Novel Active Vibration Absorber with Magnetorheological Fluid

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Abstract. Disturbing vibrations diminish the performance of technical high precision devices significantly. In search of a suitable solution for reducing these vibrations, a novel concept of active vibration reduction was developed which exploits the special properties of magnetorheological fluids. In order to evaluate the concept of such an active vibration absorber (AVA) a demonstrator was designed and manufactured. This demonstrator generates a force which counteracts the motion of the vibrating body. Since the counterforce is generated by a centrifugal exciter, the AVA provides the capability to compensate vibrations even in two dimensions. To control the strength of the force transmitted to the vibrating body, the exciter is based on a tunable MR coupling. The AVA was integrated in an appropriate testing device to investigate its performance. The recorded results show a significant reduction of the vibration amplitudes by an order of magnitude.

1. Introduction

A multitude of technical high precision devices generate unintended vibrations while they are operating. By reducing these disturbing vibrations, the performance of the devices can be significantly enhanced. An already known approach to solve this problem is the semi-active damping of vibrations with magnetorheological (MR) fluids [1]. In MR dampers, the influence of a magnetic field on the rheological properties of the MR fluid is exploited to control the damping force [2-4].

Another general technical solution to minimize disturbing vibrations is based on an active vibration absorber (AVA). In such a device, an active force is generated by an appropriate actuator which acts against the motion of the vibrating body. If the strength of the counter-force equals that of the force which causes the disturbing vibration, the forces compensate one another and the vibration is canceled.

The key question is how to generate a force of correct strength and phase to counteract the disturbing vibration. Piezoelectric actuators [5] have received much attention in this respect, but are expensive and show only small displacements. The use of a centrifugal exciter is a well known solution for generating a periodic force, because it is a light, small and cost-effective device which can produce very high forces at low power consumption. However, a problem of this approach is that the strength of the generated force increases quadratically with the rotation frequency of the exciter. Thus, the generated force at each tuned rotation frequency is fixed and cannot be changed independently.

A possible technical solution for an adjustably controllable centrifugal exciter is described in a US patent [6]. Furthermore, various real-time controlled techniques for reducing disturbing vibrations were developed for a multitude of technical applications, i.e. in the helicopter industry [7, 8].
This paper addresses a novel concept of controllable vibration reduction, in which a centrifugal exciter is connected to a force-modifying transmitter based on magnetorheological fluids. This combination leads to an active vibration absorber, where the MR fluid modifies the force of the centrifugal exciter to the required strength.

2. Concept and realization of the active vibration absorber

In order to prove the feasibility of the novel concept, a demonstrator of the active vibration absorber with a centrifugal exciter and an MR fluid for the reduction of vibrations was designed and manufactured. A scheme of the demonstrator is presented in Figure 1.

Figure 1. Scheme of the active vibration absorber

The assembly can be attached to a vibrating body in order to minimize the amplitude of its vibrations. The demonstrator consists of two main components. The first component is a centrifugal exciter which generates a rotating force. The second component is a tunable MR coupling device which enables a controlled transmission of the force generated by the centrifugal exciter to the vibrating body.

The tunable coupling device exploits the MR shear mode. The force is transmitted between two parallel plates which are moveable with respect to each other, parallel to their surfaces. The first plate is fixed to the vibrating body and the second plate is connected to the centrifugal exciter. The gap between the two plates contains the MR fluid. The magnetic circuit with the coil for generating the requested magnetic field is integrated in the tunable MR coupling device (see Figure 1). The centrifugal exciter generates a high rotating force whose amount quadratically increases with the rotation frequency.

The magnetic field strength and the phase of the exciter must be tuned in such way, that the force which is transmitted to the vibrating body compensates the vibration force. Due to the broad variability of the shear stress of MR fluids, the counterforce transmitted by the MR coupling device can be adapted to meet a large range of requirements in terms of force and frequency.

Since the counterforce is generated by a centrifugal exciter, this vibration absorber provides the opportunity to compensate vibrations even in two dimensions. This is advantageous for a multitude of applications where rotating machines cause vibrations in the plane of the rotation. Figure 2 shows a photograph of the demonstrator of the novel AVA.

3. Experimental evaluation

3.1. Design of the testing device

In order to study the performance of the active vibration absorber, the manufactured demonstrator was integrated in a testing device, which is able to provide vibrations within the range between 15 Hz and 30 Hz. Figure 3 shows a scheme of this testing device.
The disturbing vibration force for the testing is generated by a second centrifugal exciter fixed on the same plate to which the active vibration absorber is attached. While the AVA is turned off, the disturbing force will cause an oscillation of the plate. By turning on the centrifugal exciter of the AVA, the second centrifugal force is generated. If the force transmitted to the plate, connecting the two exciters by the tunable MRF coupling, has the same value but the opposite orientation, the two generated forces compensate each other and the disturbing vibration of the system is drastically reduced.

In order to investigate, whether the tunable MRF coupling will be able to transmit only a diminished amount of energy, the exciter of the disturbing vibration of the test rig has to generate a lower centrifugal force than the one in the active vibration absorber. By modulating the magnetic field strength of the tunable MRF coupling, only that portion of the force has to be transmitted which is necessary to achieve a maximum vibration reduction. The vibration amplitudes are recorded by an accelerometer which is attached to the plate. Figure 4 reveals the experimental set-up of the testing device.

3.2. Investigations and results
A self-manufactured MR fluid with an iron particle concentration of 50 vol.% in silicone oil as carrier liquid was used for the investigations with the AVA. This selection was motivated by the intention to transmit high forces by the MR fluid.

For the sake of simplicity, the following discussion is limited to vibrations in only one dimension. The aim of a first test series was to study the performance of the demonstrator at vibration frequencies
in the range of 19 to 28 Hz. Within the tested frequency range, a high reduction of the vibration amplitudes was achieved. Figure 5 presents the recorded amplitudes at a frequency of 25 Hz by way of example.

The results demonstrate that a significant reduction of the vibration amplitudes can be achieved with the active vibration absorber. Figure 5 depicts that a significant decrease of the vibration amplitude by an order of magnitude is possible without an appreciable effort of electronic control.

Furthermore, it has been demonstrated that it is possible to modify the force transmitted by the MR coupling by varying the magnetic field strength inside the MR fluid. If the magnetic field is optimized, the disturbing force and the counter-force nearly equalize each other and the vibration amplitude is reduced significantly. If the magnetic field is too weak, an insufficient force is transmitted by the MR coupling and the amplitude of the vibration increases. If the strength of the magnetic field is too large, an excessive force is transmitted and the vibration amplitude also increases. A comparison of these different conditions in terms of magnetic field strength is given in Figure 6.

4. Conclusions

A novel concept of an active vibration absorber (AVA) was developed, which combines the efficiency of force generation by a centrifugal exciter with the controllability of force transmission by MR fluids. With an experimental set-up, it could be demonstrated that the amplitude of a vibration can be decreased by an order of magnitude. This principle can be adjusted to a large range of different working conditions, while the power consumption is very low.

Moreover, the concept of an active vibration absorber with an MR fluid provides a powerful tool for the effective reduction of disturbing vibrations, even in two dimensions. By reducing these unintended vibrations, the performance of large number of technical high precision devices can be significantly enhanced. This approach has a large potential for many applications in transportation and industry, where disturbing vibrations are caused by rotating engines.

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References

[1] M. Mao, W. Hu, Y.-T. Choi, N. M. Wereley: A magnetorheological damper with bifold valves for shock and vibration mitigation, J. Intelligent Mater. Syst. Struct. 18 (2007) 1227-1232
[2] J. Ehrlich, H. Böse: Novel magnetorheological damper with outstanding fail-safe characteristics. Proceedings of Actuator 2008 – 11th International Conference on New Actuators (2008) 495-498
[3] S. J. Dyke, B.F. Spencer, Jr., M.K. Sain and J.D. Carlson: An Experimental Study of MR Dampers for Seismic Protection, Smart Materials and Structures 7 (1998) 693-703
[4] U. Lange, S. Vassileva, L. Zipser: Controllable magnetorheological dampers for shock and vibration. Proceedings of Actuator 2002 – 8th International Conference on New Actuators (2002) 339-342
[5] A. Illgen, V. Wittstock: Piezo based active vibration absorber for gear box noise reduction in wind turbines, Fraunhofer-Institut für Keramische Technologien und Systeme-IKTS, Dresden: Piezocomposite Applications. CD-ROM: September 27-29, 2007, Dresden, ISPA2007
[6] G. J. Orzal, Gregory: Adjustably controllable centrifugal vibratory exciter, US Patent 4568218
[7] M. Jolly, S. Hildebrand, R. Altieri, M. Ferguson, D. Ivers: Helicopter vibration control system and rotary force generator for canceling vibrations, US Patent 7448854
[8] I. Reed, H. Wilmer: System for controlling higher harmonic vibrations in helicopter rotor blades, US Patent 5314308