A mathematical model of an MR fluid in operational conditions of a damper's work

Pawel Skalski[*a)]
[*] *Centre of New Technologies, Institute of Aviation, Warsaw, 02-256, Poland*

Summary The main goal of this paper is a mathematical description of a magnetorheological fluid (MR) in operational conditions of a damper's work. The research was performed on a damper prototype with an MR fluid. On the basis of carried out experiments, the conventional yield point and the maximum shear stress of analyzed MR fluid were estimated. Identified viscoplastic model (modified Bodner-Partom model) was used to develop simulations that verify the proposed mathematical model with data derived from experiments.

Magnetorheological (MR) fluids, beside ferromagnetic and electrorheological fluids, belong to the non-Newtonian rheostable fluids, which are characterized by a yield point. Magnetic, ferromagnetic and electrorheological fluids are colloidal suspension of microscopic solids in the liquid carrier, and their main characteristic is rapid grouping of particles into a dense grid under the influence of an external stimulus [1].

Magnetorheological fluids are composed of ferromagnetic particles of a magnetic material with a diameter of several micrometers (from 0,5 [μm] to 0,8 [μm]) and liquid carrier of low viscosity, about 0,2÷0,3 [Pa·s] [6]. Ferromagnetic particles of an MR fluid are additionally covered with a special layer enhancing their magnetic susceptibility and reducing their tendency to form aggregations. Other substances, including anti-corrosion and anti-sedimentation substances, are also added in small amount [1].

Being a subject of the special interest in this work, magnetorheological fluids are very useful in solving damping problems which are one of main engineering dilemmas of construction and exploitation of machines and devices. Recently, a big increase of interest in this type of smart material is being observed. Generalizing, it can be said that MR fluids are applied mainly in semi- active vibration damping. They are used e.g. in: dampers, shock absorbers, clutches and brakes [2], [4]. MR dampers and MR shock absorbers are applied e.g. in damping control, in operation of buildings and bridges [3], as well as in damping of high-tension wires [8].

In the development and production area of MR fluids, LORD Company is a dominating figure on the global market, producing fluids and devices, it contributes to their development. Despite plenty of works being currently led at universities and research centres, still the need of a better and more extensive knowledge of particular properties of these liquids is noticed, their behaviour in exploitative conditions, as well as learning all possibilities to control their rheological properties.

One of important tasks which concerns MR fluids, and which wasn't so far precisely and explicitly described, is the issue of the mathematical description of MR fluid's properties, when the fluid is in a state of real working conditions.

With reference to various materials, we can find different models of viscoplastic laws. There is no model describing fluids and solid materials equally. There are models characteristic for fluids or solid materials.

The author of presented paper took the attempt to describe the MR fluid's behaviour, by using constitutive equations which are generally applied for metals. Before taking such a decision one should think and answer following question: whether and why, and which constitutive equations, proper for metals, can be used in the mathematical description of MR fluid's properties and behaviour?

Responding to the question, we should note that in certain operational conditions an MR fluid changes its density, becoming semi-solid, or even solid. It is one of an MR fluid's most significant features.

The author of this work decided to undertake an analysis of magnetorheological fluid's viscoplastic properties in operational conditions of a damper's work, to be able to apply the viscoplastic laws typical for metals, for description of properties and behaviour of MR fluids.

In the research program, an attention was devoted to the damper prototype which was designed and carried out in Institute of Machine Design Fundamentals at the Warsaw University of Technology. The conducted experiments concerned MRF 132 DG fluid, used in the T-MR SiMR 132 DG damper prototype (Fig. 1) which design has been simplified by eliminating the gas spring. Lack of this element in the construction equipment and very small friction, caused by functioning without liquid, constitute about 1-2% of the total resistance force of the piston rod in the device under tests. This allowed for results of liquid flowing through the gap in the head of the working unit, without including those working devices.

[a)] Corresponding author. Email: pawel.skalski@ilot.edu.pl.

Fig. 1. View of an MR damper prototype

Residual magnetism is one of the problem encountered during operation of the device with a magnetorheological fluid, the housing was made of brass. This allowed, to minimize the occurrence of a residual magnetism to zero.
Analyzing experimental results, the author suggested, modified Bodner-Partom model for the description of the MR fluid, containing parameters *n*, R_0, D_0, dependent on four variables: the value of plastic shear rate $\dot{\gamma}^I$, the value of current intensity *i*, value of temperature *t*, and the value of the gap's height *h*. The mathematical model was written in the form [7]:

$$\dot{\gamma}^I = 2D_0 \exp\left[-\frac{1}{2}\left(\frac{R_0(t,i,h)}{\sqrt{3}\tau}\right)^{2n(t,i)} \frac{n(t,i)+1}{n(t,i)}\right]\operatorname{sgn}(\tau), \quad (1)$$

where:

$$n(t,i) = 0{,}18 + 0{,}10i - 0{,}0001t, \quad (2)$$

$$R_0(t,i,h) = \frac{1}{h}(6{,}8 - 0{,}07i - 0{,}01t). \quad (3)$$

The method of identifying parameters of modified Bodner-Partom model was conducted basing on the viscoplastic analysis of tested MR fluid. Obtained solutions of identifying model for damper with the MR fluid were characterized by high accuracy, what was confirmed by the statement of the results of numerical simulations and experimental data. The identification based on the outline presented, among others in [5], refers to the physical phenomena and is not based on so-called: *black boxes*. It is undoubtedly a major advantage of this type of identification, comparing with heuristic methods such as simulated annealing, genetic algorithms or particle swarm optimization.

CONCLUSIONS

In this paper, the constitutive equations of the Bodner-Partom model are applied to describe a magnetorheological fluid behaviour in the damper. Conducted experiments on the T-MR SiMR 132 DG damper served for the identification of the Bodner-Partom law parameters. Modified mathematical model of Bodner-Partom law incorporating in its structure, not only the shear rate, but also the current intensity, the temperature and the height of the gap, presents in its description the behaviour of the damper with a magnetorheological fluid.

References

[1] Carlson J. D., Weiss D., A growing attraction to magnetic fluids, Machine Design, Aug. 8, 61-66, 1994.

[2] Carlson J. D., Low-cost MR fluid sponge devices, Proceeding of the 7th International Conference on ER Fluids and MR Suspensions, World Scientific Publishing Co. Pte. Ltd., Honolulu Hawaii, 1999.

[3] Dyke S. J., Spencer B. F., Sain M. K., Carlson J. D., Modeling and control of magnetorheological dampers for seismic response reduction, Smart Materials and Structures, 5(5), 565-575, 1996.

[4] Goncalves F. D., Characterizing the behavior of magnetorheological fluids at high velocities and high shear rates, PhD thesis, Virginia Polytechnic, Blacksburg, 2005.

[5] Klosowski P., Woznica K., Non-linear viscoplastic constitutive laws in selected applications for an analysis of structure (in Polish), Danzig, 2007.

[6] Sapinski B., Snamina J., Maslanka M., Rosol M., Facility for testing of magnetorheological damping systems for cable vibrations, Mechanics vol. 25/3, AGH, Kraków, 2006.

[7] Skalski P., Analysis of viscoplastic properties of a magnetorheological fluid in operational conditions of a damper's work, Ph.D. thesis, Warsaw University of Technology, 2010.

[8] Wu W., Theoretical and experimental study on cable vibration reduction with tmd-mr damper, Ph.D. thesis, Louisiana State University, 2006.