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A STUDY OF HYDRAULIC RESISTANCE OF VISCOUS BYPASS GAP IN MAGNETORHEOLOGICAL DAMPER

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Abstract

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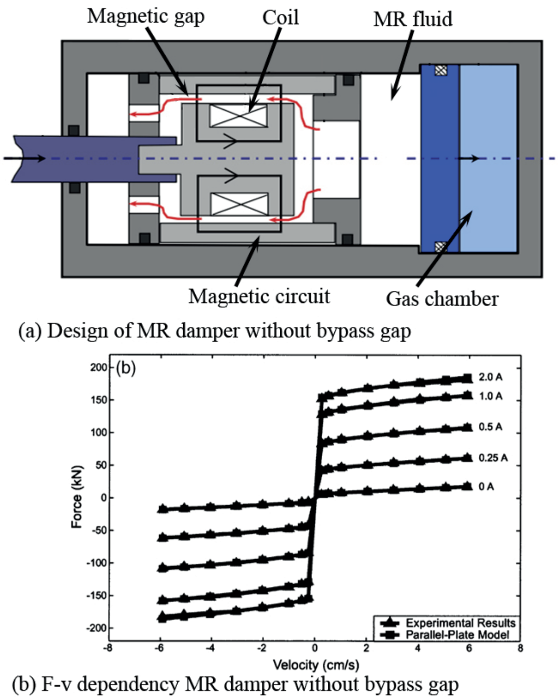
The paper presents hydraulic resistance of viscous bypass hole in magnetorheological damper. The suitable design of bypass hole is essential for efficient function of MR damper in automotive industry. In the paper analytical hydraulic model of bypass gap is compared with experiments. The commonly used hydraulic model of bypass gap does not agree with experiments.

Keywords:Magnetorheological fluid, MR fluid, MR damper, bypass hole, magnetorheological fluid damper

INTRODUCTION

Magnetorheological (MR) fluid is a kind of smart material. It is composed of micro-scale magnetic particles, carrier oil and additives. Upon the application of an external magnetic field, the MR fluids are 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, 2011). This effect is caused by clustering the particles in the direction of the magnetic field. This phenomenon is known as the MR effect. MR fluids are attractive because they provide a simple and rapid response interface between electronic controls and mechanical systems. MR damper is used in automotive industry (Nguyen, 2009), for the control of seismic vibrations in buildings (Yang, 2002), in railway industry (Guo, 2014) or for damping in stay cable bridges (Choi, 2007). MR damper provides high force dynamic range, is reliable and has low energy consumption (Yang, 2002). The common design of MR damper is composed of electromagnetic coil, magnetic circuit and MR fluid Fig. 1(a). The amount dissipation energy of MR damper is possible to change by electric current.



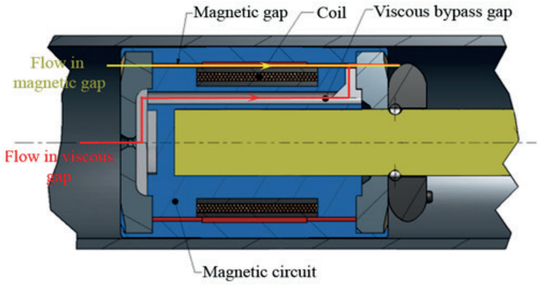
(a) Design of MR damper without bypass gap

(b) F-v dependency MR damper without bypass gap

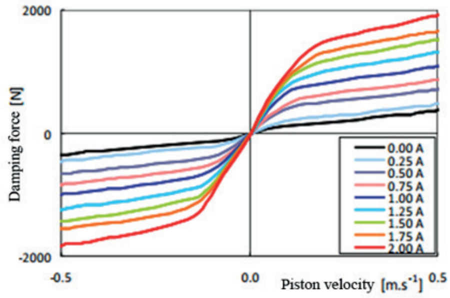
1: *Convention design of MR damper (Wang, 2011), F-v dependency (Yang, 2002)*

One of the important curves describing behaviour of MR damper is damping force dependency of piston velocity (F-v). F-v dependency of common MR damper has step change of damping force in low piston velocity Fig.1(b) followed by a small change damping force. This MR damper is similar to friction damper in adaptive regime. The undesired jump in damping force results causes an undesirable hardness to the vehicle. This phenomenon might degrade ride comfort (Sohn, 2015).

Foister patented parallel connection of magnetic and bypass gap in MR damper. In common design of MR damper MR fluid flows only in magnetic gap Fig. 1 (a). Foister proposed parallel connection of magnetic gap and bypass viscous gap which in not expose by magnetic field Fig. 2 (a). If MR fluid flows through viscous bypass gap, magnetic gap exhibit high hydraulic resistance (close magnetic gap). This proposed change caused inclining of F-v dependency in low piston velocity Fig. 2 (b). This is the way how to improve ride comfort in automotive application.



(a) Design of MR damper with bypass gap

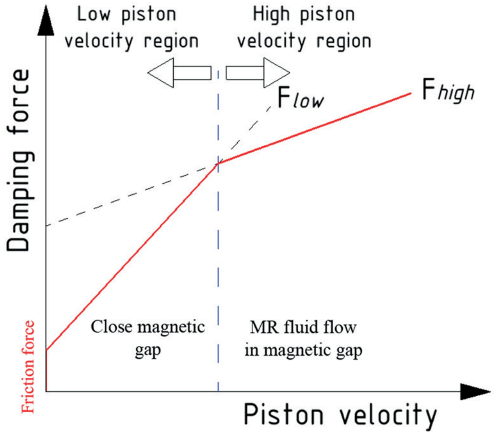


(b) F-v dependency of MR damper with bypass gap

2: *Design of MR damper with bypass gap and F-v dependency (Roupec, 2011)*

Hydraulic model of MR damper

In the paper (Sohn, 2015) Sohn describes essential methodology design of hydraulic section of MR damper. Damping force in MR damper with bypass gap is composed of hydraulic resistance of bypass gap F_{bypass}, friction of seal $F_{friction}$ and hydraulic resistance of system $F_{viscous}$ in low piston velocity Fig. 3.



3: *Schematic of total damping force*

Magnetic gap does not create damping force in low piston velocity because of MR fluid does not flow through magnetic gap (close magnetic gap). The effect of magnetic gap is sufficient in high piston velocity.

The analytical model of hydraulic resistance of magnetic gap upon magnetic field was published in many papers (Yang, 2002; Choii, 2008). Hydraulic resistance of bypass gap in MR damper was not well established. Sohn (Sohn, 2015) published analytical hydraulic model of bypass gap in MR damper in the paper. The model is based on the Euler equation. For the modelling of bypass gap is assumed that MR fluid is incompressible and heat loss is negligible. Steady-state behaviour of the fluid and laminar flow are also assumed. Damping force can be expressed as follows

$$F_{bypass} = (A_p - A_r)\, g\rho h_{bypass}\,,$$

where A_p piston area [mm^2], A_r piston rod area [mm^2], ρ density of fluid [kg × m], g gravitational acceleration [$m \times s$], h_{bypass} viscous head loss [–]. The final equation for solution of hydraulic resistance of viscous bypass gap in MR damper (Hagen–Poiseuille equation)

$$\Delta p = \frac{32 L v \mu}{D^2}\,.$$

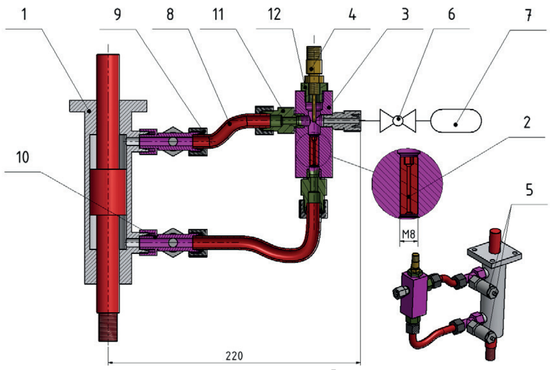
In authors's preliminary tests were observed that this analytical model does not agree with experiments.

The main goal of this paper is to propose the comparison of the analytical model of hydraulic resistance of gap in MR fluid with experiments.

MATERIALS AND METHODS

Experimental unit

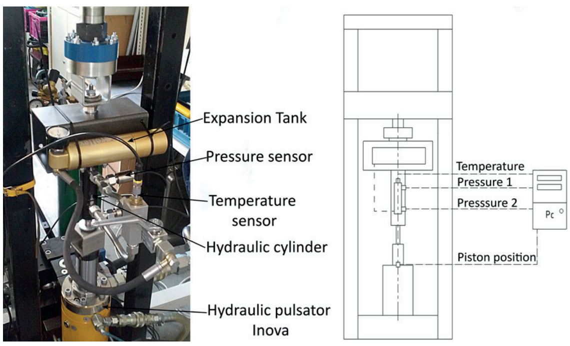
The experimental unit was designed for test of hydraulic resistance of viscous gap. The experimental unit is composed of commercially available hydraulic cylinder (1), hydraulic fittings (8, 9, 10, 11, 12) and block (3). Replaceable nozzle (bypass gap) (2), expansion tank (7) with hydraulic valve (6) and temperature sensor (4) are located in the block (3). Pressure in system was measured by two pressure sensors PDCR 317-2375 (5).



4: *Experimental unit*

Measurement methodology

The experimental unit was placed to hydraulic pulsator Inova. Hydraulic pulsator Inova creates a flow of MR fluid through test nozzle (gap) by pulsation of hydraulic piston. Stroke, temperature, pressure up and under piston were measured. The logarithmic sweep with constant amplitude of stroke 10 mm was used. Tested system was pressurized by 10 bars using the expansion tank. The expansion tank was separated from the test system by hydraulic valve before the experiment. Therefore, expansion tank's stiffness could have the effect to experiment. Data was measured with sampling frequency of 2000 Hz.



5: *Experimental unit*

Hydraulic piston velocity was solved from measured stroke of piston and time. The velocity in nozzle gap was solved from hydraulic piston velocity and continuity equation of flowing. In the first phase was measured p-v dependency of hydraulic system without nozzle (without position 2 in Fig. 4). In second phase was measured p-v dependency of system and nozzle. Hydraulic resistance of nozzle was created by subtraction of p-v dependencies.

RESULTS

MR fluid and geometry of nozzle

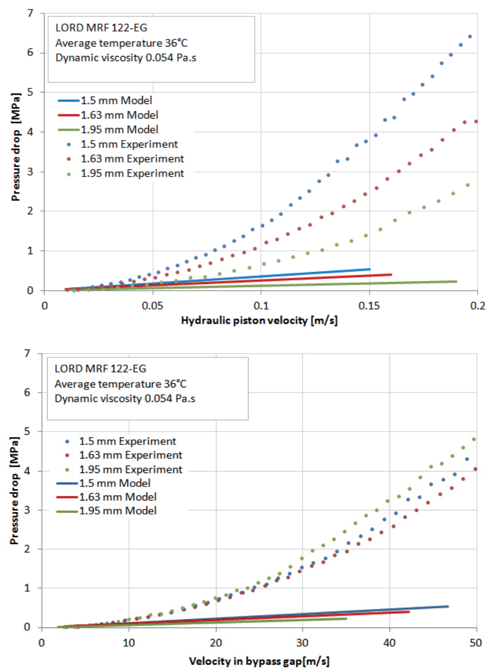
The commercially available Lord MR fluid was tested. MR fluid 122-EG and 140-CG was used. The different diameter and length of nozzle was tested. The list of geometry nozzles is in Tab. I. Diameter and chamfer of nozzle were measured by microscope and calibrate scale.

Influence of nozzle diameter

Pressure drop of every nozzle fig. 6 was plotted in the graph dependency of piston velocity and pressure drop. The average temperature during the tests was 36 °C. Dynamic viscosity of Lord MRF 122-EG is 0.054 Pa.s for average temperature during the test. Data from analytical model are showed in Fig. 6 by solid line. Maximal piston velocity from analytical model is limited by critical Reynolds number. This is because the premising of analytical model is laminar flow.

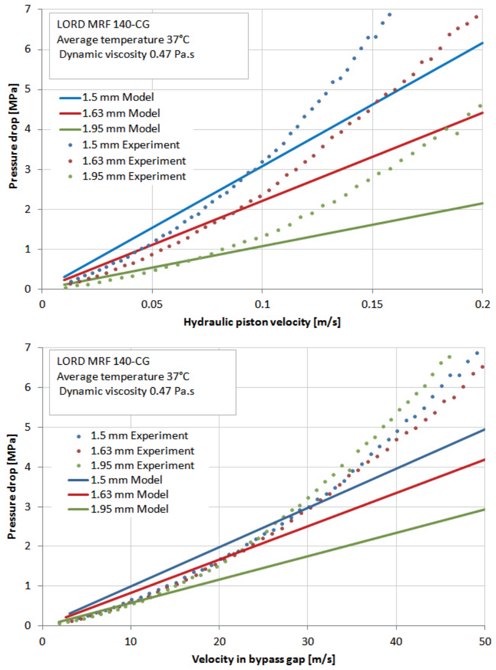
I: *Geometry of nozzles*

Diameter [mm]	Length [mm]	Chamfer [mm]
1.65	4.2	0.07
1.6	7.2	0.09
1.66	13.8	0.08
1.63	14.8	0.07
1.5	14.8	0.08
1.95	14.8	0.08



6: *p-v dependency of LORD MRF 122-EG*

The difference between analytical model and experiment for piston velocity 0.1 m/s was in the range 500 % to 600 %.

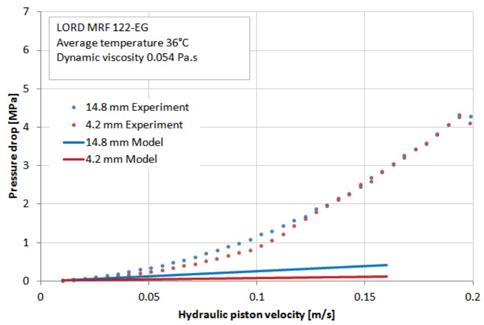


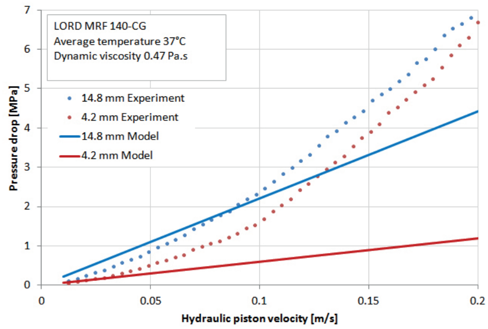
7: *p-v dependency of LORD MRF 140-CG*

The average temperature of Lord MRF 140-CG during tests was 37 °C. Dynamic viscosity of Lord MRF 140-CG is 0.47 Pa.s for average temperature during tests. The difference between analytical model (solid line) and experiment for piston velocity 0.1 m/s was in the range 10 % to 30%.

Influence of length of nozzle

The influence of length of nozzle to pressure drop for nozzle diameter 1.63 mm was tested. The average temperature during tests was 36 °C and 37 °C.





8: *p-v dependency of different length of gap*

The difference between 14.8 mm and 4.2 mm length of nozzle is 25.2 % for MRF 122-EG in velocity 0.1 m/s. Pressure drop is independent to length of nozzle over the velocity 0.15 m/s. The difference between 14.8 mm and 4.2 mm length of nozzle is 31.8 % for MRF 140-CG in velocity 0.1 m/s.

DISCUSSION

According the results a published analytical model is not suitable for description of hydraulic resistance of gap working in MR fluid Lord MRF 122-EG. The difference between analytical model and experiments is in hundreds of percent. Lord MRF 140-CG exhibits significantly smaller difference between model and experiment than Lord MRF 122-EG. The significant difference between analytical model and experiment is also in course of p-v dependency. The possible causes of differences between model and experiment are neglect influence of develop velocity profile of MR fluid in nozzle and neglect influence of entrance losses. The influence of the shape and volume of the particles to hydraulic resistance was not studied. Further research will be focus on numerical model with influence of turbulent flow and entrance geometry.

CONCLUSION

In this paper was published hydraulic model of viscous bypass gap in MR damper. For Lord MRF 122-EG and Lord MRF 140-CG analytical model with different geometry of bypass gap was compared with experiments. A large difference between analytical model and experiments was observed. The error of model is more pronounced for Lord MRF 122-EG than Lord MRF 140-CG. For the design geometry of viscous bypass gap in MR damper is frequently used analytical model undesirable. Subsequent research is focused on create a suitable hydraulic model of viscous bypass gap in MR damper.

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