

# CHARACTERISATION AND MEDICAL APPLICATIONS OF MAGNETORHEOLOGICAL FLUIDS

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**Abstract:** Magnetorheological fluids are composed by magnetic particles suspended within a carrier fluid which allow to change their rheology when subjected to a magnetic field. This property can be controlled very accurately by varying the magnetic field intensity which provides a rapid and effective system to control the response of very diverse fluid-mechanical devices. The characterisation of two new magnethoreological fluids is presented. The force response when the magnetic field varies is studied in static and dynamic conditions. This paper sets out some of the opportunities and advantages provided by this fluids both for medical and non-medical applications.

## 1 INTRODUCTION TO THE MAGNETORHEOLOGICAL FLUIDS

Magnetorheological fluids (MR-fluids) are capable to change their rheology when subjected to a magnetic field. This property can be controlled very accurately by varying the magnetic field intensity, which provides a rapid and effective system to control the response of very diverse fluid-mechanical devices.

These kinds of fluids are composed by magnetic particles suspended within a carrier fluid. Thus, they are typically composed by micrometer or nanometer scale spheres distributed in a mineral oil.

The response of the magnetorheological fluids is the result of the induced distribution of the magnetic suspension particles (usually in the 0.1-10  $\mu\text{m}$  range) within the fluid when an external magnetic field is applied (usually about 100 mT in air). The microscopic particles align themselves along the lines of magnetic flux. Thus, the resulting chains of particles restrict the movement perpendicular to the direction of the lines of flux, leading to an anisotropic behaviour and to an increase in the viscosity of the fluid (Torcuato, 2006).

This phenomenon is considered completely reversible and almost instantaneous (response time is about 10 milliseconds) for these fluids.

The magnetically controllable properties of magnetorheological fluids depend on the carrier fluid and its additives, the magnetic field applied, the working condition and the size, shape, concentration, density and distribution of the particles.

The first patent related to MR-technology was issued to inventor Jacob Rabinow in the 1940s, though this technology remained with little practical use. However, in the last twenty years there is a serious research in this field, especially when other technologies began to converge that made their use practical and a real possibility.

Numerous research efforts have been carried out in order to improve the magnetorheological fluids, in specialised companies like Lord, Repsol-YPF and in different universities.

Although MR-fluids have many potential applications, they are limited by aspects like their high density and wear in materials due to presence of iron, very high cost or precipitation of particles.

## 2 CHARACTERISATION OF NEW MAGNETORHEOLOGICAL FLUIDS

The Machines Engineering Division (DIM) belonging to the Technical University of Madrid (UPM) has collaborated with the company Repsol-YPF and the Applied Physics Department of the University of Granada in the development and characterisation of new magnetorheological fluids for shock-absorbers used for different applications.

Two oils have been developed: MR-Lub1 and MR-Lub2. The carrier fluid is the same for both of them but the second one includes a higher percentage of magnetic particles. The cited characterisation was carried out in a commercial damper mounted in a MTS damper test system shown in figure 1.



Figure 1: MTS Damper Test System.

The first characterisation includes an static test (velocity of the damper below 1mm/s) to determine the effect of the electric intensity (which produces a magnetic field) in the increase of the damping force in the damper.

The results for MR-Lub1 are depicted in figure 2, which shows a non-linear behaviour.

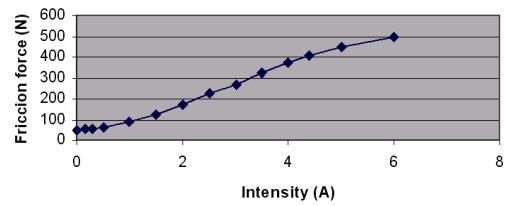


Figure 2: Damping force vs. Intensity for MR-Lub1.

The reversible magnetorheological behaviour is shown in figure 3, obtained for a of the damper at a velocity of 130mm/s and a stroke of 25mm. The traction and compression cycles are depicted for the MR-Lub1. The force obtained at each point when the intensity is growing is very similar to the force measured when intensity is decreasing. Nevertheless, the results show a slight remaining magnetisation when low intensities around 1A are applied.

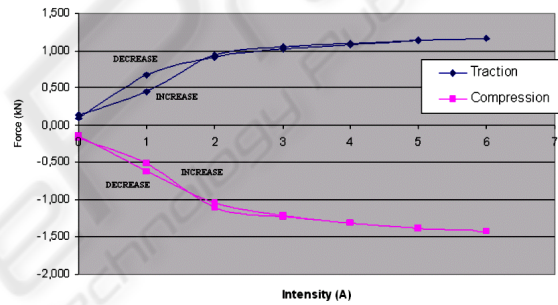


Figure 3: Static force vs. Intensity for MR-Lub1 in traction and compression cycles.

Figure 4 shows a comparison between dynamic tests in the shock absorber with MR-Lub1, MR-Lub2 and two commercial fluids by Lord at a velocity of 1m/s. The higher quantity of magnetic particles in MR-Lub2 than in MR-Lub1 leads to an increase in the sum of the traction (T) and compression (C) forces. A similar Force-intensity behaviour is observed in all the tests performed.

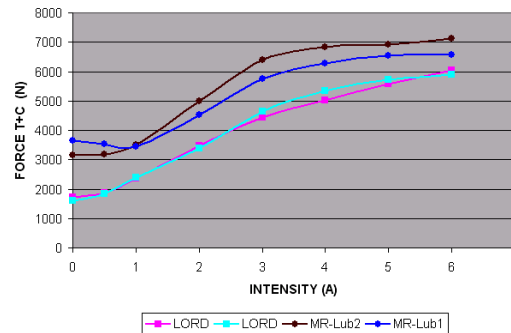


Figure 4: Dynamic force vs. Intensity.

### 3 POSSIBLE NON-MEDICAL APPLICATIONS FOR MR-FLUIDS

Nowadays, the main manufacturers of Magnetorheological fluids (Lord, 2008) offer specific solutions for many applications mainly within the following sectors:

- Suspension systems
- Fan Clutches
- Crash-protection systems
- Buildings and bridges
- Medical applications

In the near future many other applications are expected to be available, because their possibilities are almost endless.

The most extended application for the fluids developed is the use in a magnetorheological suspension, where a controllable fluid replaces traditional hydraulic oil in each shock absorber. As sensors monitor road and vehicle conditions, a controller modifies the intensity applied and therefore the damping characteristics are adjusted in real-time. This enables remarkable improvements in both ride comfort and handling.

Magnetorheology has had a large role in recent advances in military and automotive industries. The called MR-Technology has been integrated not only in military tactical and combat vehicles but also in primary suspension systems of high performance vehicles designed by Cadillac, Audi, Ferrari, Honda and others. In addition, these new technologies are used in seat and cab suspension designs of agricultural and other off-highway vehicles in order to improve operation environment.

Apart from the use for suspension applications, there are a lot of patents concerning MR-fluids for fan clutches. The main aims of these inventions are to provide smooth, efficient torque-transfer in clutch devices. The designs include a large range of applications in order to improve the controllability and the high off-state drag.

Another present application for MR-fluids is obtained by combining the variable control magnetorheology with advanced sensors in passenger protection systems. In these cases, the protection systems can be adjusted to provide the perfect resistance based on the impact severity and the passenger size.

There is also a civil and structural application in skyscrapers and long bridges protection, which are susceptible to vibrations induced by high winds and seismic activity. In order to mitigate their effect, large dampers are built into their design, which

protect against shocks through a continuously controllable and cost-effective solution. Figure 5 shows a Rheonetic Seismic Damper by Lord.

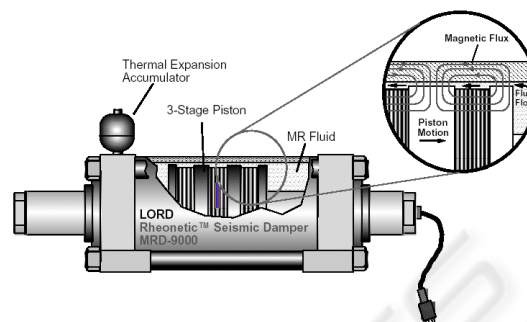


Figure 5: Example of a Rheonetic Seismic Damper, obtained from Lord's website.

### 4 SOME POSSIBLE MEDICAL APPLICATIONS FOR MR-FLUIDS

The main medical applications for MR-fluids are considered haptic devices, new prosthesis development and innovative cancer therapies.

#### 4.1 Haptic Devices

Tactile and force feedback systems are used in surgery training assisted by computer. Active dampers have been developed based on MR-fluids and their utilization in haptic systems provides a very precise control which enhances the skills of the surgeons (Bar-Cohen, Mavroidis et al., 2001; Neelakantan, 2002; Rizzo, 2007).

In particular, by using sensorized surgical instruments, suitable signals could be acquired and used for controlling the haptic device. The surgeons could use the surgical instruments to interact with biological tissues and organs during a simulated operation and, probe their compliance by touching the haptic device (Scilingo, Sgambelluri et al, 2003).

#### 4.2 Prosthetic and Rehabilitation

The company Lord, in collaboration with Biedermann Motech, manufacturer of prosthetic components, has developed a device that improves the mobility of leg amputees. The new design, shown in figure 6, is based in MR-dampers and produces an increase in gait balance, stability and energy efficiency.

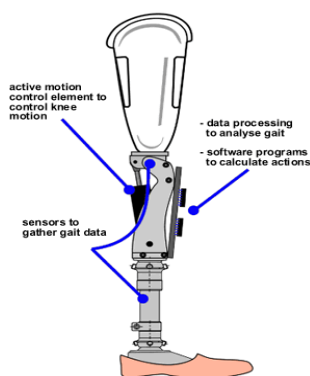


Figure 6: New prosthesis for leg amputees, obtained from Lord's website.

Other medical systems based on similar active control elements are used in training devices for rehabilitation purposes which allow an adjustable resistance to the movement according to the evolution of the patient (Dong, 2005).

### 4.3 Cancer Therapy

The biocompatibility and tolerability by humans and animals to magnetorheological materials have been tested successfully (Sheng, Flores and Liu, 1999).

Some techniques developed for cancer therapies target chemotherapeutic agents to the tumor sites employing magnetic nanoparticles as carriers is a promising cancer treatment reducing side effects of conventional chemotherapy.

Electron microscope investigations show that the ferrofluids can be enriched in tumour tissue and tumour cells (Alexiou, 2006). Therefore, these studies show a remarkable improvement to the conventional cancer therapy but still causes toxicity to the body.

Other interesting studies are based in MR-fluids introduced into the blood vessels supplying the tumor. When a magnetic field is applied a seal is formed, which blocks the blood flow and cut the alimentation in oxygen, leading to tumor necrosis. There are interesting in-vitro investigations on these therapies (Sheng, Flores and Liu, 1999) concerning the study of the seal kinetics and pressure resistibility of the formed seal.

## 5 CONCLUSIONS

In this paper the characterisation of two new magnetorheological fluids in a damper is presented. The force response when the magnetic field varies is

studied both in static and dynamic conditions. The remaining magnetisation when the external field stops is analysed.

Different possible applications for the two fluids developed are indicated for medical or non medical purposes. In the future, the new possibilities of the magnetorheological fluids are incalculable.

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