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HYDRAULIC RESISTANCE OF MAGNETORHEOLOGICAL DAMPER VISCOUS BYPASS GAP

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Abstract: *The paper presents hydraulic resistance of viscous bypass gap in magnetorheological damper using FEM system Ansys. The appropriate design of bypass gap is essential for efficient function of MR damper in automotive. In the paper, a numerical hydraulic model of bypass gap filled with MR fluid is compared with experiments on the designed test rig. Maximal difference between numerical model and experiments for various geometries and MR fluids is 24%.*

Keywords: Magnetorheological fluid, MR fluid, magnetorheological damper, MR damper, bypass gap.

1. Introduction

Magnetorheological (MR) fluid is composed of micro-scale ferromagnetic particles, carrier fluid and additives. Upon the application of an external magnetic field, the MR fluid is able to change their behaviour from a fluid state to a semi-solid or plastic state, and vice-versa, in a couple of milliseconds (Wang et al., 2011). This effect is caused by arrangement the particles in the direction of the magnetic field fig.1. This phenomenon is known as the MR effect. MR fluids are attractive because they provide a simple and rapid response interface between electronic control systems and mechanical systems. This behaviour of MR fluid uses magnetorheological (MR) damper.

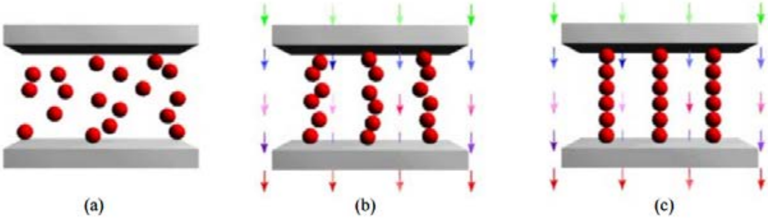

Fig. 1: MR effect (Yang et al., 2002), a) without magnetic field, b) and c) in magnetic field.

MR damper is device which can resize the dissipated energy depending on the current in the coil. MR damper is using in automotive industry (Nguyen et al., 2009), in railway industry (Guo et al., 2014), for damping in stay cable bridges (Choi at al., 2007) or for the control of seismic vibrations in buildings (Yang et al., 2002). The common design of MR damper is composed of electromagnetic coil, magnetic circuit and MR fluid fig. 2. One of the important curves describing the behaviour of MR damper is damping force dependency on piston velocity and electric current (F-v-I). MR damper exhibits rapid growth of force in dependence on piston velocity for small velocities followed by small increase of force in dependence on piston velocity for higher velocities. This non-linearity in F-v dependency causes an undesirable hardness to the vehicle, which might degrade ride comfort (Sohn et al., 2015). Foister et al. (2009) proposed parallel connection of magnetic and bypass gap in MR damper which is not exposed to magnetic field fig. 2(b). This gap is usually designed as nozzle in the piston of MR damper. MR fluid flows through the viscous bypass gap in case the active zone exhibits high hydraulic resistance. The proposed change caused inclination of slope of F-v dependency in low piston velocity fig. 2(b). Sohn et. al (2015) describes essential analytical hydraulic model of bypass gap operating in MR fluid. However, this model does not include turbulent flow or entrance losses.

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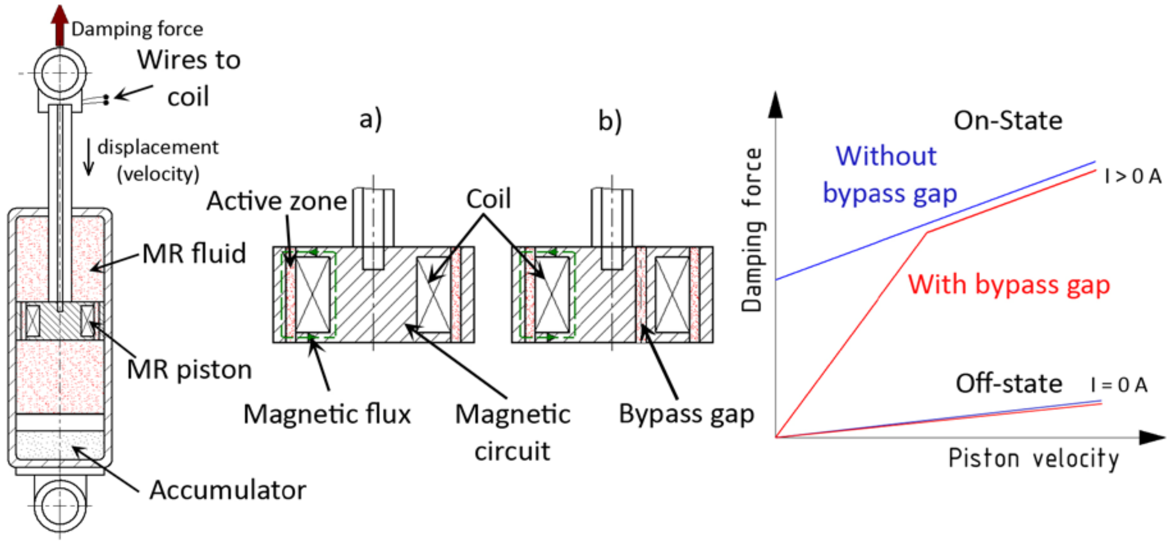

Fig. 2: MR damper; a) piston without bypass gap; b) piston with bypass gap.

The main goal of this paper is to propose the numerical hydraulic model of viscous bypass gap operating in MR fluid and to compare the results from simulation with experiments.

2. Methods

2.1. Experimental unit and methodology of testing

The experimental unit was design for efficient testing of hydraulic resistance of bypass gap filled by MR fluid. This equipment simulates behaviour of bypass gap in MR damper when current is applied. The experimental unit (fig. 3 left) is composed of commercially available hydraulic cylinder (1), hydraulic fittings (8, 9, 10, 11, 12) and block (3). In the block, there are located replaceable nozzle (bypass gap) (2), expansion tank (7) with hydraulic valve (6) and temperature sensor (4).

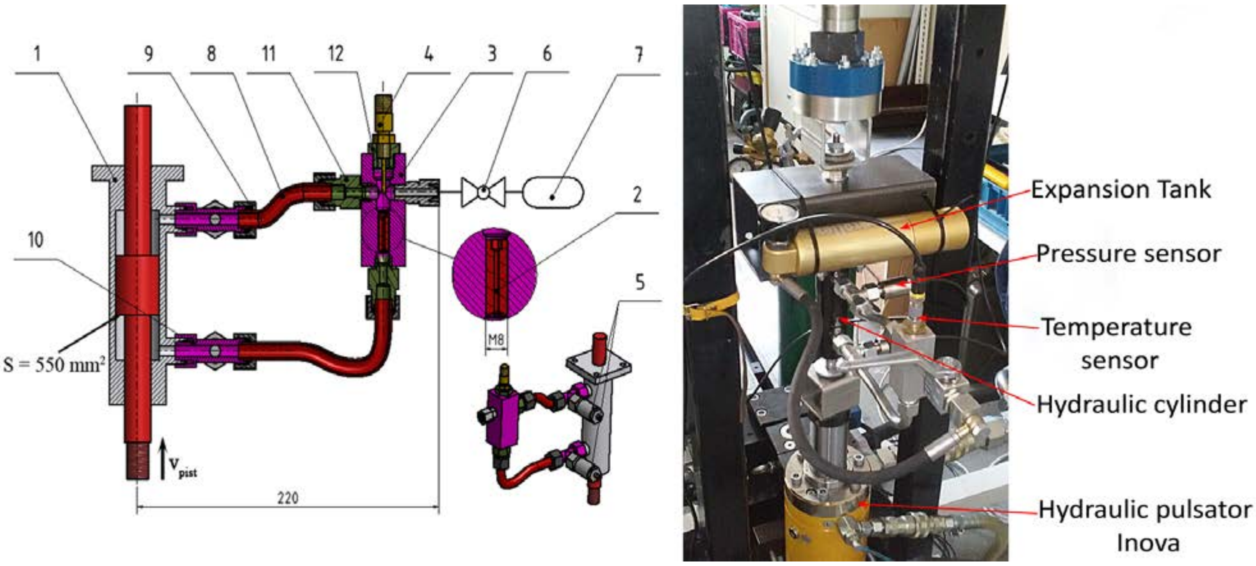

Fig. 3: Experimental unit.

The experimental unit was mounted to the stand with hydraulic pulsator Inova. Hydraulic pulsator Inova moves with the piston (1), which creates a flow of MR fluid through the test nozzle (bypass gap). Stroke, temperature, pressure above and under piston was measured fig. 3(5). The logarithmic sweep with constant amplitude of stroke 10 mm was used. Using the expansion tank, the tested system was pressurized to 10 bars. Expansion tank was separated from tested system by hydraulic valve before the experiment. Therefore, an expansion tank stiffness did not affect the experiment. The data was measured with sampling frequency 2000 Hz.

2.2. Numerical model

Hydraulic model of test nozzle was created by FEM software Ansys CFX. The parabolic velocity profile with mean velocity v_s and intensity of turbulence 5% was set on inlet. The average static pressure 0 bar was set on the outlet. The boundary conditions were smooth wall and no slip wall. The k-ε turbulent model was used. MR fluid was described by dynamic viscosity for each average temperature obtained from experiment. Residual target (RMS) was set 0.0001. The geometry of nozzle fig. 4 was discretized by 45 726 tetrahedral elements.

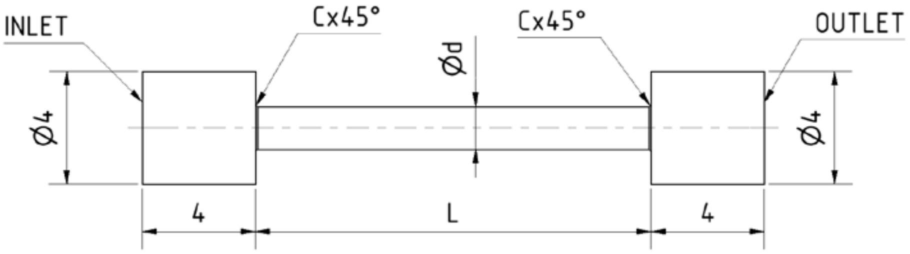

Fig. 4: Geometry.

2.3. MR fluids and geometry of nozzles

Commercially available MR fluids Lord MRF 122-EG (solids content by weight 72%) and Lord MRF 140-CG (85%) were tested. The diameter and length of nozzles are in tab. 1.

Tab. 1: Geometry of nozzles.

�d [mm]	L [mm]	C [mm]	�d [mm]	L [mm]	C [mm]
1.65	4.2	0.07	1.63	14.8	0.07
1.6	7.2	0.09	1.5	14.8	0.08
1.66	13.8	0.08	1.95	14.8	0.08

3. Results

3.1. Lord MRF 122-EG

The different diameters of nozzles with constant length 14 mm filled with MR 122-EG were tested. The results show the biggest difference between the pressure drop calculated from simulation and pressure drop measured from experiment for 2 mm nozzle. This difference at velocity 0.2 m/s is 19.5%. The next experiment was for different lengths of nozzles at the same diameter 1.6 mm. The difference between experiment and model was 14% for length 4 mm.

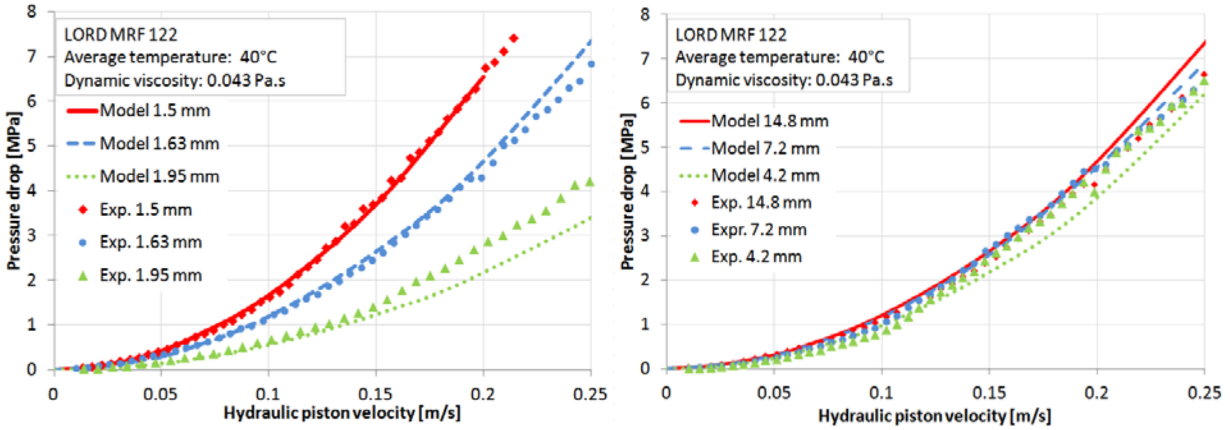

Fig. 5: Influence of diameter (left) and length (right) of nozzle.

3.2. Lord MRF 140-CG

The different diameter of nozzles with constant length 14 mm filled with MR 140-CG was tested. The results show the biggest difference between model and experiment for velocity higher than 0.15 m/s. The next experiment was for different length of nozzles with the same diameter of 1.6 mm. The difference between experiment and model was 24% for the length 7.2 mm.

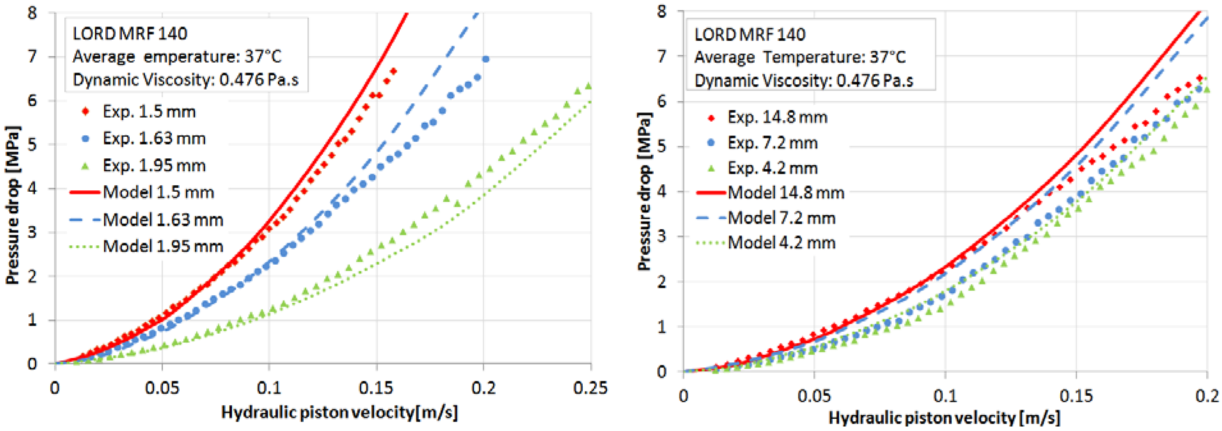

Fig. 6: Influence of diameter (left) and length (right).

4. Conclusions

In this paper, the result from hydraulic numerical model of viscous bypass gap in MR damper was published. For Lord MRF 122-EG and Lord MRF 140-CG, the numerical model with different geometry of bypass gap was compared with experiment. A difference between numerical model and experiments was observed especially for velocity higher than 0.15 m/s. The maximal error of numerical model is 24%. This error was observed for MRF 140-CG, diameter of nozzle 1.6 mm and length 7.2 mm. Presented numerical model is sufficiently accurate for majority of MR damper designs.

Acknowledgement

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