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Magneto Rheological Semi-Active Damper with External By-pass Circuit in Modular Structure

In order to perform experimentally studies, in the paper it is presented a simple method which was elaborated to realize reliable, at low cost and reproducible semi-active dampers with magnetorheological fluids, having external magnetic circuit. The main components are common constitutive elements of industrial hydraulic and pneumatic drivers, having the supplementary advantages being manufactured in a large scale of overall dimensions and demanding minimal modifications. As accumulator, a similar type of hydraulic or pneumatic cylinder was used. The work of the whole damper can be optimized by modifying the nitrogen pressure and interior volume of accumulator. Another important advantage of this conception is the possibility to realize a modular structure composed by the damper, accumulator and magnetic field generator, interconnected by flexible elements.

Keywords: *magnetorheological fluid, semi-active, by-pass circuit, modular structure*

1. Introduction

The magnetorheological fluids (MRF) are colloidal suspensions, which exhibit large reversible changes of flow properties, such as the apparent viscosity, under the action of an enough powerful magnetic field. Due to these properties, the magnetorheological fluids are ideal materials to realize dampers with semi-active control. The basic operating modes of magnetorheological fluid devices are presented in fig. 1. The robustness and the simple mechanical design of magnetorheological (MR) dampers make them a natural candidate for a semi-active control device. They require minimal power while controlling high forces suitable for full scale applications. They are fail-safe since they behave as passive devices in case of a power loss [2]. MR fluids are suspensions of small iron particles in a base fluid. They are able to reversibly change from free-flowing, linear viscous liquids to semi-solids, having controllable yield strength under a magnetic field. When the fluid is exposed to a magnetic field, the particles form linear chains, parallel to the applied field. These chains impede the flow and solidify the fluid in a matter of milliseconds. This phenomenon develops a yield stress which increases as the magnitude of the applied magnetic field increases [3].

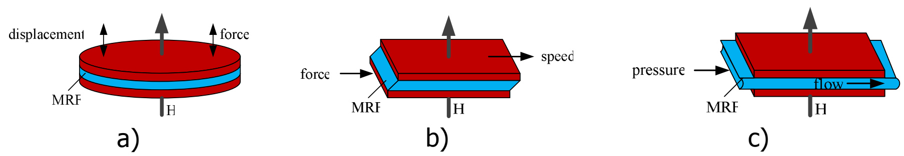


Figure 1. a) Squeeze mode, b) Shear mode, c) Flow mode [1]

2. Magnetorheological fluid damper with external circuit

In Fig. 2 it is presented the semi-active MRF damper, with external magnetic circuit. The piston 1, fixed on the shaft 2, passes through the cylinder 3, filled with MRF. The accumulator 4 is filled with pressurized nitrogen and acts over the piston 5, which has the role to reduce the effect of shocks assumed by the damper shaft and balances possible dilatations of work fluid. The fluid can pass from one side of piston 1 to the other one by bypass duct 6. One electromagnet 7 lays on the bypass duct and acts over the fluid viscosity assuring the possibility of work optimization.

At one extremity of the accumulator cylinder it is placed the filling device 8 which permits the nitrogen charging, monitorized by the manometer 9. The valve 10 assures the possibility to optimize the accumulator behavior.

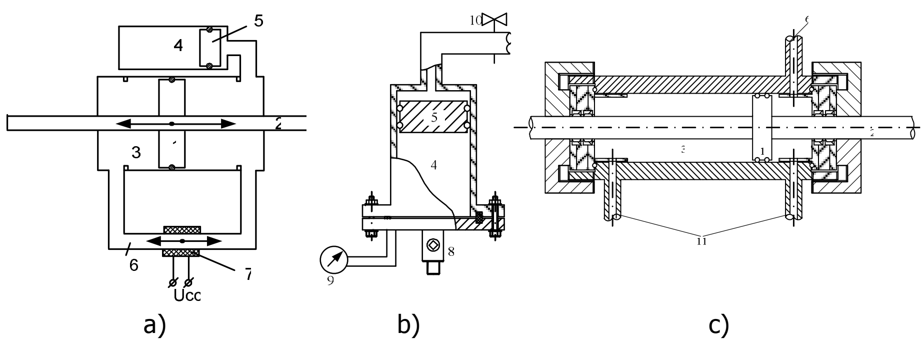


Figure. 2. Semi-active MRF damper with external circuit: a) Block diagram, b) Accumulator, c) MRF damper

In literature, the most known model to characterize the behavior of MRF dampers is the Bingham plastic model. This model is an extension of the Newtonian flow and it is obtained by also taking into account the yield stress of the fluid. It assumes that flow will occur when the dynamic yield stress is reached. The total stress is given by

$$\tau = \tau_y\left(\dot{\gamma}\right) + \eta\dot{\gamma}, \tag{1}$$

where τ_y is the yield stress induced by the magnetic field, $\dot{\gamma}$ is the shear rate and η is the viscosity of fluid. In this model, the relationship between the damper force and the shear velocity may also be given as

$$F=\begin{cases} F_y\, sgn(\dot{x})+C_0\dot{x}, & for\ \dot{x}=0 \\ -F_y<F<F_y, & for\ \dot{x}=0 \end{cases}, \tag{2}$$

where C_0 is the post-yield damping coefficient and F_y is the yield force. In the post-yield part, the slope of the force-velocity curve is equal to the damping coefficient which is essentially the viscosity of the fluid, η. Both C_0 and F_y are functions of the control current input, *i,* and can be modeled as second order polynomial functions:

$$F_y(i) = F_{yc}i^2 + F_{yb}i + F_{ya},\ C_0(i) = C_c i^2 + C_b i + C_a. \tag{3}$$

The model coefficients may be found by minimizing the mean square error between the experimental and the model-predicted damper force [4].

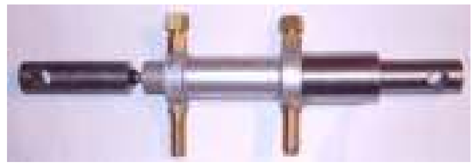
Other MRF damper fluid models in the literature include the Herschel-Bulkley model, which takes into account the post-yield shear thinning and thickening behavior and the Bouc-Wen model, where the parameters of the model can be adjusted to control the linearity in the unloading and the smoothness of the transition from the pre-yield to the post-yield region [5].

2. Device realizing

The assembly is composed of four modules: damper, accumulator, magnetic field generator with incorporated bypass device.

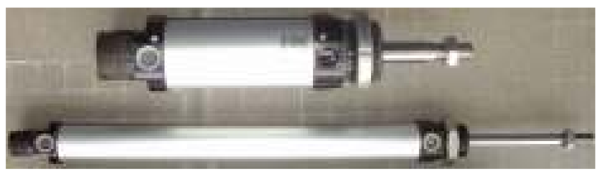
To realize the damper, common components control devices of hydraulic drives were used, with minimum modifications.

In fig. 3.a, the common industrial hydraulic damper is presented, where, at the extremities, small aeration devices were mounted. In fig. 4, also common industrial pneumatic dampers are presented, with different capacities and section shapes [6].

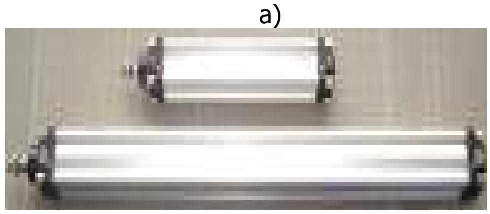
 

a) b)

Figure 3. a) Modified hydraulic damper, b) Modified mini hydraulic damper [1]



a)



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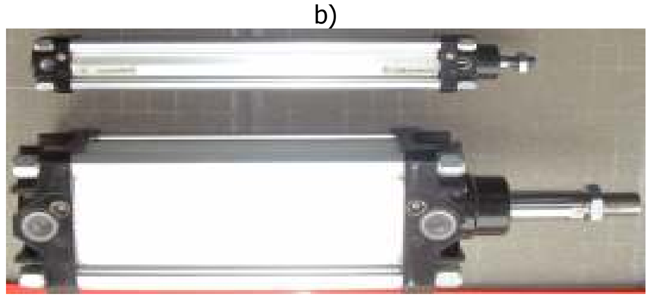

c)

Figure 4. Pneumatic damper: a) Circular section, b) Square section, c) Square section of small and big capacity

Another advantage of this solution is the fact that the damper can be manufactured of any material, due to the absence of the internal magnetic field. In addition to this advantage, it is also the fact that the construction of the device is modular, so that a large scale of dampers, of different dimensions, can be used, fig. 3, 4.

The accumulator has the role to take over the effects of volume modifications of fluid, due to the temperature variations. In the interior of cylinder, there is a piston which separates the nitrogen filled part and the part in contact to the magnetorheological fluid.

This classical solution was improved by adding two new facilities: the part containing the nitrogen was equipped with a gas charging device, which permits the control of pressure, as a function of the application.

At the opposite extremity, it was mounted a valve, with continuous control. Its role is to modify, in very large limits, the damper behavior, between the limit situations, when the accumulator executes its basic function (above defined) or it works like a gas damper. A remarkable aspect is the fact that any dampers, presented above, can be adapted as accumulator, with the mentioned modifications.

For reasons of simplicity, another type of accumulator, presented in fig. 5.a, was realized, using common components of heat installations [1]. In the case when the damper is big, in order to use a smaller quantity of magnetorheological fluid, it is adopted another solution.

In this case, the magnetic field generator acts on a device, equipped by two pistons and containing MRF; the rest of circuit is filled by silicon oil, used in vacuum technique, due to its very low viscosity. In the series of figures 5.b, and 6.a, there are presented a few bypasses with two pistons.


a)


b)

Figure 5. a) Multifunctional accumulator, b) Magnetic field generator, together with a bypass

a) b)

Figure 6. a) Bypass devices, with filling elements, b) Flexible connectors, with 2 aeration elements [1]

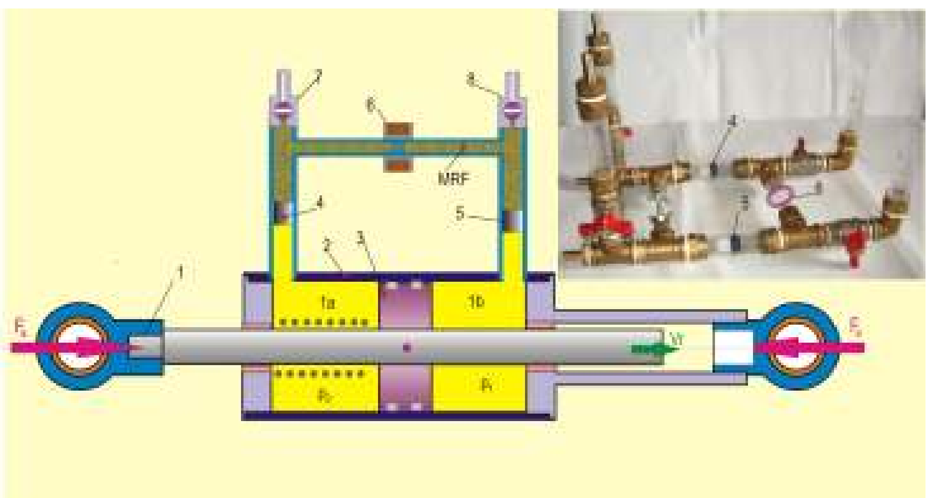

Figure 7. Magnetorheological semi-active damper with external valve

Figure 8. Flow limiter with discs (with slots)

A set of flexible connection elements, guarantied by the producer until the pressure of 60 Barr, are presented in fig. 6.b. The transparent components exist, also, in metallic execution (Cu, Al). Their interchangeability is facilitated by the fact that all constitutive elements are screwed.

Taking into account the fact that the MRF has a relatively high viscosity, the elimination of air bubbles is a very important and obligatory operation in the filling process. The presence of bubbles in the MRF has a negative influence on the fluid behavior and measurement results. That is why, in the majority of figures, it can be remarked the presence of aeration elements.

As magnetorheological fluid it was used the type MRHCCS4-B, produced by LIQUIDS RESEARCH Limited from U.K.

3. Conclusions

In conclusion, the presented material represents a suggestion, useful to the researchers, to realize a modular system, based on a semi-active MRF damper, with external circuit, by adapting common components control devices of hydraulic drives [1].

The obtained system offers important advantages, like: replacing of any module, without modifying the rest of configuration; effecting of precision settings, by the setting facilities, offered by the accumulator; the magnitude of the magnetic field generator is no more limited by the interior dimensions of cylinder, being possible the use different types of MRF; the damper dissipated heat does not influence the MRF.

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