

# 709. Evaluation of the resistance force of magnetorheological fluid damper

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(Received 11 September 2011; accepted 14 February 2012)

**Abstract.** The aim of this research was to examine the resistance force generated by linear hydro-cylinder type magnetorheological fluid (MRF) damper acting in different regimes. MRF damper performance has been investigated experimentally by using universal computerized material properties testing machine. Measurements of resistance force have been carried out for different speeds of the damper piston motion under different strength of the magnetic field. Dependences of the force on these parameters (speed and magnetic field strength) have been obtained. It was defined, that the force increases practically linearly when increasing strength of the magnetic field and when increasing piston speed.

**Keywords:** smart material, magnetorheological fluid, linear cylinder, damper, resistance force.

## Introduction

Science and technology have made amazing developments in the design of electronics and machinery using standard materials, which do not have particularly special properties (i. e. metals, plastics, ceramics, technical fluids etc.). Combination of these materials may give special materials with controllable properties. Such materials are called smart materials, they have one or more properties that can be dramatically altered. Each individual type of smart material has a different property which can be significantly altered, such as viscosity, volume or conductivity. The property that can be altered determines what type of applications the smart material can be used for [1].

Fluids with controllable properties are also assigned to smart materials. These fluids respond to an applied electric or magnetic field with a change of their rheological behavior. Controllable fluids are commonly referred to as electrorheological (ER) or magnetorheological (MR) fluids. Interest in controllable fluids derives from their ability to provide simple, quiet, rapid response interfaces between electronic controls and mechanical systems. Such fluids have the potential to change radically the way electromechanical devices are designed and operated [2].

The main characteristic of MR fluids is the dependence of viscosity of the fluid on the strength of the magnetic field. The change of viscosity proportionally to the magnetic field strength is reversible, moreover, it runs within a very short time, a few milliseconds. MR fluid may be changed from liquid state to almost solid and then return to an initial state [3]. Therefore MR fluids are widely used in various types of devices, operating basing on principles of hydrodynamics. As an example the equipment which requires the creation of controlled damping and resistance forces [4] may be mentioned such as active shock absorbers, control dampers, hydraulic controls, servo valves, actuators, clutches and brakes, chocking/locking device, breakaway devices, structural composites etc. [5].

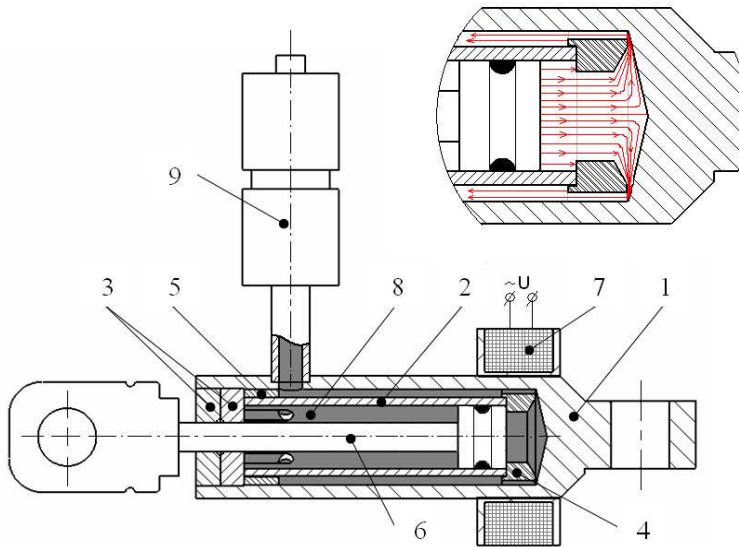
The main parameter of the classical linear hydraulic cylinder type damper is its resisting force. It depends on the dimensions of cylinder and piston, piston speed, bypass channel dimensions and hydraulic fluid viscosity. When the working fluid in the cylinder is the MR fluid its viscosity depends on the strength of magnetic field, in which the cylinder is placed, so varying this parameter the resistance force of the cylinder may be controlled [6, 7].

The aim of this research was to examine the resistance force generated by linear hydro-cylinder type magnetorheological fluid (MRF) damper acting in different regimes. The damper has been designed and manufactured in Kaunas University of Technology. The dependencies of the resistance force generated by the MRF damper on the speed of movement of the piston and on the strength of magnetic field (and herewith – the viscosity of the hydraulic fluid) have been investigated experimentally.

## MRF damper

MR fluid damper under research is a linear hydraulic cylinder type shock absorber, filled with a magnetorheological fluid MRF-140CG (LORD corporation, USA) [8]. Device has been designed and developed at the Kaunas University of Technology, its construction is shown on the Fig. 1. The working diameter of the cylinder is 13 mm and the stroke is 44 mm.

The main parts of the double-tube configuration MRF linear damper are: damper frame-outer tube (1), inner tube (2), cover of damper frame (3), hub with two channels (4), centering hub (5), piston with rod (6), magnetic field induction coil (7), magnetorheological fluid (8) and expansion reservoir (9) (cylinder with the spring-loaded piston) ensuring initial pressure of the fluid (Fig. 1.). The magnetic coil (7) contains 700 windings of 0.33 mm thickness copper wire, its resistance is  $12.4 \Omega$  and inductivity 1.0 mH. The piston (6) mounted on the rod moves inside of the inner tube (2) and makes the fluid (8) flow from the one chamber to another through two narrow (cross-section area  $2 \text{ mm}^2$ ) channels between the inner and outer tubes (2) and (1). Such design ensures the damper the ability to effectively remix MR fluid during operation thus reducing the sedimentation of the solid magnetizable particles the fluid contains.



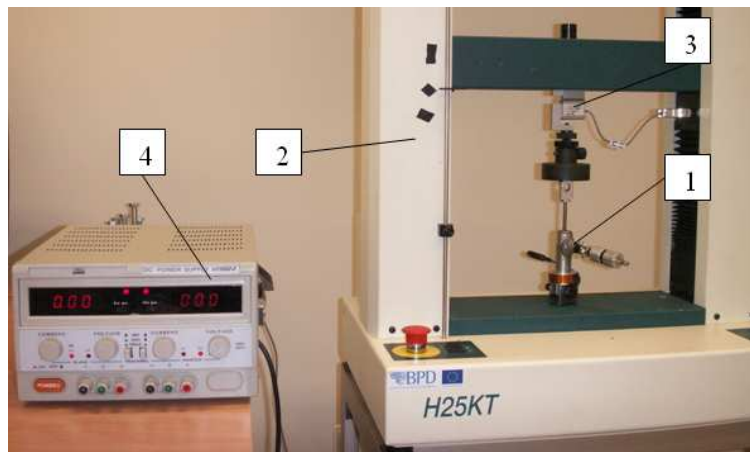
**Fig. 1.** MRF linear damper: 1 – damper frame-outer tube; 2 – inner tube; 3 – cover of damper frame; 4 – hub with two channels; 5 – centering hub; 6 – piston with a rod; 7 – magnetic field induction coil; 8 – magnetorheological fluid MRF-140CG; 9 – expansion reservoir

MRF fluid is suspension of micron-sized, magnetizable particles in a carrier fluid. This fluid is hydrocarbon based magnetorheological fluid formulated for general use in controllable energy-dissipations such as shocks, dampers and brakes. The fluid has high concentration of iron particles that equals approximately 85.44%. So when the fluid is exposed in the magnetic

field it could change the viscosity characteristics more than other MR fluids having lower concentration of iron particles. MRF-140CG fluid can be used in the MR devices working in valve mode when the fluid flows through an orifice or in shear mode when the fluid resists shearing between two surfaces [8, 9]. In the considered case the MR damper works in the valve mode.

### Measurement of the resistance force of a MRF linear damper

To determine the influence of the magnetic field strength and linear velocity of the damper piston motion on the resistance force generated by the damper a test stand was built (the scheme see on Fig. 2). The stand consists of: MRF linear damper (1), mounted in the grips of the dual column universal computerized machine for testing materials properties H25KT (Tinius Olsen, USA) (2) having a load cell HTE-1000N (3) for measuring load; power supply device HY3002-2 (Sinometer, China) [10] (4), ensuring the possibility to regulate voltage and current in the coil generating magnetic field.



**Fig. 2.** The experimental stand: 1 – MRF linear damper; 2 – universal computerized machine for testing material properties H25KT; 3 – load cell HTE-1000N; 4 – power supply device HY3002-2

The universal computerized machine H25KT (25 kN frame capacity) was used for plunging into the cylinder the initially extended piston with a rod with a constant speed. Simultaneously the resisting force generated by the damper was measured by load cell HTE-1000N mounted on the crosshead of the machine. The main parameters of the machine are: force accuracy of 0.5% of applied load across the load cell display range, displacement resolution of 0.0001 mm; speed resolution of 0.001 mm/min, maximum crosshead travel of 1100 mm and testing speed range of 0.001-1000 mm/min [11].

The resisting force generated by the damper was investigated at the absence of magnetic field (passive mode) and at three levels of strength of magnetic field  $B$  (0.013, 0.025 and 0.038 T) (active mode) generated by induction coil, thus changing the viscosity of the MR fluid in the damper and herewith the resisting force. The strength of the magnetic field was controlled by changing the electric current strength  $I$  in the magnetic coil by means of the power supply device HY3002-2.

At each regime of magnetic field strength the resisting force, generated by damper during the 30 mm stroke of the piston, has been examined for five different speeds  $V$  of plunging the piston into cylinder (60, 120, 210, 300 and 450 mm/min) (see Table 1).

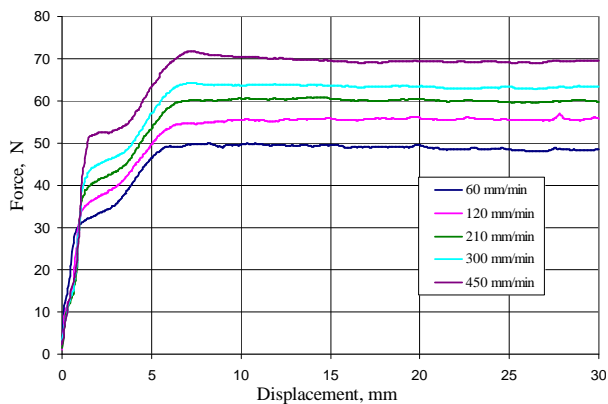
**Table 1.** Examined regimes of operation of MR fluid linear damper

Regime	$I, A$	$B, T$	$V, mm/min$				
			60	120	210	300	450
1	0	0	60	120	210	300	450
2	0.5	0.013	60	120	210	300	450
3	1	0.025	60	120	210	300	450
4	1.5	0.038	60	120	210	300	450

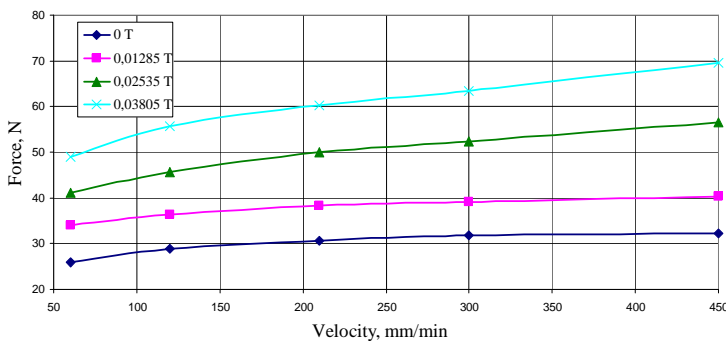
## Results of the research

A set of curves, representing the variation of the resisting force generated by damper at maximal magnetic field strength regime and different speeds of piston motion is shown on Figure 3. It can be seen, that in this case the steady value of the resisting force generated by damper increases from 49 to 70 N (21 N increment) when increasing speed of piston motion from 60 to 450 mm/min (Fig. 3). When the magnetic field is absent, the resisting force drops to 26-33 N (7 N increment) depending on the speed of piston motion, that is the stronger is the magnetic field, the stronger is the influence of the speed of piston motion. The transitional strengths of the magnetic field give the corresponding intermediate values of the resisting force, as shown in the Figure 4.

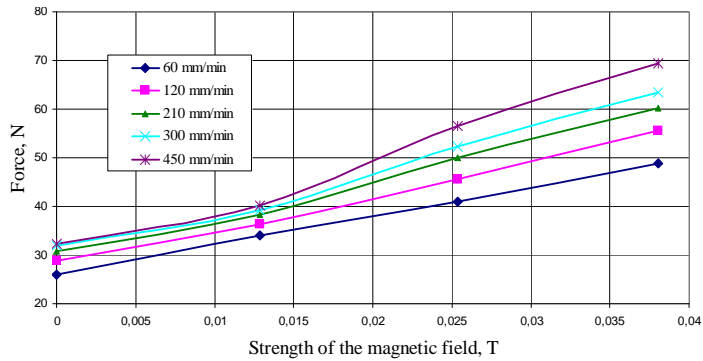
Figure 5 shows the dependencies of the resisting force generated by MRF damper on the strength of the magnetic field at the different speed of the piston motion.



**Fig. 3.** The dependencies of the resisting force generated by MRF damper on the speed of piston motion at maximal strength of the magnetic field



**Fig. 4.** The dependencies of the resisting force generated by MRF damper on the speed of piston motion at the different strength of the magnetic field



**Fig. 5.** The dependencies of the resisting force generated by MRF damper on the strength of the magnetic field at the different speed of the piston motion

It can be seen from the Figures 4 and 5 that the steady resisting force generated by MRF damper raises almost linearly with increasing both the speed of piston motion and the strength of the magnetic field surrounding the damper. However the influence of the speed of piston motion is somewhat more noticeable at the lowest speeds (Figure 4), while the increment of the force due to strengthening the magnetic field is slightly more articulated when the magnetic field is stronger (Figure 5).

In all examined cases the force reached its steady value in near 7 mm of the total 30 mm damper piston stroke, and in addition it grows unevenly (Fig. 3), what may be explained by the influence of the expansion reservoir (response threshold of its spring-loaded piston to be investigated subsequently).

## Conclusions

An experimental research of the resisting force generated by original linear hydro-cylinder type magnetorheological fluid (MRF) damper has been performed by using a test stand based on the universal computerized machine for testing materials properties. The dependencies of the resisting force generated by the MRF damper on the speed of motion of the damper piston and on the strength of magnetic field, changing the viscosity of the MR fluid, have been obtained and evaluated.

It was found that the damper ensures the range of the resisting force from 26 to 70 N at the speeds of motion from 60 to 450 mm/min and the strength of the surrounding magnetic field from 0 to 0.038 T.

At maximal magnetic field strength the steady value of the resisting force generated by damper varies from 49 to 70 N (21 N increment) when increasing speed of piston motion from 60 to 450 mm/min. When the magnetic field is absent, the resisting force drops to 26-33 N (7 N increment) depending on the speed of piston motion, that is the stronger is the magnetic field, the stronger is the influence of the speed of piston motion.

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