CHARACTERISATION OF MAGNETO-RHEOLOGICAL FLUIDS FOR ACTUATORS APPLICATIONS

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Abstract:

Magnetorheological fluids (MRF) are magnetically controlled fluids and they find more and more industrial applications in actuation functions. These include shock absorbers, semi-active dampers, clutches, brakes, haptic actuators & devices. Several of these applications have been studied by Cedrat Technologies for its industrial customers, and a device-oriented test bench has been developed in order to characterise the magneto-mechanical properties of MRF such as the magnetisation curve, the yield stress …. It is based on a large electromagnet which is able to produce a magnetic field into a tube containing the MRF sample. The magnetisation curve is determined using the permeameter method. It allows designing the magnetic circuits for applications. The variable damping versus field is measured using a dynamic method. The yield stress is measured using various static loads. It allows designing devices with the right braking/holding forces in the applications.

Keywords: Magneto-Rheological Fluids, magnetic & fluidic characterisation, MRF control stiffness, Fail-safe shock absorber, active valve.

Introduction

Magneto Rheological Fluids (MRFs) are magnetically-controlled fluids. MR Fluids find more and more industrial applications in actuation functions. These include shock absorbers, semi-active dampers, clutches, brakes, haptic actuators & devices… These functions are used in automotive & bike applications such as engine mounts, shock absorbers, suspensions and seat dampers [1][2]. They are seriously considered in anti-seismic dampers in civil engineering structures. To design such an application as well as some others being studied by Cedrat Technologies for its industrial customers, a device-oriented test bench has been developed in order to characterise the magneto-mechanical properties of MRF such as the magnetisation curve, the fluidic behaviour … by different experiments.

This paper will describe the method for characterising the fluid properties, first the magnetic characterisation, next the fluidic characterisation. Then, an exemple application will be presented.
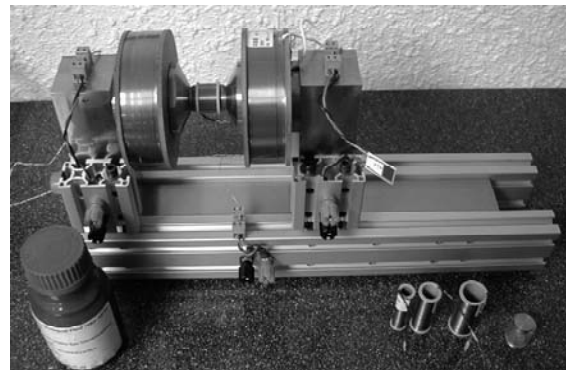
MRF fluid characterisation

The knowledge of the magnetic characteristics of the MR Fluid is very important to simulate and design actuators on FEM CAD (FLUX software) in order to optimise the operation.

The magnetisation curve is determined using the permeameter method. This method allows measuring the permeability and the magnetic saturation of samples.

This measurement is based on a large electromagnet, which is able to produce a magnetic field into a tube containing the MRF sample

Three parts constitute this permeameter: two coils supplied in current exciting the device, a good magnetic material allowing the magnetic conduction toward the MRF sample.


Fig. 1: *Permeametre allow measuring magnetic fluid characteristics*

The Fluid sample is placed between two poles in an amagnetic container.
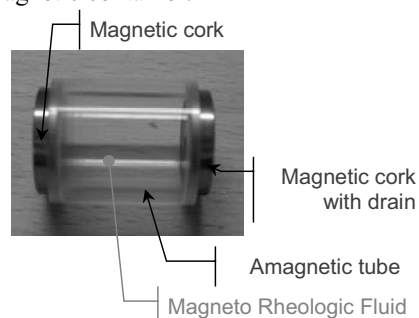

Fig. 2: *Fluid container for characterisation*

The measurement of the magnetic flux through the sample allows computing the magnetic properties of the fluid. This flux through the MRF sample and through the amagnetic container is measured thanks to a measuring coil placed around the container.

However, only the flux through the MRF sample must be considered to evaluate the fluid properties. A FEM computation thanks to FLUX CAD allows estimating the flux through the container and the flux leakage in order to increase the precision.
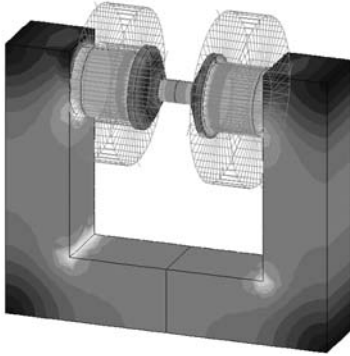
Fig. 3: FEM CAD of permeameter(FLUX CAD)

An analysis of the measured and the computed results allows refining results.

Several MR Fluids from Lord corp. or from our partner ISC.Fraunhofer Institute have been characterised: ISC AL505 (50% iron particles), ISC AL127/ AD275/LORS 132AD (30-36% iron particles), ISC AL273 (20% iron particles)
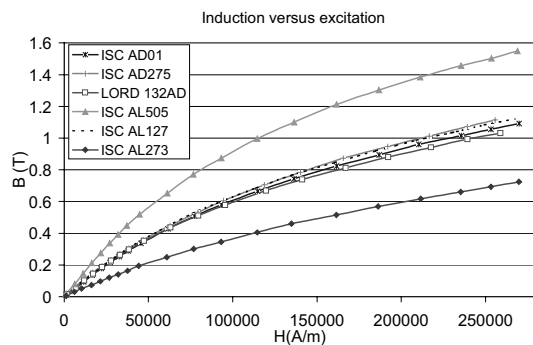

Fig. 4: Magnetic properties for different fluids

The percentage of the iron particles in the fluid modifies the magnetic properties: an increase of the ratio of the iron particles causes an increase of the permeability of the fluid.

The knowledge of MRF magnetic properties allows designing magnetic structures on FEM software with efficiency and optimise the operation point.

Fluidic characterisation in flow mode

The knowledge of MRF fluidic properties is essential to design fluidic paths of actuators. A test bench has been designed and manufactured in order to characterise the fluid properties in flow mode.
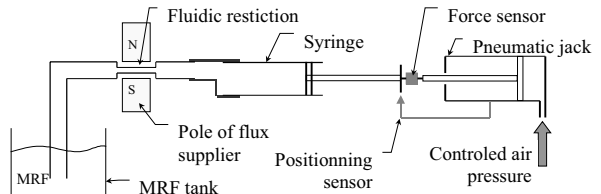
Fig. 5: Scheme of a MRF test bench for fluidic characterisation

The principle is to control the flow through a restriction. The control of the flow can be achieved by the variation of the pressure on both sides of the restriction and by variation of the induction in the fluid restriction.
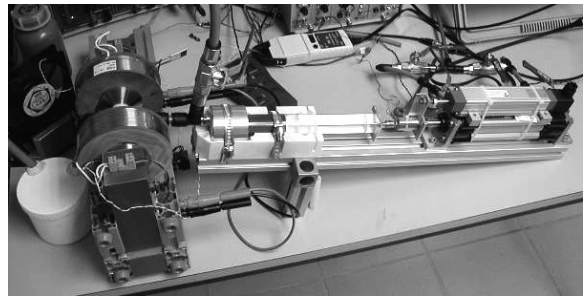
Fig. 6: Test bench for MRF characterisation

The flow through the magnetic restriction is measured by the position of the syringe piston. The pressure in the syringe is computed from the force sensor placed between the pneumatic jack and the syringe piston. A flux generator controls the magnetic induction in the fluid restriction.

Results

A pressure of $1.5.10^5$ Pa is applied on the MR Fluid in the syringe. The flow through the restriction (D=3mm, L=20mm) is measured. The flow depends on the induction level in the fluid restriction.

By this experiment, we can cheek that the MRF bench is working as an electrically controllable active valve without moving parts.
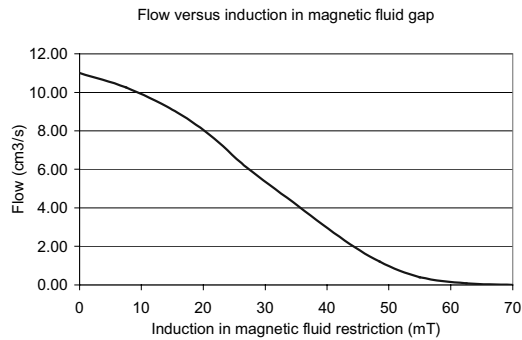
Flow versus induction in magnetic fluid gap

Fig. 7: *Flow versus induction*

An increase of the induction in the fluidic restriction decreases the flow through the restriction. For an induction upper 70mT and a pressure of 1.5Bar, no flow is possible: the restriction operates as a valve.

The induction corresponding to the flow blockage depends on the pressure in the syringe.

The flow evolution versus the induction is not linear, the maximal sensitivity is achieved for an induction level about half the stop flow induction.

The influence of the pressure on the flow is measured as a function of induction.

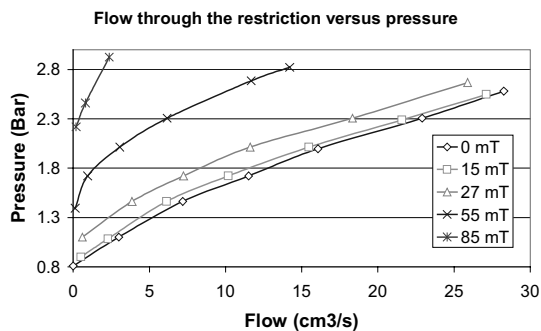**Flow through the restriction versus pressure**

Fig. 8: Flow versus pressure

A pressure under 0.8Bar does not cause a flow. So, friction losses are estimated around 0.8Bar.

Without induction, an increase of the pressure increases quasi linearly versus the flow. The slope of this curve depends on the viscosity of the fluid.

The addition of an induction in the restriction decreases the flow. The fluidic behaviour can be divided in two stages: In the first stage, a significant increase of the pressure has a low effect on the flow. In the second stage, the slope of the curve is independent of the induction, the induction can be considered as an offset on the pressure.

This fluidic behaviour after first stage of the flow installation can be written in this equation:

$$Q = Q(\eta) - Q(B)$$

Where Q is the total flow, Q(η) is the flow resulting of the viscosity value and Q(B) is the offset flow.
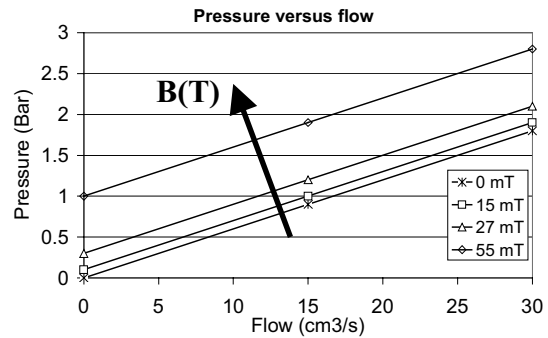
A simple model can be suggested:

Fig. 9: Model of flow versus pressure

This model allows approaching the flow behaviour of the fluid and simplifies the design of the fluidic device [4].

Adaptive Landing Gears for Improved Impact Absorption in aircraft

Another new application where Cedrat Technologies is also involved is the Adaptive Landing Gears for Improved Impact Absorption in aircraft. This application is studied with Messier-Dowty and EADS in the ADLAND project, co-ordinated by the Institute of Fundamental Technological Research (Poland) [EC project, IST programme contract No: - FP6-2002-Aero-1-502793-STREP]. The project deals with evaluating two options for adaptive shock absorbers to be applied in aircraft landing gears : the MRF option and the piezo valve option.

Typically, usual shock absorbers are designed as passive devices with characteristics adjusted to the most frequently expected impact loading. However, in many cases the variation of real working conditions is so high, that the optimally designed passive shock absorber does not perform well enough.

For example, the large variations in impact loads found under different landing conditions means that the full stroke length of a passive device will not always be utilised. In contrast to the passive systems the project focuses on active adaptation of energy absorbing structural elements where the system of sensors recognises the type of impact loading, and activates energy absorbing components to guarantee optimal dissipation of impact energy.

The objective is to design a shock absorber with a control of the stiffness, reliability and fail-safe strains [3]. CEDRAT TECHNOLOGIESSA has been involved in the design of the magnetic circuit of the MRF based shock absorber.
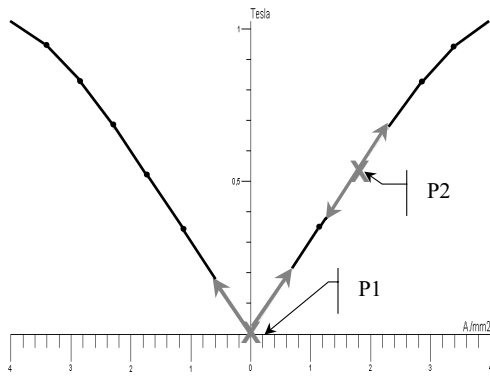
Fig. 10: Induction control (stiffness) versus nominal operating point

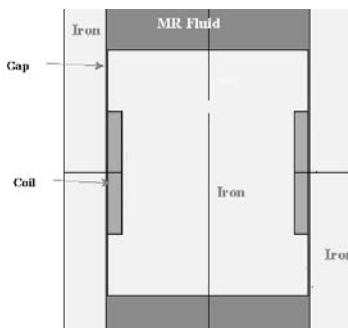The P1 point corresponds to a device without power supply and without offset device.

Fig. 11: device without offset device

When the coil is supplied, the induction in the fluid gap increase and the stiffness increase. Moreover, considering the fail-safe operating, the minimum stiffness is achieved without current and no means exist to have a more compliant shock absorber than the fail-safe stiffness.

The P2 point corresponds to a device with a permanent magnet and without power supply.
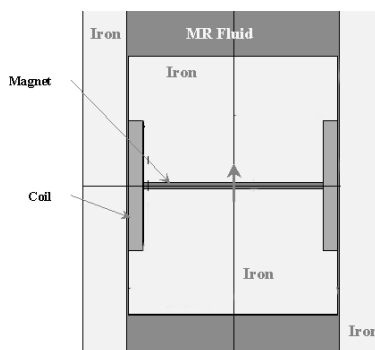

Fig. 12: device with a permanent magnet (Offset device)

The permanent magnet allows adding an offset. Thanks to a smart design, the induction in the fluid can be increased or decreased depending on the current. The device can be designed in order to have an optimised fail-safe operation and the stiffness of the shock absorber can be totally controlled with the current power supply.

Conclusion

A permeameter have been designed and manufactured in order to characterise magnetic properties of Magneto-Rheological Fluids. Several MR Fluids have been characterised and their magnetisation curves have been compared.

The fluidic test bench allows evaluating the flow behaviour of the MRF though a restriction. The properties of this non-Newtonian fluid have been shown and a model has been presented.

An aeronautic shock absorber has been designed and manufactured in the frame of the European project ADLAND and a test campaign will validate the design.

The characterisations of the MR Fluid allow Cedrat technologies to master this technology and to design actuators.

Acknowledgements

References

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