Self-Locking MRF Actuators for Dampers and Latches

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Abstract:
MRF actuators are new electromechanical components using Magneto Rheological Fluids (MRF). When submitted to a high enough magnetic field, MRF switch from a liquid to a near solid body. These new developed MRF actuators were developed in order to reach three aims: to offer a blocking force at rest which can be strongly reduced by applying a current, to provide an electrically-controllable resistive force over a stroke of 30 mm, to perform the control of the force in a very short time, typically in a few milliseconds. Thus, these MRF actuators can be used for two main applications: damper and latch - lock. Experiments on two versions of the actuator (a single piston rod and a feed through output axis) allows to get a blocking force around 100N, which is more than 10 times the actuator weight (its mass is 700gr). The required current and electric power required to cancel the blocking force are only 1.6A and 4W. The paper will further present the design and the electromechanical properties of the Self-breaking MRF Actuators for dampers & latches and new results on the control of these actuators.

Keywords: Magneto Rheological Fluid ; MRF; Shock absorber ; Semi Active Damping of Vibration ; Semi Active Control of Vibration ; Damper ; Electric Brake ; Lock ; Latch ; Smart & Active fluid ;

Introduction

The MRF actuators are new electromechanical components using Magneto Rheological Fluids (MRF) [1]. These smart fluids are characterized by their ability to change their rheological properties versus applied magnetic field. With a sufficient field, they can switch from a liquid to a near solid body. This effect is reversible and it operates in few milliseconds. This effect can be used for generating controllable damping, smart shock absorption or braking capabilities. Most of MRF actuators (see for ex [2]) offers a controllable breaking force but does not offer a blocking force at rest for offering a self-locking operation.

Aim

The purpose of the new developed MRF actuators is to reach three aims:

- to offer a blocking force at rest, which can be strongly reduced by applying a current,
- to provide an electrically-controllable resistive force over a stroke of 30 mm,
- to perform the control of the force in a very short time, typically in a few milliseconds.

Applications

The MRF actuator can be used for two main applications: damper and latch - lock. In some cases, these two applications can be combined. For example in some embedded instruments, it is interested to damp vibrations when the lock / unlock operations occur. The self-locking feature has been obtained in the developed actuator thanks to a particular magnetic circuit designed with FLUX software [2] and knowledge acquired on MRF fluid magnetic and rheological properties [3].
The first application is the optimised damping that needs controllable energy dissipation. The device provides dissipated energy control in real time thanks to the current control. In a few milliseconds, the energy dissipation can be increased by 500%. A maximum damping can be maintained without power supply and thus the fail safe operating can be guaranteed in several applications. Moreover, vibrations damping and shocks absorption can be optimised thanks to a closed loop.
The second main application is the locking in position. The current control allows blocking the load in any positions along the stroke. Therefore, the MRF actuator acts as a linear electro-mechanical break without moving parts. Whatever the piston rod position, if the motion force is lower than the maximal force damping (@0A), the control of the current allows getting the lock of the rod.

Architectures

The aim of these prototypes is to allow damping and latching of a moving device.
Two architectures of the device are designed, manufactured and tested:

- a damper with a single piston rod, the device allows damping a movement versus the frame
- a damper with a double piston rod which allow transmitting the movement through the damper which operates in series with the motion line.

The twice devices operate in flow mode with a twin tube structure.

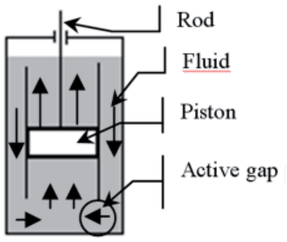

Fig. 1: *Twin tube structure*

The twin tube structure allows separating the fluidic aspect to the magnetic aspect in the design and considering the combination of the fluidic and the magnetic effects only in the active fluid gap.
The active fluid gap section is around 1 x 56.5 mm² and the length of the fluid gap area is around 3mm. The magnetic filed computed thanks to FLUX Cad is controlled between 0 to 0.8 T in the active fluid gap.
The 132DG Lord MR fluid properties have determined the range of induction in the active fluid gap in order to have the best compromise between linearity, performances and power consumption.
A permanent magnet of 0.38 cm3 is used to create a magnetic field of 0.8T in the fluid gap without power consumption. That allows a blocked or a maximal damped behaviour without current consumption.
The coil resistance is around 1.4 Ohms with an inductance close to 36mH, so the time constant is around 25ms.

A perfect tightness needs a high compressibility of joints, which is cause of a significant friction. In this application, the friction force must be minimised. An adapted solution is found to guarantee perfect tightness and minimal joint friction (around 20N).

The damper with a single piston rod (fig 2) presents several technological difficulties to solve in order to have a symmetrical behaviour between push and pull operation and in order to allow an operating in all orientations.


Fig. 2: *Damper with a single piston rod*

The movement of the rod causes an increase of the volume in the cavity and so a compressible volume must be added into the fluid to accumulate the excess of the fluid when the rod enters. An external accumulator can achieve this function but the global volume and the integration of the device is more difficult in a limited size. A simple free air bubble can achieve this function of accumulator but the damper-latch cannot operate in all orientations. Indeed, with a non-located compressible volume like an air bubble, the orientation of the device must be chosen in order to locate the bubble far from the controllable fluid gap. In fact, the transit of the bubble through the active fluid gap suppresses the force control of the device, as a part of the air bubble is present in the fluid gap. The best solution is to locate and fix the compressible zone in the fluid cavity in order to avoid the transit of this compressible volume through the active gap. A fluid tight moss fixed in one room can be used to absorb the volume modification caused by the rod movement. The problem of volume variation is solved and the damper can operate in all orientations.
A test campaign has been performed and the first measurements achieved show the damper operates perfectly in the push direction but cavitation effect modifies the operation in the pull direction.

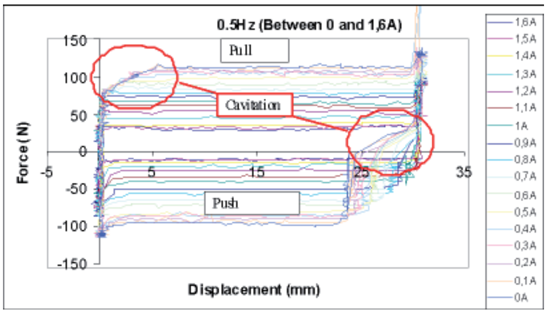

Fig. 3: *Performances with cavitation effects*

When the traction force is higher than a specific value (force corresponding to cavitation pressure), the cavitation phenomenon appears. This phenomenon is linked to the evaporation of the MR fluid when the vacuum in the fluid room goes below the saturation vapour pressure. As soon as the cavitation appears, the rod goes to the end stop because the stiffness of the device becomes null. As the moss is located in one room and as the moss keep constant pressure, the phenomenon appears when the pressure dropped in the room without moss, so only in pull direction operating. In order to allow a symmetric operation of the damper, the cavitations effect must be suppressed. An increase of the pressure in the fluid cavity allows rejecting the cavitation out of operating force range. The prototype is filled with a pressure of four bars to suppress this cavitation effects.
A test campaign allows checking the performances of the damper as a resistive force generator. The results

show that the cavitation is suppressed and performances are similar in both directions.

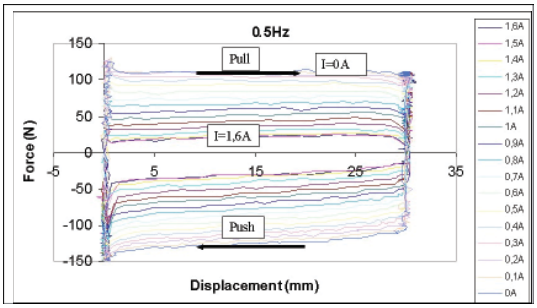

Fig. 4: *Performances of damper with a single piston rod @ low frequency*

The damper (fig 5) with a double piston rod allows transmitting the movement through the damper.

Fig. 5: *Damper with a double piston rod*

On this prototype, like the rod goes through the device, no variation of the cavity volume must be compensated (excepted thermal expansion). The moss solution to compensate volume variation is not required.

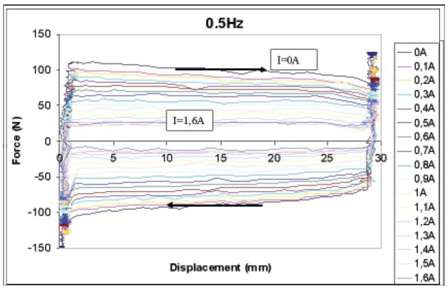

Fig.6: *Performances of damper with a double piston rod @ low frequency*

As this device can operate without accumulator, the device operates all the time in "push operating" in one fluid room and no cavitation is possible. It is important to note that the sealing must be considering with attention because the seal around the rod must be able to resist to high pressure under a shock.

The results show similar performances in the twice directions and a wide range of force control.

Latch performances

When the device is used in a latch, the rod is locked without power consumption. The moving parts are locked as long as the force applied through the load on the latch does not exceed the maximal locking force (around 100N for these prototypes).
However, after experiment, it appears that the locking is apparent but non-ideal: if a force is applied on the rod along a significant time, a slow movement of the rod is measured. Indeed, the magnetic field application allows increasing the shear stress and should block the movement but as the real fluid behaviour does not follow the Bingham model, a low displacement is observed.

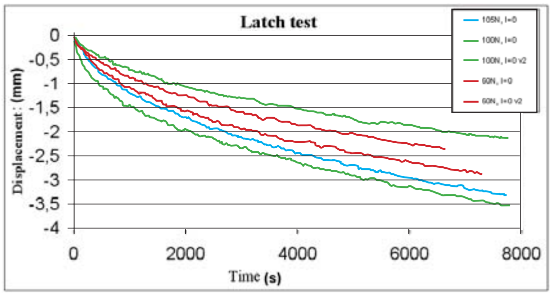

Fig. 7: *Displacement versus time in locking position*

When the device is locked the rod speed is close to 2.3µm/s. The speed is very low and imperceptible for human, however, after 2 hours under 100N, the displacement for the rod reaches more than 1 millimetre. Therefore, the device cannot be used to latch a load for a significant time but it is perfect to fix a position for several minutes with a localisation precision of about 0.1mm. The speed of the load can be controlled too thanks to the real time control. This control could allow a smooth stop of the load before position fixing thanks to damper effect.
Finally both devices have comparable performances because most of parts are common (tab 1). Note that the required electric power is very low regarding the produced resistive forces.
To conclude for the latch function, the MRF actuators can be used as a lock only to fix in position a moving part along a limited time function of the wished precision position.
The typical application where this device could be used is a position control in real time of a load actuated by an all or nothing actuator, as bistable or monostable actuator. This device could allow controlling in position and speed an all or nothing actuators as hydraulic, pneumatic or electromagnetic actuator.

Damper test and performances

MRF actuators have been tested as controllable dampers by trying to exploit their variable dissipation force. Their minimal force is around 20N and the maximal force is closed to 100N. The force can be modified by 500% in few milliseconds due to the Magneto rheological fluid.

References	Unit	A-MRF single piston rod	A-MRF double piston rod
Notes			
Stroke	mm	30	28
Damping force @ 0A	N	120	90
Damping force @ 1.6A	N	25	16
Dissipated energy pers cycle @ 0A	Nm	7.2	5.04
Dissipated energy pers cycle @ 1.6A	Nm	1.5	0.72
Total weight	g	640	730
Diameter	mm	43	43
Height (without stroke)	mm	94	97
Max current	A	1.6	1.6
Electrical interface		1 coils = 2 wires	1 coils = 2 wires
Winding resistance	ohm	1.67	1.65
Winding inductance	mH	10.82	9.95
Electric time response	ms	6.5	6
Electric dissipated power @1.6A	W	4.3	4.2

Tab.1: *MRF Actuators performances*

The damper dissipates a maximum energy without power consumption and the supplying allows decreasing the dissipated force. A fail safe operating can thus be guaranteed.

Implementation of damper

Different MRF dampers are implemented on a flexible structure to damp vibrations.
The adding of a damper on the device allows decreasing the mechanical oscillations of the flexible structure. Several dampers with a couple of values of resistive force are tested and the behaviour of the flexible structure is strongly influenced by the damper characteristics. A strong damper with a high resistive force modifies the stiffness of the beam and the mechanical oscillation frequency too. This kind of damper could be used to move the resonant frequency in order to avoid damage of the structure when the excitation frequency varies. In fact, the damper is control in real time in order to avoid the excitation frequency to be the same the structure resonance frequency. A weak damper does not modify significantly the mechanical characteristics of the flexible structure (frequency...). The efficiency to decrease the oscillation could be lower but interesting. For example, the damping of a structure with a small damper with a controllable force from 3 to 6 N allows to decrease the quality factor from 36.7 to 23.5 so a decrease of 36% of the quality factor when the damping is maximised.
In all case, pay attention to design and compute dampers, which guarantee a real efficiency and a real controllability of the damping versus the aim of the control.

Conclusion

As targeted, both developed MRF actuators offer blocking at rest, electrically controllable resistive force and fast control. They operate in all orientations and in both directions (Pulling & pushing): several physical limits were solved like the cavitations, the sealing and the volume variation when the rod goes in the damper.
A test campaign has been performed to assess the technologies versus the theoretical expectations. Force versus displacement at different currents, shows the achievement: locking at rest, controllable forces, pulling & pushing operations with similar properties for both actuators. Typical performances for the both actuator types are given in the Tab 1 and are very satisfying.

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References

[1] J.D.Carlson, P.Sheng, W.Wen, Magnetorheological and electrorheological fluid highlight 2006, Actuator Conf Proc, pp 2 35-239
[2] http://www.cedrat-groupe.com/en/software-solutions/flux.html
[3] Magnac, G., P. Meneroud, M.F. Six, G. Patient, R. Leletty and F.Claeyssen, 2006, Characterisation of magneto-rheological fluids for actuators applications, ACTUATOR 2006, 856-859.
[4] Florian Zschunke, 2005, Aktoren auf Basis des magnetorheologischen Effekts
[5] Rui Loureiro, Wiliam S.Harvin, Design and characterisation of a low profile controllable magneto-rheological fluid based actuator for vibration mitigation, ACTUATOR 2006Bremen
[6] Leng J.S., Asundi,A and Liu, Y. "Active Vibration Control of Smart Composite beam with Embedded Optical Fiber Sensor and ER Fluid", ASME Conference. 1998