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DESIGN OF FAST MAGNETORHEOLOGICAL DAMPER USING SOFT MAGNETIC COMPOSITES

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Abstract: *The article investigates the suitability of soft magnetic composite (SMC) material for construction of magnetorheological damper piston. The SMC materials have, in comparison with steel, high electric resistance, which secures very short response time of magnetic induction in the magnetic circuit. In comparison with ferrite materials, the SMC materials have better mechanical properties and high magnetic saturation level, which secures high dynamic range. The disadvantage of SMC material is low permeability. The measurements and simulations showed that MR damper piston made of SINTEX STX SMC prototyping material achieves high magnetic flux density in the MR damper piston gap (only 20 % lower than piston made of steel) and very short response time of magnetic flux density in the gap (more than 20 times shorter than in case of steel piston).*

Keywords: MR damper, Fast response, Soft magnetic composite, SMC.

1. Introduction

The response time and the dynamic range of Magnetorheological (MR) damper is one of the key factors influencing performance of semiactive suspension. Strecker (2015) described the dependence of MR damper response time on the passenger car semiactive suspension controlled by Modified groundhook algorithm. The simulations and measurements showed that the response time 8 ms (usual for commercial MR dampers) is too long for efficient semiactive control. Therefore it is necessary to develop MR dampers with short response time. Reasons of long response time of MR devices were described in Maas (2011). One of the most important sources of long response time of MR dampers are eddy-currents. They can be eliminated using material with high electrical resistivity. Strecker (2015) designed a fast MR damper, with response time of damper force on control signal up to 1.5 ms. The magnetic circuit of the MR damper was made of ferrite material Epcos N87. Ferrites have good permeability (μ_r = 2200) and very high electrical resistivity 10 Ω.m. This material, however, has bad mechanical properties, very poor machinability and low magnetic saturation (490 mT). Therefore, the dynamic range of MR damper made of ferrite material is much smaller in comparison with the piston made of steel. Another way of reducing the eddy currents while keeping high dynamic range seem to be the use of structured cores made of steel. The steel cores with a structure preventing eddy currents can be printed from pure iron by 3D SLM print (Palousek, 2017). It is, however, very difficult to design the appropriate structure. Soft magnetic composites (SMC) seem to be suitable material for construction of MR damper piston. The electrical resistivity of SMC materials can be more than thousand times higher than the resistivity of steel, which practically eliminates eddy-currents (Shokrollahi, 2007). The magnetic saturation level of SMC materials is much higher than in case of ferrites, which allows designing of MR dampers with higher dynamic range. Some SMC materials are easily machinable. However, SMC materials have very small relative permeability. Therefore it is necessary to evaluate the suitability of this material for the design of MR damper.

2. Methods

The objective was to design a new MR damper piston which eliminates eddy currents induced in the magnetic circuit of the MR damper and which enables large control range of achievable magnetic flux

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density in the gap of MR piston. The performance of the new piston made of soft magnetic composite material was compared to the piston made of 11SMn30 steel.

The geometry of the MR damper piston used for measurements is in Fig. 1. The new piston was made of SMC material SINTEX STX prototyping material with relative permeability $\mu_r = 430$, electrical resistivity 280 μΩ.m and magnetic saturation $B_S = 1.46$ T. In order to verify magnetic FEM model, transient and static magnetic flux density dependencies in the gap filled by air were measured. The model is necessary for estimating the dependency of magnetic flux density on the current in the gap filled by MR fluid, because this dependency can not be measured directly by Hall probe.

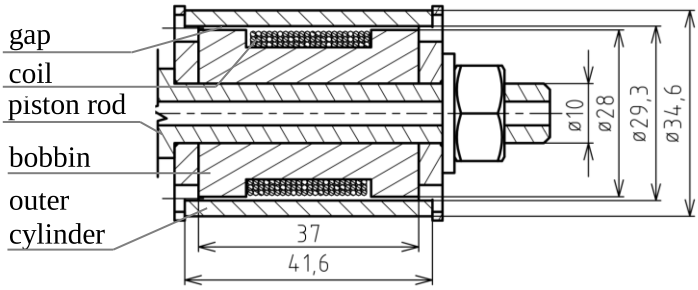


Fig. 1: Dimensions of MR piston.

2.1. Magnetic model

Magnetic model was done in Ansys electronics desktop 17.1. The magnetic circuit was modeled in 3D. Because of magnetic circuit symmetry, it was enough to simulate only 1/8 of the magnetic circuit. The time step of transient analysis was 0.0125 ms, the length based mesh consisted of 53779 elements.

2.2. Measurement of response time of B

The response time of the magnetic flux density on electric current step was considered as the time needed for reaching 63.2 % of the steady state magnetic flux density at 2 A. The current was generated by fast current controller of our construction. Magnetic flux density in the gap was measured by Tesla meter FW Bell 5180. All the signals were collected by DEWE 50 data acquisition station (Fig. 2).

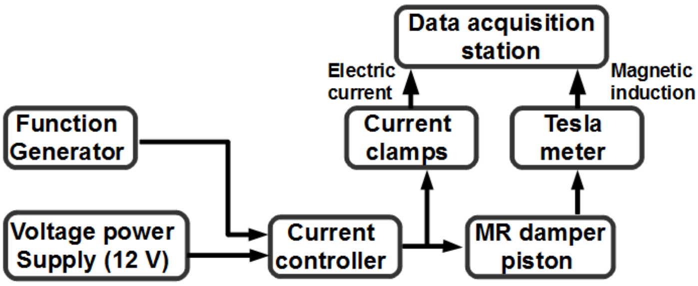


Fig. 2: Block scheme of measurement.

3. Results

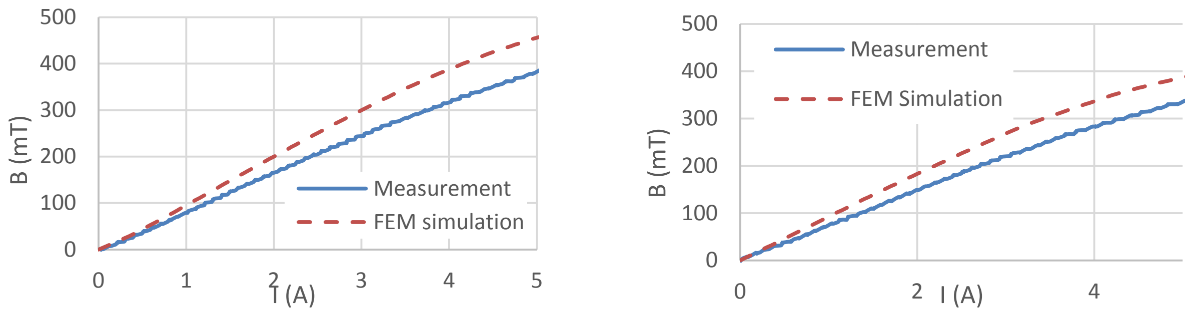
3.1. Static analysis

Fig. 3 compares the dependencies of magnetic flux density in the gap filled by air on the electric current in the coil. The differences between measured and simulated values are up to 15 %. It can be seen that magnetic flux density in the piston made of SMC material is lower than in the piston made of steel. The magnetic circuits with air in the gap are not saturated even at 5 A.

Fig. 4 shows the simulated values of magnetic flux density in the gap filled with MR fluid. The magnetic flux density in the gap of the piston made of SMC is about 15 % lower than for steel variant.

3.2. Transient analysis

Fig. 5 compares measured and simulated responses of magnetic flux density on the electric current for the piston made of steel and with air in the gap. The measured response time of the magnetic flux density on current step is 1.7 ms. The response time of the current is 0.12 ms.



a) b)

Fig. 3: Magnetic flux density in the gap with air for piston made of: a) steel, b) SMC Sintex.

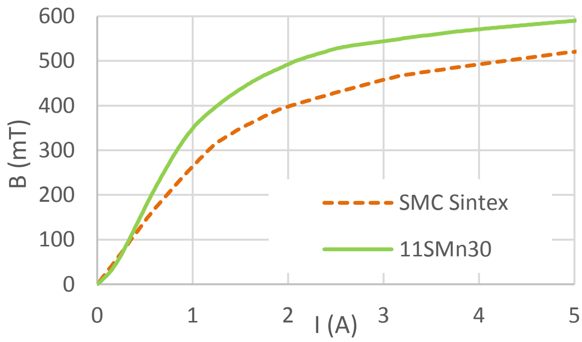


Fig. 4: FEM simulation of magnetic flux density in the gap filled by MR fluid.

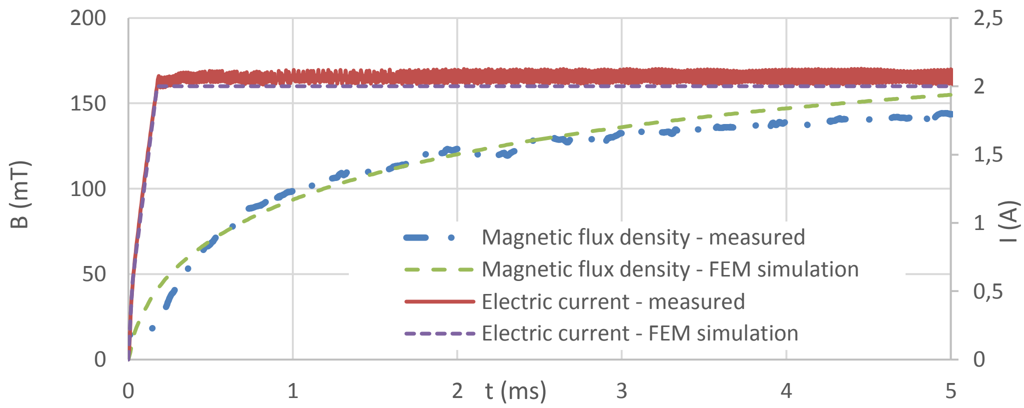


Fig. 5: Transient response of magnetic flux density in the gap with air on electric current – piston made of 11SMn30.

Fig. 6 compares measured and simulated responses of magnetic flux density on the electric current for the piston made of SMC Sintex material and with air in the gap. The response time of the magnetic flux density on current step is 0.56 ms. The measured response time of the current in this case is 0.37 ms.

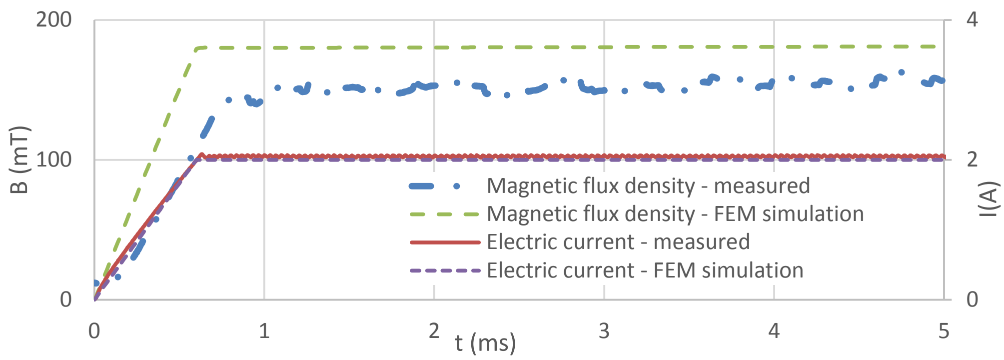


Fig. 6: Transient response of magnetic flux density in the gap with air on electric current – piston made of SMC Sintex material.

Fig. 7 shows the simulation of magnetic flux density in the piston gap filled by MR fluid for piston made of SMC Sintex and piston made of steel. The simulation shows that the predicted response time of magnetic flux density in the gap of steel piston is 8.1 ms. The course of magnetic flux density for piston made of SMC is similar with electric current. The predicted response time is 0.3 ms. The overall response time of MR damper force on control signal can be expected longer because of response time of MR fluid (time needed for forming MR particles chains). The response time of MR fluid was measured between 0.45 – 0.6 ms (Goncalves et al., 2005). The overall response time of the MR damper with piston made of SMC material can be therefore expected shorter than 1 ms.

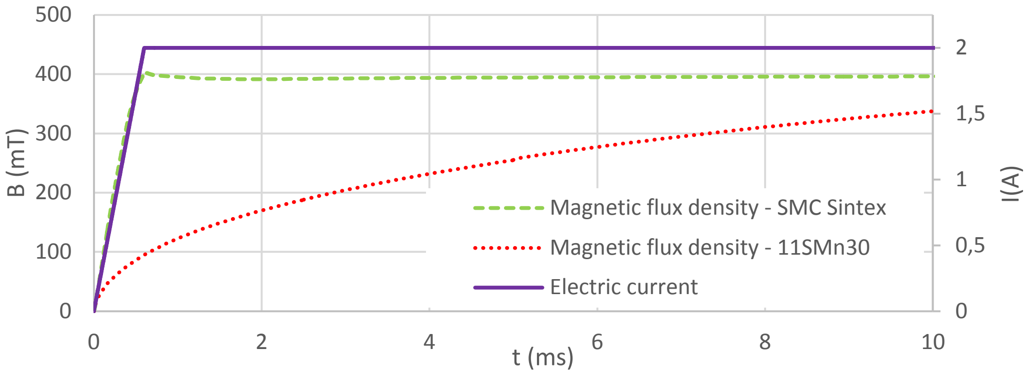


Fig. 7: Transient response of magnetic flux density in the gap with air on electric current – piston made of SMC Sintex.

4. Conclusions

Measurements and simulations clearly showed that the use of SMC material can significantly improve the performance of MR damper. The FEM model was verified by measurements of the magnetic flux density in the piston gap filled by air. The measurements proved very good agreement of simulations and measurements. Despite much smaller relative permeability of SMC Sintex material, the FEM simulation showed that magnetic flux density in the gap of piston made of SMC material filled with MR fluid is only 20 % lower than in case of piston made of steel. The response time of the magnetic flux density in the piston made of steel is 8.1 ms. Such value corresponds to the force response time measured by Strecker (2015). The use of SMC Sintex material reduces the response time of magnetic flux density in the gap filled by MR fluid to 0.3 ms, which is more than 20 times shorter than in case of steel piston.

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