582. Research of the flexible bellow with the magnetorheological fluid

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Abstract. MR fluids are widely used in various structures such as controlled dampers, brakes, clutches, etc. Application of these fluids can reduce energy costs and weight as well as increase device operational speed and lifetime. In order to exploit all the qualities of MRS and ERS properties it is necessary to occasionally mix the fluids and monitor them. These systems are still under research and development in laboratories worldwide. This article describes the developed and tested flexible bellow, which can determine whether the MR fluid is under influence of sedimentation and whether it can operate correctly or it is necessary to perform the mixing.

Keywords: magnetorheological fluid, flexible bellow, sedimentation.

Introduction

This article studied flexible bellows with the magnetorheological fluid. Bellows is a tube shaped spring element of the corrugated side surfaces [1]. Its special feature is the large deformations with nearly linear stiffness characteristic. When Bellows is well-stocked by the rheological fluid, we can be observe MR fluid characteristic and performance when magnetorheological fluid is left at the rest for some hours and at this time sedimentation process is running. These experiments were carried out by measuring of the two MR fluids then they are exposed to a magnetic field and measuring flexible bellow shift dependence from the current strength of the induction coil.

Flexible bellows

Flexible bellows are used for making linear displacements of force or other factors: pressure, temperature. Therefore, they are often applied for the flow measurement and in control devices for various compensations. Flexible bellows are used in pneumatic and hydraulic gears because they generate large power when subjected to high pressure.

Seamless flexible bellows are made from thin-walled pipe, but multi-punched bellows are welded for ring elements (corrugates).

When making high power and compensating bellow construction, we are limited by the strength of the stock assessment. During metrological cases, there is a need to calculate bellow effective area changes in deformation process and to determine process deviations from the linear loads. It is also necessary to check bellow stability zones of high strain, thrilling stability and durability of loading cycles [1].

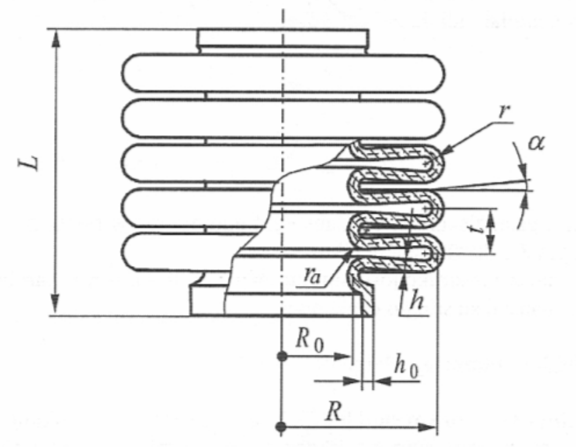

Fig. 1. Geometric parameters of a flexible bellow [1]

Bellow technical parameters

Bellow corrugates can be treated as circular plates, and we can express as symphonic springs stiffness:

$$c = \frac{Eh^3}{2nA_Q rR} \cong (4,3...4,8)\frac{\pi E h_0^3}{R^2 n} \tag{1}$$

Here $A_Q = f\left(\frac{R}{R_0}\right)$ – corrugates coefficient; R – outside radius (at the outside corrugates wall center line), mm; R_0 – inside radius (at the inside corrugates wall center line), mm; h – wall thickness, mm; h_0 – inside corrugates deviation from the tube outside, mm.

Bellow corrugates stress is calculated as:

$$\sigma_{10} = \frac{p\pi r^2 F}{2\pi rh} \tag{2}$$

The same can be nomographic calculation of stresses: circular σ_{20} and bending σ_{1M} and σ_{2M}.

Bellows are from 4.5 mm to 190 mm in diameter and are suitable for working temperatures between - 260°C to 550°C. The maximum allowable operating environment pressure for bellows is calculated as follows:

$$p_{kr} = \frac{8\pi E h^3}{k\, n\, L\left(R + R_0\right)^2} \tag{3}$$

Bellows may function when they are influenced by transverse and torsional loads.

Then corrugates shear stress is calculated as follows:

Inside

$$\tau_v = \frac{T}{2\pi h R_0^2} \qquad (4)$$

Outside

$$\tau_i = \frac{kT}{2\pi h R^2} \qquad (5)$$

Bellows service life depends on load type and bellow material and is from 8 to 70 thousand cycles. [1]

Research of flexible magnetorheological bellow

The device under study was assembled after producing the necessary components. Fig. 2 illustrates this device that consists of 7 units with 3 of them being standard.

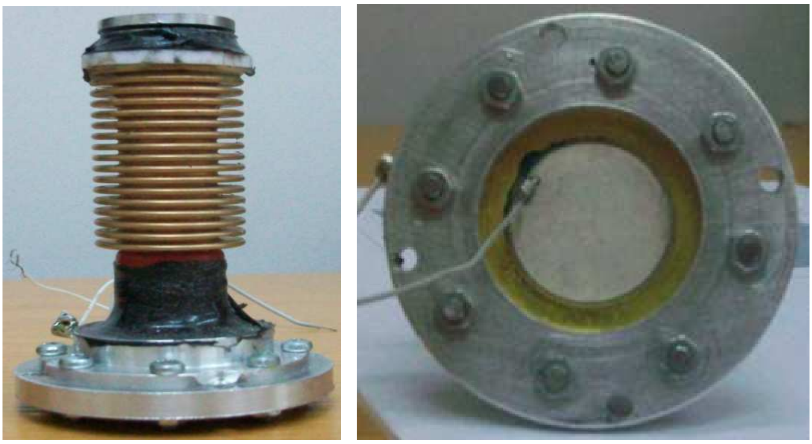

Fig. 2. Image of the device produced by using model constructed with SolidWorks

During assembly of the device from the components, gaps have been filled with a thin layer of sealant. Later, this device was completed with the magnetorheological fluid and attached to the stand (Fig. 3). Induction coil size was chosen on the basis of the flexible bellows outside diameters. Induction coil was made from 0,223 mm wire diameter, coil turns – 900, coil resistance – 46 Ω, coil inductivity – 23 mH. Permissible permanent current 0,40 A, short-term (till 3 seconds) – 1,35 A.

Experimental setup (Fig. 3) consists of:

Power supply: „*V&A Instrument HY3002-2*“;

Capacitive gap measurement device: „*DISA 51D11*“;

Measurement instrument: *Multimeter „Fluke – 87 IV „*.

In order to accurately measure small displacements we simulated experimental setup using SolidWorks software Experimental setup is adjustable and sufficiently rigid so that measurement accuracy is under insignificant influence.

The measuring device operating principle is based on the electromagnetic vibration LCR circuit operating principle. During these measurements the constant are: inductance and resistance parameters (capacity is variable). The capacity was changed by adjusting air gap between sensor plate and the measured surface (Fig. 5). The measured capacity is converted to voltage signal ant it is about U = ± 6V. And because this capacity sensor has a mechanical distance controller, it can be easily calibrated. By measuring the voltage dependence on shift we can easily express MR bellow plate push in micrometers.

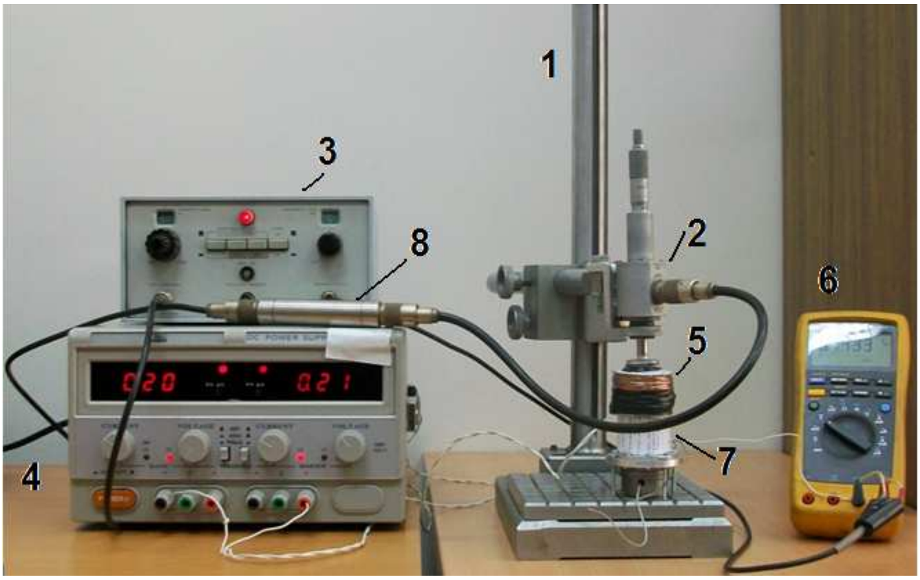

Fig. 3. Experimental setup: custom-made adjustable stand, 2. capacitive gap measurement device, 3. reactive impedance converter, 5. induction coil, 6. multimeter, 7. flexible magnetorheological bellow, 8. oscillator

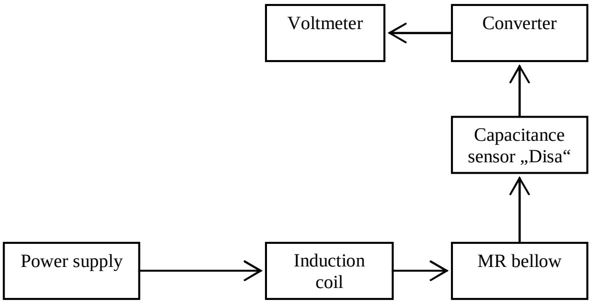

Fig. 4. Experimental setup block diagram

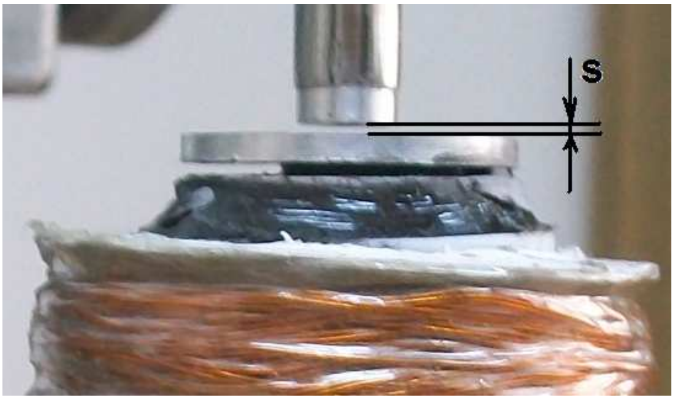

Fig. 5. Air gap between sensor plate and the measured surface of MR bellow

For the first study we selected magnetorheological fluid MRF-140CG from the "Lord Company". This fluid has high concentrations of iron particles, approximately 70%, so when the fluid is exposed to a magnetic field it can changed the viscosity characteristics more than other MR fluids with lower concentrations of iron particles. The study was carried in eight days by measuring the deformation of bellow, when the bellow is exposed to a magnetic field.

On the first day the magnetorheological fluid was well mixed and poured into the bellow without air. Next, it was fixed to the experimental setup and the capacity sensor was calibrated. Measured results are provided in Fig. 6.

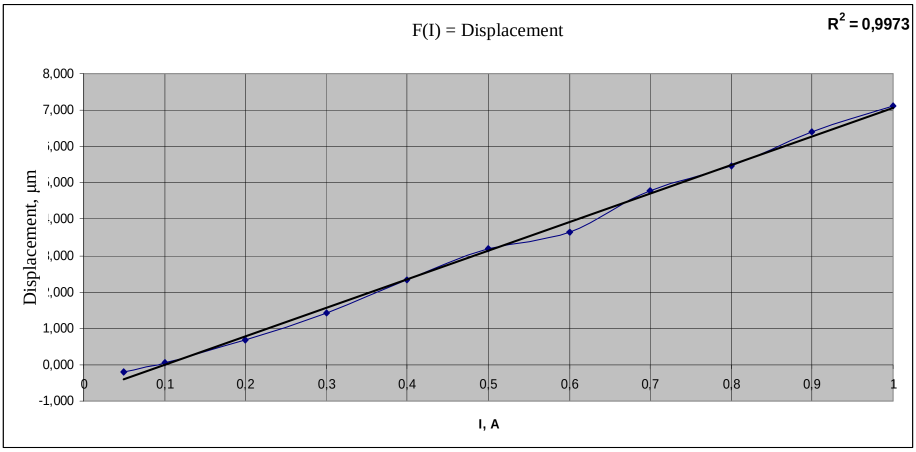

Fig. 6. Measured MRF-140CG parameters with bellow when MR fluid was perfectly mixed and unaffected by the sedimentation

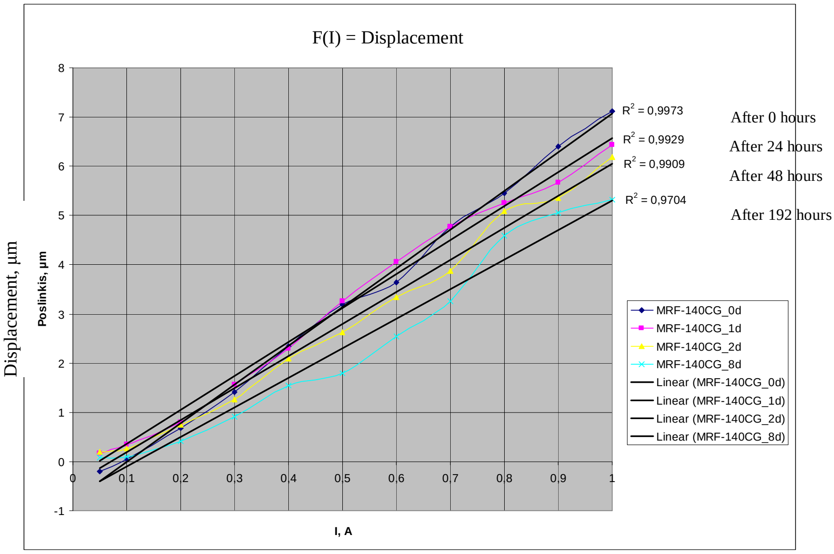

Fig. 7. Measured MRF-140CG parameters with bellow when MR fluid was left from 0 to 192 hours (0 – 8 days) for sedimentation

Fig. 7 presents measured characteristics of the bellow with MRF-140CG. The characteristics indicate that in the sedimentation process the maximum MR fluid particle settling velocity develops at the first 48 hours, after that MR fluid particle settling velocity decreased. This is because the MR fluid consists of many particles of different size, some particles are larger and some are smaller. Larger particles are heavier and more exposed to the gravitational field, so they quickly settle, while smaller particles remain suspended

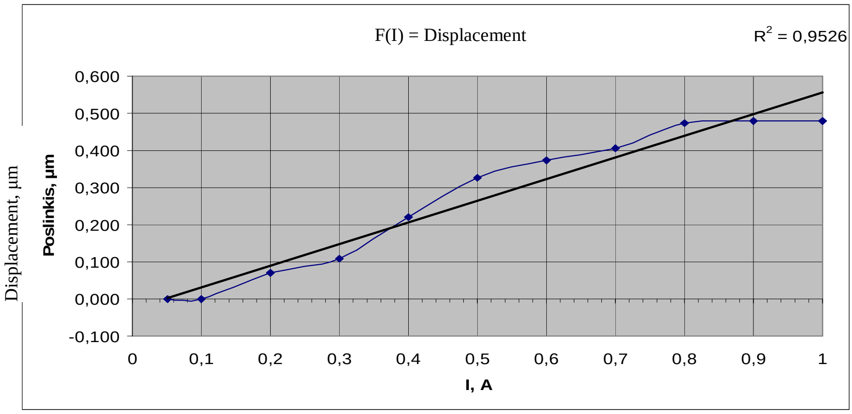

Fig. 8. Measured MRF-122EG parameters with bellow when MR fluid was perfectly mixed and unaffected by the sedimentation

During the next investigation stage the bellow was cleaned and washed, subsequently filling it with MRF-122EG fluid. On the first day the magnetorheological fluid was well mixed and poured into the bellow without air. After that it was fixed onto the experimental setup. Measured results are provided in Fig. 8.

After the measurements magnetorheological fluid was left at rest for 24 and 48 hours. After the sedimentation process we re-measured bellow deformations. After several days of testing, we noticed deterioration of MRF-122EG fluid performance, because, when operating the same magnetic field for the MR fluid, over time bellow deformation decreased and, after 48 hours of active sedimentation, it essentially stopped. The results are presented in Fig. 9.

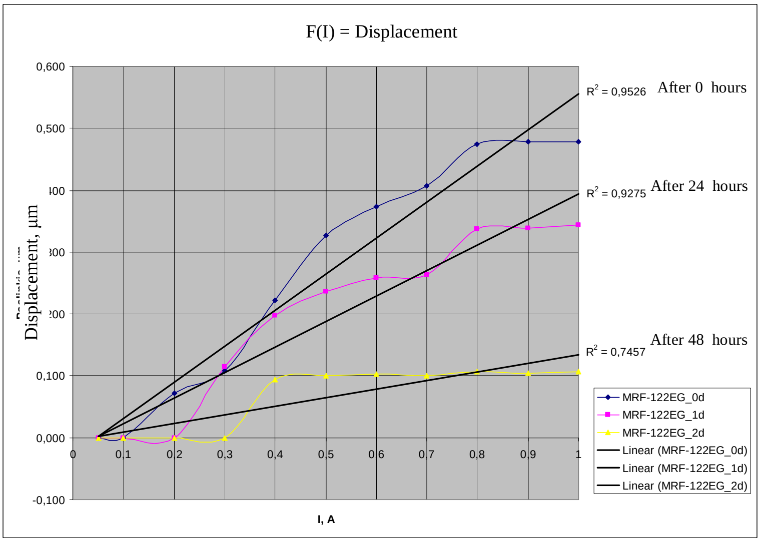

Fig. 9. Measured MRF-122EG parameters with bellows when MR fluid was left from 0 to 48 hours (0 – 2 days) for sedimentation

Fig. 9 indicates measured characteristics of the bellow with MRF-122EG. The measured characteristics reveal that in the sedimentation process the maximum MR fluid particle settling velocity develops at the first 48 hours, after that MR fluid particle settling velocity reduces and essentially becomes zero. This is because the MR fluid is made of lower concentration of particles and when particles were exposed to gravity, the sedimentation process proceeds faster because larger MR fluid consists of oil and solid particles settling at least with no interaction with one another, in contrast to higher concentrations MR fluids.

After several days of testing with the MRF-140CG and with the MRF-122EG fluids, the measured characteristics were obtained that are given in Fig. 10.

Fig. 10 provides measured MRF-140CG and MRF-122EG characteristics. These characteristics demonstrate that at the sedimentation process the maximum MR fluid particle settling velocity develops in the first 48 hours, after that MR fluid and particle settling velocity is reduced or in some fluids it essentially drops to zero. It was also noticed that after 48 hours, MRF-122EG fluid was affected by sedimentation process, the MRF-122EG fluid is with a lower concentration of particles and at the higher magnetic field fluid performance is extremely poor and is not adequate for operation, therefore it is necessary to mix the MR fluid.

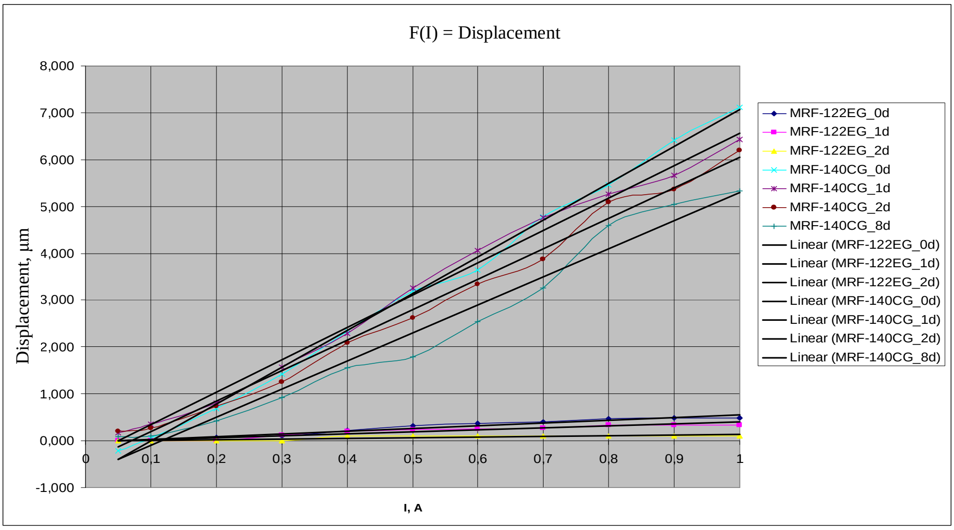

Fig. 10. Measured MRF-140CG and MRF-122EG parameters with bellow when MR fluid was left from 0 to 192 hours (0 – 8 days) for sedimentation

Conclusions

Characteristics of MRF-140CG and MRF-122EG fluid were studied in laboratory conditions by means of the bellow. We also measured the relationship between the fluid particle displacements and generated magnetic field in the electromagnetic coil.

Measurement results demonstrate that for MRF-122EG fluid the sedimentation of particles proceeds about 6 times faster than in the case of the MRF-140CG fluid.

MRF-140CG fluid particles were made 15 times greater flexible bellow shift at the 1A current of the magnetic field in comparison to the MRF-122EG fluid.

Maximum bellow deformation effect was observed when subjecting MRF-122EG fluid particles to a 0,8A current of the magnetic field.

It was determined that magnetorheological fluid MRF-122EG after 48 hours of sedimentation resulted in extremely poor fluid performance, which is inadequate for operation purposes, therefore it is necessary to perform mixing of the MR fluid.

References

[1] **J. Dulevičius, V. Eidukynas, M. Liutkevičius, L. Naginevičienė, A. Pavilionis, K. Pilkauskas, S. Žiedelis, P. Žiliukas** (2000) Mašinų elementai: skaičiavimas ir konstravimas. Kaunas: Technologija. 459p.

[2] **http://www.lord.com/tabid/3318/Default.aspx [watch date: 2009-10-24]**

[3] **LORD Corporation. http://www.lord.com [watch date: 2009-10-24]**

[4] **http://www.lord.com/Home/MagnetoRheologicalMRFluid/Products/MagnetoRheologicalMRFluids/tabid/3360/Default.aspx [watch date: 2009-10-27] .**

[5] **http://www.lord.com/Default.aspx?tabid=3795 [watch date: 2009-10-27] .**

[6] **http://smart.ippt.gov.pl/adland/ [watch date: 2009-10-27] .**

[7] **www.duke.edu/~hpgavin/papers/seattle01b.pdf [watch date: 2009-10-27] .**

[8] **http://www.iop.org/EJ/article/1742-596/149/1/012045/jpconf9_149_012045.pdf?request-id=ec619fad-3db2-4197-a384-ee266a20e6f8 [watch date: 2009-10-27] .**

[9] **http://www.ieee.org/portal/site/sscs/menuitem.f07ee9e3b2a01d06bb9305765bac26c8/index.jsp?&pName=sscs_level1_article&TheCat=6010&path=sscs/07Fall&file=Gilbert.xml [watch date: 2009-10-15] .**

[10] **http://www.lord.com/Default.aspx?tabid=3795 [watch date: 2009-10-18] .**

[11] **Jolly, M. R., J.W. Bender and J. D. Carlson, —Properties and Applications of MR Fluids, SPIE 5th Annual Int. Symposium on Smart Structures and Materials, San Diego, CA, 15 March, 1994.**