Performance of magnetorheological fluids in a novel damper with excellent fail-safe behavior

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Performance of Magnetorheological Fluids in a Novel Damper With Excellent Fail-Safe Behavior

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Abstract. A novel magnetorheological damper, whose magnetic circuit contains beside an electromagnet also two permanent magnets, is described and tested. Without any consumption of electric energy, a medium damping force is achieved, which ensures an excellent fail-safe behaviour in case of an electric power loss. This medium damping force can be increased or decreased, depending on the polarity of the current in the coil. Furthermore, the performance of the damper with different MR fluids was investigated. By this way, the influence of the composition of the MR fluid in terms of the concentration of iron particles between 20 and 50 vol.% on the damping force could be evaluated. Finally, the damping force after various storage times of the damper was studied and indicated a good redispersibility of the MR fluid.

1. Introduction

In a magnetorheological (MR) damper the damping force is continuously influenced by the strength of a magnetic field which controls the rheological characteristics, i.e. the flow resistance of an MR fluid. The increase or decrease of the damping force can be achieved within some milliseconds, due to the fast response of the MR fluid. A large number of different MR damper designs have been proposed so far. Such adaptable MR dampers have already been commercialized as automotive shock absorbers [1] or semi-active seat dampers in trucks and busses [2].

The magnetic field in an MR damper is usually generated with a coil in a magnetic circuit [3-5]. The circuit guides the magnetic flux through the active part of the fluid valve where the MR fluid is stiffened, causing a resistance force against the motion of the piston of the damper. This principle implies that the lowest damping force is generated when no current is generated in the coil. When a failure of the electric power supply occurs, the MR damper automatically switches to its softest damping state. This fact restricts the selection of the damping characteristics because the powerless state must fulfill the requirements of an appropriate fail-safe behavior.

An objective of this work is to propose a novel MR damper with a magnetic circuit containing an electromagnet and additionally permanent magnets in order to achieve an improved fail-safe behavior. Another objective is the evaluation of the performance of the novel MR damper filled with MR fluids having different compositions and corresponding properties.

2. Design of the MR damper

The novel MR damper has a piston which contains the magnetic circuit with a coil and two permanent magnets. A scheme of the piston and the magnetic flux in the circuit in different operation modes are

shown in Figure 1. The permanent magnets generate a magnetic base field which remarkably solidifies the MR fluid in the MR valve without any electric power supply. In addition, the coil generates a magnetic field which strengthens or weakens the magnetic field of the permanent magnets in the active MR gap as requested, depending on the polarity of the current in the coil. The magnetic flux density was simulated with a Finite Elements Method (FEM). A particular advantage of the magnetic circuit is its capability to reduce the magnetic flux density in the MR valve to nearly zero. This allows to drastically reduce the damping force, caused by the permanent magnets, and to achieve a large range of damping forces. More details of the magnetic circuit were described in [6]. A demonstrator of the novel MR damper was manufactured and is shown in Figure 2. It contains a gas accumulator for the compensation of the volume change of the piston rod in the damper due to the motion of the piston.
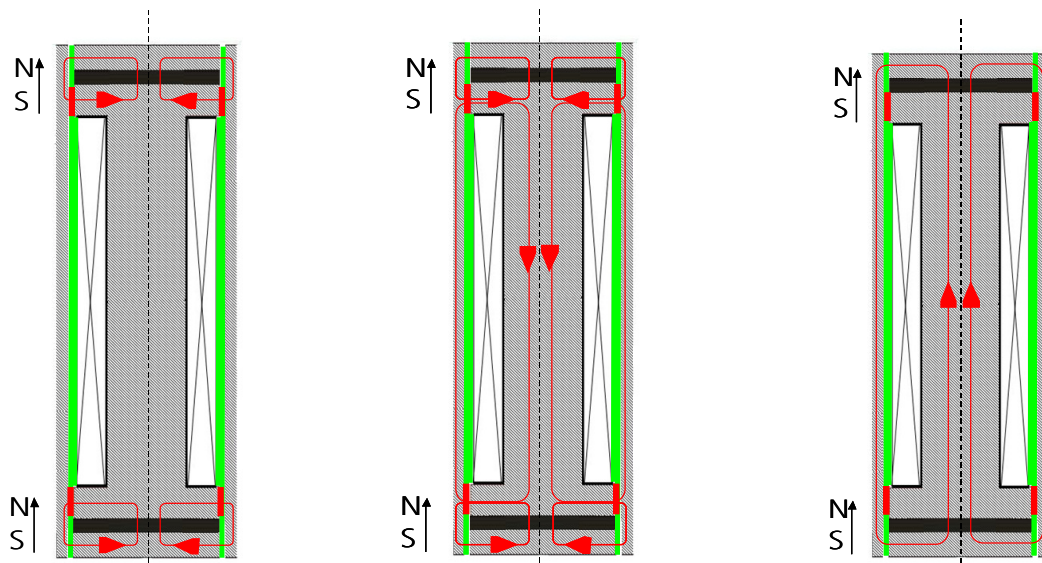

Figure 1. Scheme of the piston of the novel MR damper with the magnetic circuit in three different operation modes: without coil current (left), with positive coil current (middle) and with negative coil current (right). The annular MR fluid gap is green and the MR valves and magnetic flux lines are red.
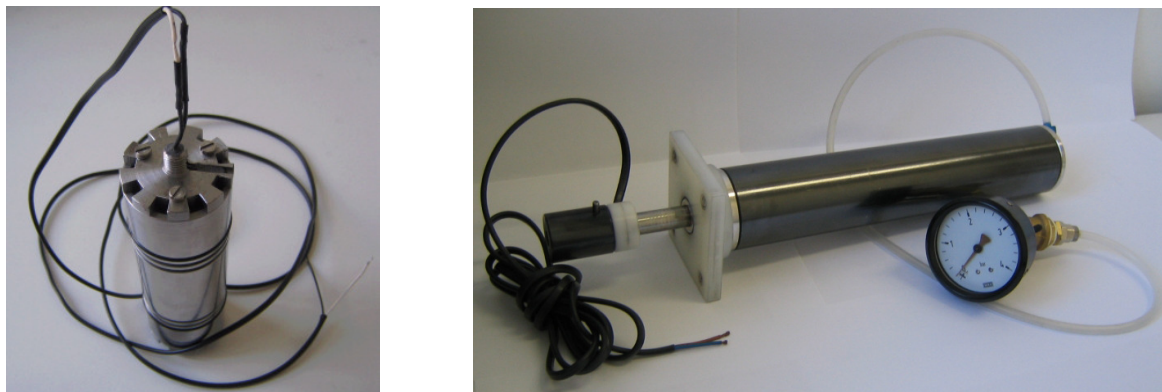
Figure 2. Photographs of the novel MR damper: piston with electric connection (left) and damper with pneumatic connection to accumulator (right)

3. MR fluids used in the damper

The characteristics of the MR damper were evaluated by using various MR fluids with different profiles of properties. This procedure offers the possibility to compare the performance of the MR fluids and to study the influence of their composition on the damping characteristics. The MR fluids mainly differed in their concentrations of the magnetizable iron particles, which determine the MR effect, i. e. the enhancement of the shear stress in the magnetic field. The performances of three MR fluids with iron concentrations of 20, 36 and 50 vol.%, respectively, were compared. Figure 3 shows the flow curves without magnetic field and the dependence of the shear stress on the magnetic flux density for the three MR fluids. The data was measured in shear mode with a rheometer MCR 300 from Anton Paar, equipped with a magnetorheological cell.
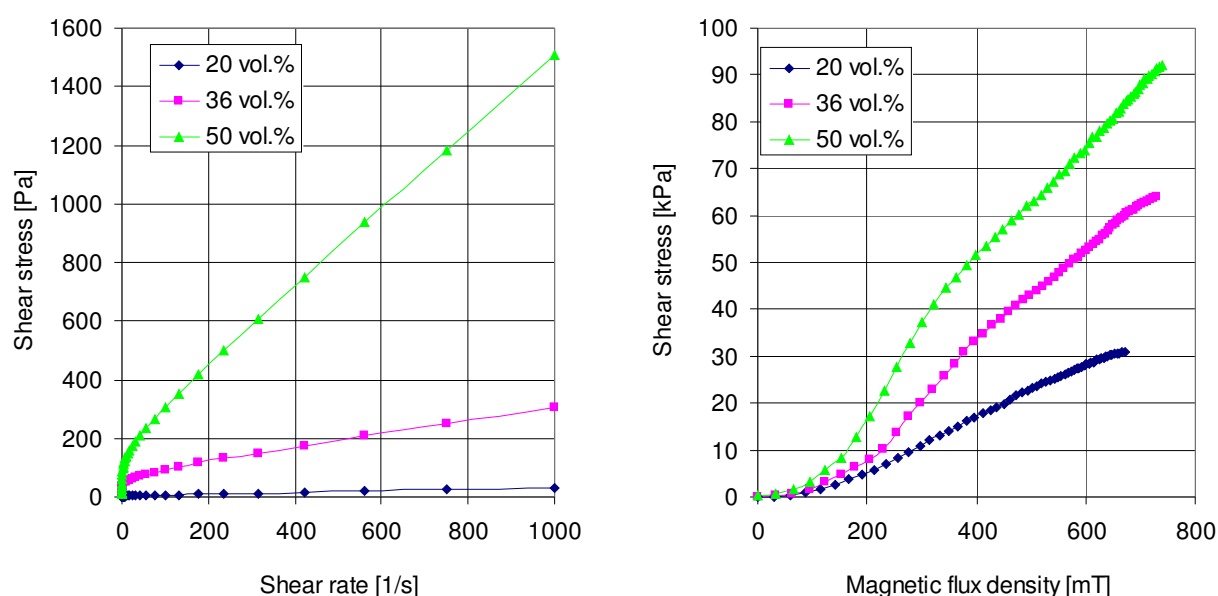
Figure 3. Properties of MR fluids with different particle concentrations (in vol.%): flow curves without magnetic field (left) and shear stress vs. magnetic flux density at 25 °C and shear rate 100 s^{-1}

4. Mechanical evaluation of the MR damper

The damping characteristics were measured on a dynamic testing machine with a sinusoidal load with an amplitude of 8 mm and a frequency of 1 Hz. The damping force was recorded for the use of the three MR fluids at various coil currents.

More detailed investigations were performed with the MR fluid containing 36 vol.% iron particles. With this MR fluid, the influence of the storage time in the damper on the damping performance at the first strokes after defined periods of storage and after defined cycles of work was studied. These experiments yield information on the storage stability and the redispersibility of the used MR fluid under near-application conditions.

5. Results and discussion

The results of the force measurements on the MR damper containing the MR fluid with 36 vol.% iron particles are shown in Figure 4. Without any current in the coil, indicating the power-less damping state, a damping force of about 1400 N was measured. The lowest damping force was determined to be about 400 N for a negative current of -3 A and the highest force 4000 N for a positive current of +3 A. These results demonstrate the excellent fail-safe behavior of the MR damper in case of a power-failure.

Corresponding measurements were also performed with the damper containing the other MR fluids with 20 and 50 vol.% of iron particles, respectively. For the MR fluid with 50 vol.% iron particles in the damper, the maximum applicable current was restricted to 0 A, because at higher currents the damping force could destroy the accumulator in the damper. Figure 4 shows a summary of the measured damping forces, using the three MR fluids, in dependence on the coil current.

As expected, the investigations with the three MR fluids containing 20, 36 and 50 vol.% iron particles showed damping forces which, on one hand, increase with the rising iron particle content. On the other hand, the switching factor, i. e. the ratio of the maximum damping force with the strongest magnetic field to the minimum damping force with the weakest field, increased with a decreasing concentration of iron particles in the MR fluid. It was concluded that a medium iron particle content could be a good compromise for this MR damper.

Moreover, the measurements on the damper with the MR fluid containing 36 vol.% iron particles showed a good performance in terms of the stability of the damping force even after storage times of up to 36 days (see Figure 5). The initial increase in the damping force after storage of the damper, observed directly after the start of the measurement, disappeared after 1 minute of operation of the damper. This behavior emphasizes the good redispersibility of the MR fluid used in the damper.
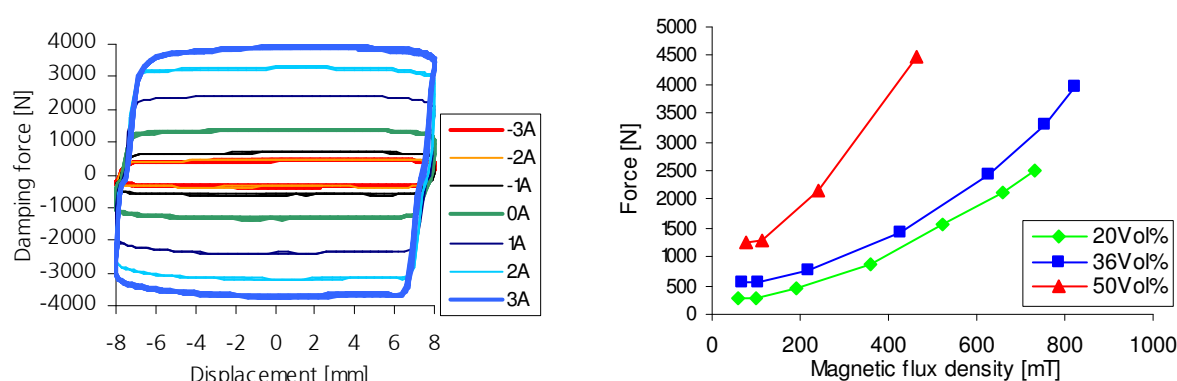
Figure 4. Damping force of the novel MR damper with the 36 vol.% MR fluid measured with a mechanical testing machine at different coil currents (left) and dependence of the damping force on the magnetic flux density for the three MR fluids with different iron contents (right)
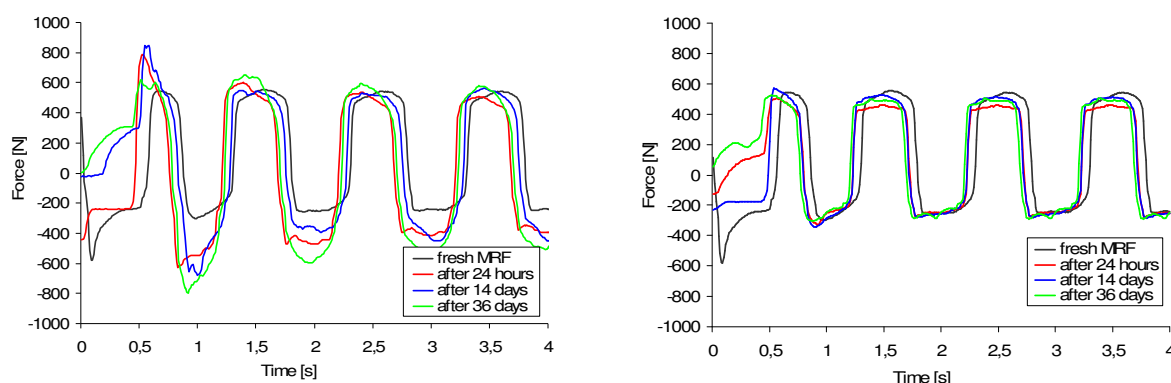
Figure 5. Damping force of the novel MR damper with the 36 vol.% MR fluid after various storage times: immediately after insertion into the testing machine (left) and after 1 min of operation (right)

6. Conclusions

A magnetorheological damper with excellent fail-safe behavior was developed and tested. Due to the integration of an electromagnet and permanent magnets, the damper generates a medium damping force without electric energy consumption, which can be increased or decreased by the electromagnet. This operation principle allows a broad variability of the damping force, as shown by this study.

The novel damper design with its special magnetic circuit offers a huge potential for a large number of products in automotive, industrial and other applications, like adaptive shock absorbers and semi-active vibration dampers. A prerequisite is the availability of an MR fluid whose properties are adapted to the damper design and working mode. The performance of a special MR fluid with a medium content of iron particles showed also very promising results in terms of storage stability and redispersibility.

Acknowledgments

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