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# Reduction of magneto rheological dampers stiffness by incorporating of an eddy current damper

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ABSTRACT

In this paper, a hybrid damper is developed to achieve lower stiffness compared to magneto rheological dampers. The hybrid damper consists of an eddy current damper (ECD) and a Magneto Rheological Damper (MRD). The aim of this research is to reduce the stiffness of MRDs with equal damping forces. This work is done by adding an eddy current passive damper to a semi-active MRD. The ECDs are contactless dampers which show an almost viscous damping behavior without increasing the stiffness of a system. However, MRDs increase damping and stiffness of a system simultaneously, when a magnetic field is applied. Damping of each part is studied theoretically and experimentally. A semi-empirical model is developed to explain the viscoelastic behavior of the damper. The experimental results showed that the hybrid damper is able to dissipate energy as much as those of MRDs while its stiffness is 12% lower at a zero excitation current.



## 1. Introduction

Active and passive dampers are usually used to control systems' damping and to reduce vibrations near the resonance frequency of systems. One of the most commonly used semi active dampers in various applications is magneto rheological dampers. Their Controllability and speed of reaction in a mechanical system have led to their wide application. Applying magnetic field to magneto rheological fluid, the fluid behavior would change from Newtonian into non-Newtonian fluid behavior [1]. The magneto rheological dampers are used in semi-active control of vehicles suspension systems [2]. The hysteric behaviors of magneto rheological dampers have been studied in some research [3–5]. Investigation of the comfort and performance of semi-active MRDs in vehicle suspension systems has been considered in some papers [6–9]. Reduction of vibrations of helicopters blade, wind turbine, spatial structures and isolators have been investigated in other works [10–17]. Applying different kinds of controller to control vibrations, using MRDs have also been conducted in research works [18–24]. ECDs are other types of dampers, where passive ECDs are more efficient than active ones. Active ECDs are used less because of having high power consumption. They are applied in space structures in space industries [25–29]. In MRDs, applying magnetic field increases damping and stiffness of the damper. Although the increase of damping is higher than that of stiffness, it is unwanted in a system [30]. Dampers are divided into passive, active and semi-active groups. Semi-active control of vibrations is the best method, concerning the power consumption, reliability and damping control [31].

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**Nomenclature**

| | |
|---|---|
| $A_p$ | Piston area |
| $A_s$ | Shaft area |
| $B$ | Magnetic flux density |
| $B_r$ | Radial magnetic flux density |
| $C_{vis}$ | Viscous damping coefficient |
| $C_{eq}$ | Equivalent damping coefficient |
| $C_{d-ECD}$ | semi-empirical ECD damping |
| $C_{d-MR}$ | semi-empirical MRD damping |
| $d$ | Gap of the valve |
| $dh$ | Thickness of the outer ring |
| $E$ | Electrical field |
| $E_d$ | Damping energy |
| $E\ (k)$ | Elliptic integral of the first kind |
| $F$ | Force |
| $F_{d-hybrid}$ | semi-empirical hybrid force |
| $F_{d-ECD}$ | semi-empirical ECD force |
| $F_{d-MR}$ | semi-empirical MRD force |
| $F_{damper}$ | Total force of the Damper |
| $F_d$ | Total Damping force of MRD |
| $F_{MR}$ | Active damping force of MRD |
| $H$ | Magnetic field intensity |
| $I$ | Electric current |
| $J$ | Current density |
| $K\ (k)$ | Elliptic integral of the second kind |
| $K_{d-ECD}$ | semi-empirical ECD stiffness |
| $K_{d-MR}$ | semi-empirical MRD stiffness |
| $L$ | Length of the piston |
| $M$ | Magnetization |
| $Q$ | Flow rate |
| $R$ | Radius of the permanent magnet |
| $R_P$ | Radius of the MRD piston |
| $r_{inside}$ | Inner radius of the magnet |
| $r_{outside}$ | Outer radius of the magnet |
| $t$ | Time |
| $v$ | Velocity |
| $w$ | Width of the coil |
| $X_d$ | Sinusoidal displacement function |
| $X_0$ | Displacement amplitude |
| $\Gamma$ | Conductor volume |
| $\mu_0$ | Air magnetic permeability |
| $\tau$ | Thickness of each pole |
| $\tau_P$ | Thickness of the magnet |
| $\tau_f$ | Thickness of the iron pole |
| $\tau_y$ | Shear stress |
| $\eta$ | Viscosity of the MR Fluid |
| $\sigma$ | Electrical conductivity |
| $\omega$ | Angular frequency |

Among the hybrid damper applications, we can refer to vibration control in helicopter blades [32] and force control in surgeon aids via HAPTIC systems [33]. Ebrahimi et al. presented a hybrid damper consisting of an electromagnetic, eddy current and hydraulic dampers made in an active way [34]. Another work on hybrid dampers with active control is the combination of elastomeric with piezoelectric dampers. Elastomeric dampers have no good controllability; hence the problem has been addressed through combining it with a piezoelectric damper in an active way [35]. Chen et al. combined magneto rheological dampers with a linear magnetic actuator which is able to dissipate more energy and functions without sensors [36]. Hybrid shape memory alloys and eddy current dampers to control vibrations are applied in [37]. Table 1 shows a comparison between MRDs and ECDs.

The purpose of this paper is to combine a non-contact ECD with a contact MRD in order to reduce the stiffness of the system with equal damping forces. The most important motivation of the combination is the nature of ECDs i.e. not having stiffness, to reduce the overall stiffness of the damper and also using low power consumption of MRDs in the active mode. In active dampers, damping coefficient should change frequently with the system oscillations. For instance, in active MRDs used in automotive suspension systems, the damping coefficient increases in the expansion stroke of springs and decreases in the contraction [6]. This is because in the contraction stroke, some portion of the kinetic energy is reserved in springs and some portion is dissipated in the damper. However, in expansion stroke, the reserved energy in springs is released and added to the kinetic energy of the system. Therefore, higher damping coefficient is needed in expansion stroke to dissipate energy. Moreover, if the damper possesses stiffness in its structure, some part of the energy is reserved in the damper itself, and then returns to the system and causes more oscillations. Reducing the MRD's stiffness through combining it with an ECD, decreases the energy storing component of the system. Therefore, the damper would play only the role of energy dissipation. Further, the required changes in the damping coefficient are implemented by the low power consumption MRD. Since ECDs require a very large magnetic field relative to the MRDs for the same value of damping force, it would have very high power consumption, specifically in the active mode. This hybrid damper can have potential applications in automotive suspension systems and vibration isolators.

The theory dominated over ECDs and MRDs is considered and the related analytical equations are derived. A semi-empirical model is developed to estimate damping and stiffness coefficients of the damper. Concerning the design's goals

**Table 1**
Comparison of ECDs and MRDs.

| Damper type | Power consumption in active mode | Contact | Behavior | Price | Maintenance |
|---|---|---|---|---|---|
| MRD | Very low | Yes | Non-linear | High | High (fluid sedimentation and leakage) |
| ECD | Very high | No | Linear | Low | No |