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FRICTIONLESS BELLOWS UNIT CONNECTED WITH THE MAGNETORHEOLOGICAL VALVE

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Abstract: *Dynamic range is one of the key parameter for effective control of magneto-rheological (MR) dampers in suspensions controlled by semi-active algorithms. This article discusses dynamic range increase ensured by elimination of friction in a device which forces fluid to flow through MR valve. The friction affects a force velocity dependency. It is a part of force that cannot be controlled. Therefore friction is unwanted in MR dampers or valves. This article describes the two versions of volumetric unit with MR valve. First, the fluid was forced by hydraulic cylinder with high friction. In order to eliminate friction, a unique volumetric unit was designed and used instead of hydraulic cylinder. It uses elastic metal bellows which can be sealed by static seals, therefore there is no contact between moving parts. Measurement of force velocity dependency was carried out for original and new volumetric unit connected with the same MR valve. The results showed that the frictionless unit exhibits a significant improvement of dynamic range for the whole range of velocities compared to original piston unit. That has positive impact to efficiency of vibration elimination of MR valve using semi-active control.*

Keywords: Vibration, Dynamic range, Magneto-rheological valve, Frictionless, Bellows

1. Introduction

Vibrations – an accompanying feature of movement are usually unwanted. Therefore, there are understandable efforts to reduce them according to Housner's study (1997). One of possible way is semi-active control using magneto-rheological (MR) damper or valves. Fundamental part of these smart devices is a coil. The coil allows creating the magnetic field with different intensity that causes various yield stress of medium – MR fluid. Carlson (1996) describes the MR fluid as suspension of iron particles, oil and additives. Yang (2002) said that efficiency of MR damper for semi-active control is affect by two factors: dynamic range and time response. Until now, the fastest damper was developed by Strecker (2015). Time necessary to change the damping of this damper is approximately 2 ms. Dynamic range (1) depends on the piston velocity and it can be calculated as ratio of the damping force in active state (F_{on}) and the force in inactivated state (F_{off}). The off state force can be determined according to Yang (2002) and Bai (2014) as the sum of force caused by flowing of viscous fluid F_η and the friction F_f. It is necessary to add a yield stress force F_τ in sum for active state.

$$D(v) = \frac{F_{on}(v)}{F_{off}(v)} = \frac{F_\tau + F_\eta + F_f}{F_\eta + F_f} = 1 + \frac{F_\tau}{F_\eta + F_f} \qquad (1)$$

Couple ways of increasing the maximal dynamic range were described. Carlson (1996) increased the maximal magnetic field strength in the gap. Yang (2002) optimized geometry of gap and piston. Cvek (2015) choses fluid that exhibits the greatest differences between the yield stress in ON and OFF states. Above mentioned authors however did not investigate the influence of sealing friction. The friction in off-state can cause significant part of damper overall force, but it is negligible in on-state. Therefore, elimination of the friction force should improve the dynamic range of MR damper. The elimination of friction was discussed in papers from Davis (1994), Seong (2013) and Lee (2015).

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In this article, the impact of friction force on dynamic range is investigated. The frictionless unit with bellows is compared to the classical concept with hydraulic cylinder with friction force caused by usual sealing.

2. Methods

The first version, where the fluid was forced to flow through MR valve by commonly used hydraulic cylinder is shown in Figure 1 – left. There are seals between cylinder and piston or piston rod. These seals are the most significant cause of friction force. That force cannot be controlled, consequently it decreases the dynamic range of MR valve. Therefore the cylinder was replaced by newly designed bellows unit shown in Figure 1 – right. When the pulsator moves relative to the frame, the fluid is forced to flow through MR valve. Damping force of MR valve was controlled by electric current in coil.

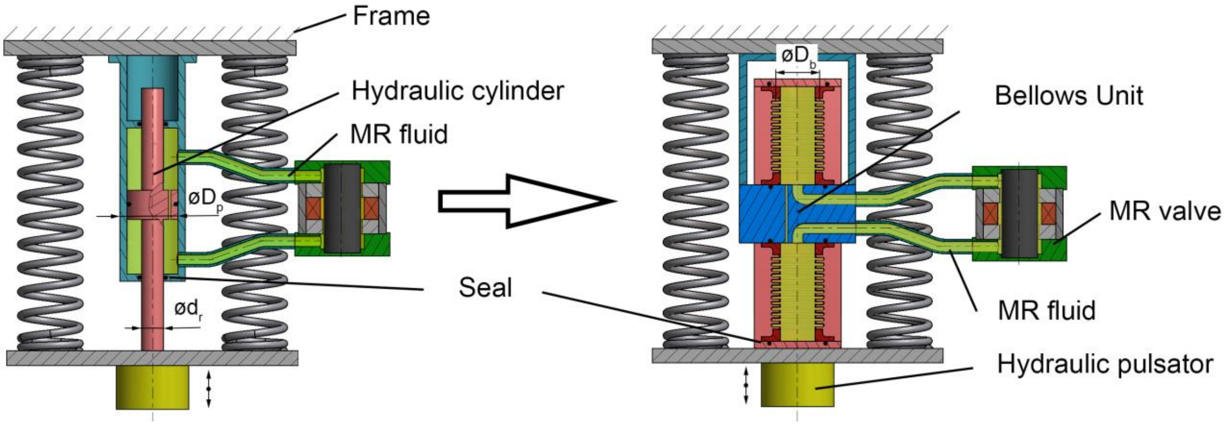

Fig. 1: Scheme of first (left) and second (right) volumetric unit

2.1. Measurement set-up

The damping and spring force *F* was measured by strain gauge load cell INTERFACE 1730ACK-50kN mounted between the upper plate and the frame. Velocity $\underline{v_o}$ was measured by sensor integrated in pulsator INOVA AH 40-150 M56. Force caused by springs was calculated and subtracted from total force by our software.

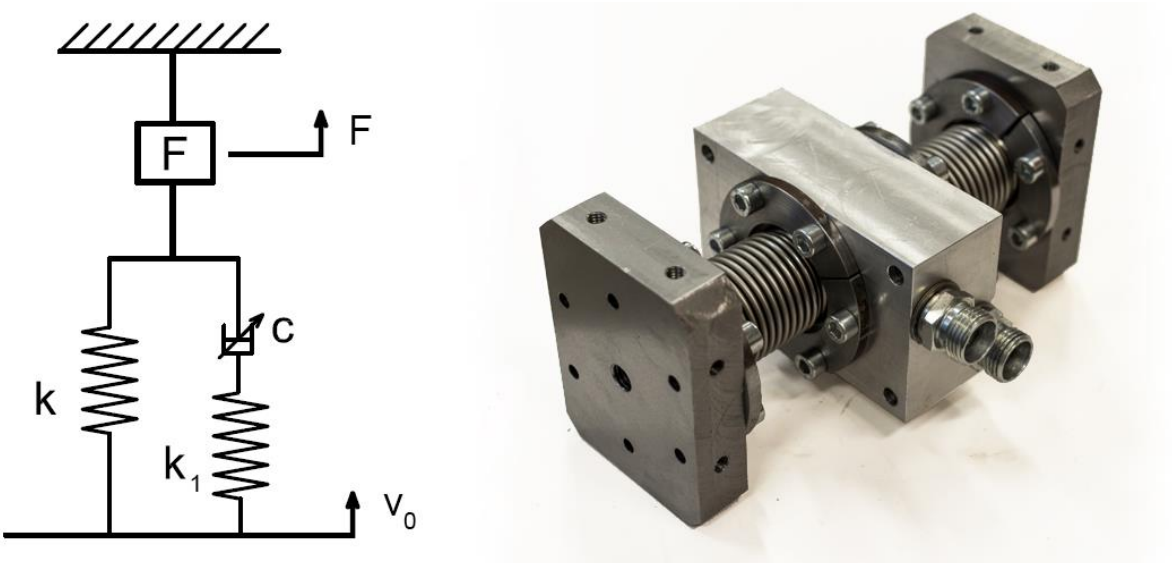

Fig. 2: Scheme of measurement (left) and manufactured bellows unit (right)

Damping of MR valve was investigated in conjunction with both volumetric units with the same settings:

Fluid	***MRF 132 DG (LORD)***
Excitation	***Linear Sweep sine***
Exc. Amplitude	***5 mm***
Exc. Frequency	***0.1 – 8 Hz***
Coil currents	***0A, 0.5A, 1A***
Bypass diameter	***1.45 mm***

3. Results

Primary stiffness k is 402 N/mm, secondary k_1 2860 N/mm and damping coefficient c cannot be determined, because force and velocity dependency of the MR valve is non-linear.

3.1. Force and velocity dependency

Force - velocity dependency of bellows unit differs especially for current 0A compared to hydraulic cylinder, because of friction decrease. This also affects the states with other currents in coil, therefore the force is lower. We can observe different slope of curves in measurement for cylinder and bellows. It is caused by different effective area. For hydraulic cylinder, the effective area is the piston area, which is given by diameter of piston $D_p = 36\ mm$ and piston rod $d_r = 18mm$ (Fig. 1). But bellows unit has no piston, therefore the middle diameter $D_b = 30.25\ mm$ of bellows waves was taken as an effective area shown in Fig. 1. Presumption that middle diameter can be considered as virtual piston was verified by test. These areas were not absolutely similar because of limited sizes of bellows and cylinders offered by manufacturers. The different effective areas for bellows and hydraulic cylinder have however minimal impact on dynamic range.

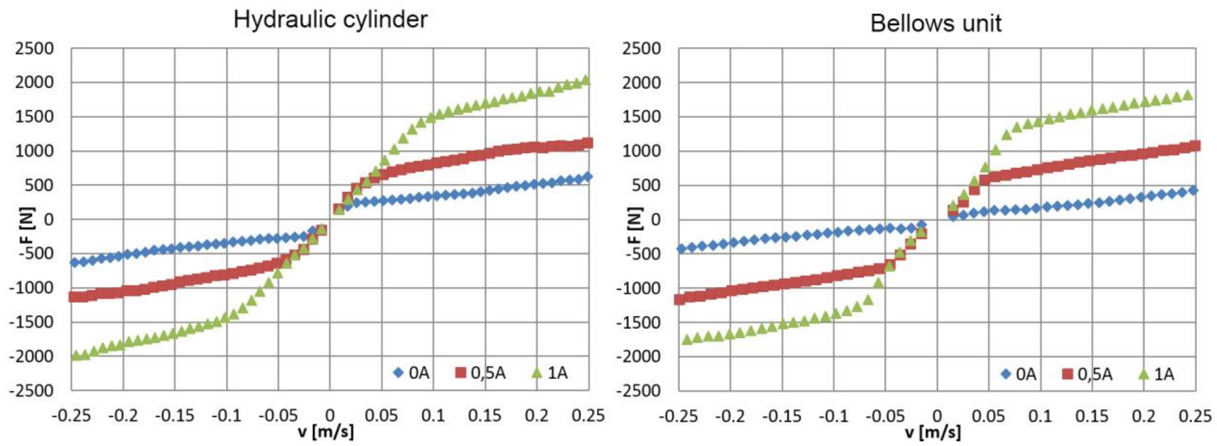

Fig. 3: Force velocity dependency of MR valve connected with the hydraulic cylinder (left) and bellows unit (right)

3.2. Dynamic range

The dynamic range $D(v)$ of MR valve can be counted using the equation (1) so the ratio between damping force with maximal current in coil ($I = 1\ A$) and no current in coil ($I = 0\ A$). The dependency of Dynamic range and velocity is shown in Fig. 4. It is obvious that the new design has a higher dynamic range for all velocity range. For the lower velocity value v < 0.08 m/s is the increase more than 100%.

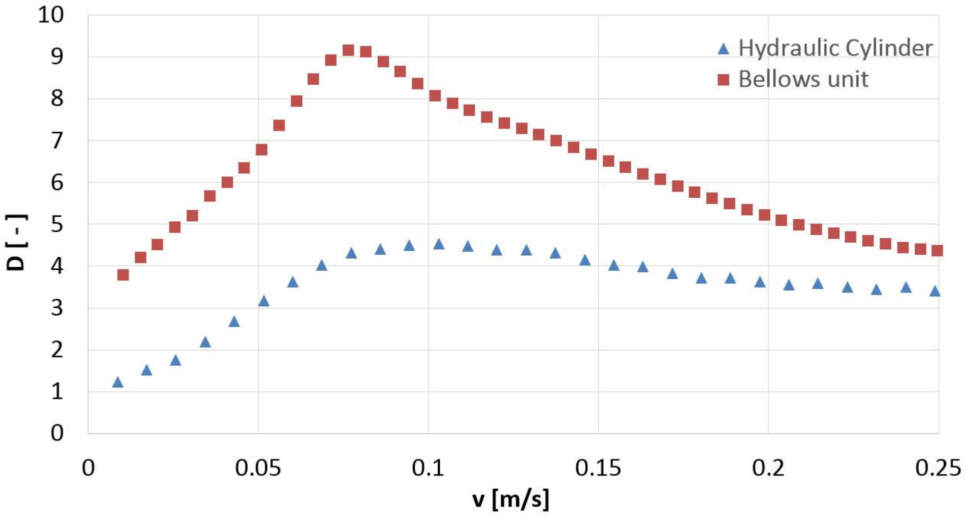

Fig. 4: Comparison of dynamic range

4. Conclusions

Two versions of volumetric unit which forced fluid flow through MR valve was designed manufactured and tested. The first version was a standard solution with hydraulic cylinder with friction caused by sealing and the second version was frictionless bellows unit. The measurement proved that the force caused by friction in damping system with MR valve has significant impact on dynamic range of such devices. The increase of dynamic range for frictionless bellows unit is more than 100% for velocity of pulsator in range 0 – 0.08 m/s. This fact should according to Yang (2002) significantly improve quality of damping using a semi-active algorithm.

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