difference is smaller than $90° \pm h$ with h as the hysteresis parameter. So, given the fact that $s < 2h$ an oscillation around the desired target position is avoided.

Mounting and Modularity

The chosen design allows the manufacturing of the complete electronics in a single PCB. Plug contacts are avoided and a conventional PCB assembly process can be used. The mechanical part consists of a stack of five flat structures for housing the motor bearing, guiding the rack and reinforcing the PCB. The assembly of the mechanical components can be easily automated. The presented absorber is easily scalable to different frequencies and forces. By changing the width and length of the beam structure the range of the natural can be determined. Also, the weight of the absorber masses can be – almost – arbitrarily chosen.

Experimental Evaluation

To assess the absorbers functionality, a test rig was established. It consisted of conventional PC with LabView software (National Instruments Corporation, Austin, TX, USA). The PC controlled a NI CompactRIO system with a type 9022 controller as well as type 9205 and type 9264 measuring boards. Using these, the signal for the shaker (model 4810, Brüel&Kjaer A/S, Naerum, Denmark) was generated and the signals provided by a vibrometer (OFV-2502, Polytec GmbH, Waldbronn, Germany) and the force/acceleration measurement head (model 8001, Brüel&Kjaer) were collected. Using Matlab (The Mathworks Inc., Natick, MA, USA) the collected data was assessed and evaluated.

Results

Figure 1 shows the tuned mass absorber in its test environment with a vibration source. The curves in figure 2 describe the behaviour with the masses at the outmost (left maximum, f_{res}=26 Hz) and innermost (right, f_{res}=68 Hz) position. Two positions in between have also been assessed. It becomes clear, that the desired functionality of setting the device's Eigenfrequency to within a certain range of $\Delta f_{res} = 42$ Hz is possible.

Discussion

We were able to show the basic functionality of the adaptive vibration absorber fully integrated into a printed circuit board. A frequency band of $\Delta f = 42$ Hz can be influenced. However, the first tests show that a second pronounced Eigenmode is also excited. Careful filtering of the signals provided by the acceleration sensors will thus be necessary. It is also obvious that a rather noticeable damping occurs. This will affect the functionality negatively and should be reduced in the next prototype. Future work will also include the reduction of the size of the central PCB.

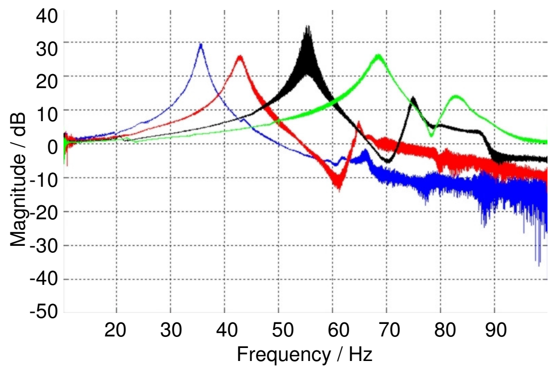

Figure 2: Results of the first assessment: The left curve shows the relation of exciting vibration and response of the device with the masses in the outmost position. The resonance frequency is 26 Hz. The rightmost curve gives the behaviour with the masses in the inner position (f_{res}=68 Hz). A frequency band of $\Delta f_{res} = 42$ Hz width can be provided.

Acknowledgement

The work on this project was funded by the German state of Hesse within the LOEWE-AdRIA project. The μC-program was created by Mr. Su Chang and optimised by Mr. Sriram Prabhu. Their support and the help during the experiments by Mr. Roman Karsten are greatly appreciated.

References

[1] Wright, R. I. and Kidner, M., Vibration Absorbers: A Review of Applications in Interior Noise Control of Propeller Aircraft. Journal of Vibration and Control, 10, pp. 1221-1237, 2004.

[2] Kela, L. and Vahaoja, P., Recent Studies of Adaptive Tuned Vibration Absorbers/Neutralizers. Appl. Mech. Rev, Bd. 62, pp. 60801-1-60801-10, 2009.

[3] Franchek, M. A., Ryan, M. W. and Bernhard, R. J., Adaptive Passive Vibration Control. Journal of Sound and Vibration, 189(5), pp. 565-585, 1996.