

台灣區流體傳動工業同業公會
102年度流體傳動與自動化控制技術研討會

中華民國102年11月06日

磁流變液阻尼器之設計特性、發展與應用

謝宗翰

逢甲大學
航太與系統工程學系

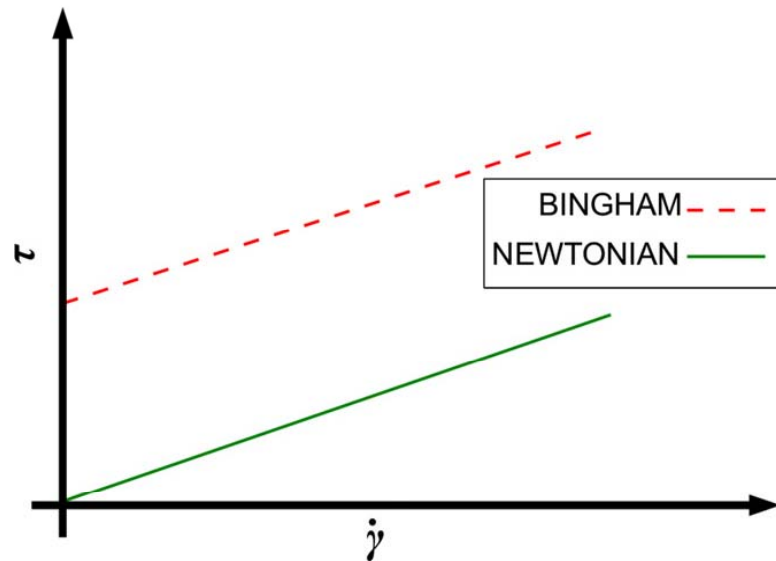
Magnetorheological Fluid Basic Theories

Magnetorheological Fluid(MRF)

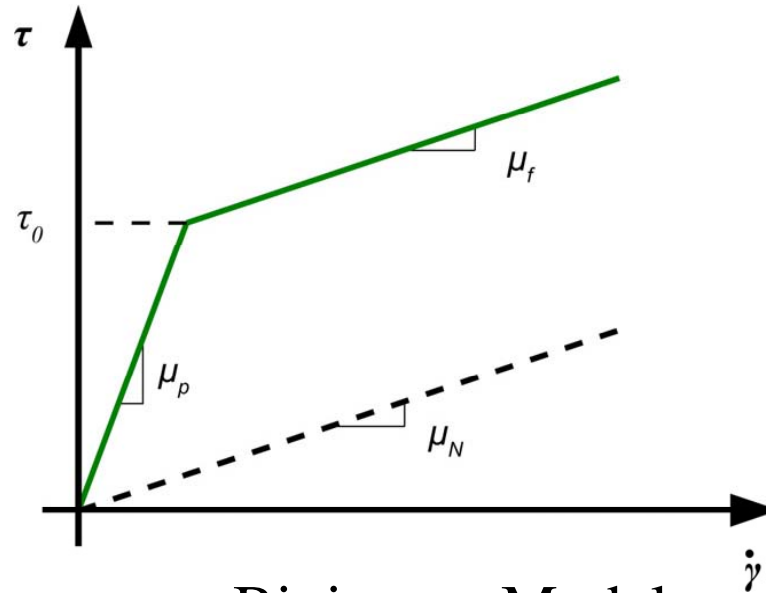
- Rheology(流變學) : The study of the flow of matter in response to an applied force, primarily in the liquid state.
- Magneto-rheological(磁流變) : Fluid properties in response to an applied *magnetic field*.
- Magneto- and electrorheology : Rabinow and Winslow's discoveries in the 1940s(Bossis, G., 2002).

Behavior of the MRF

- Newtonian fluid behavior of the basic equation : $\tau = \mu \frac{du}{dy} = \mu \dot{\gamma}$
- There are several model to describe the behavior of MRF.



Bingham Model

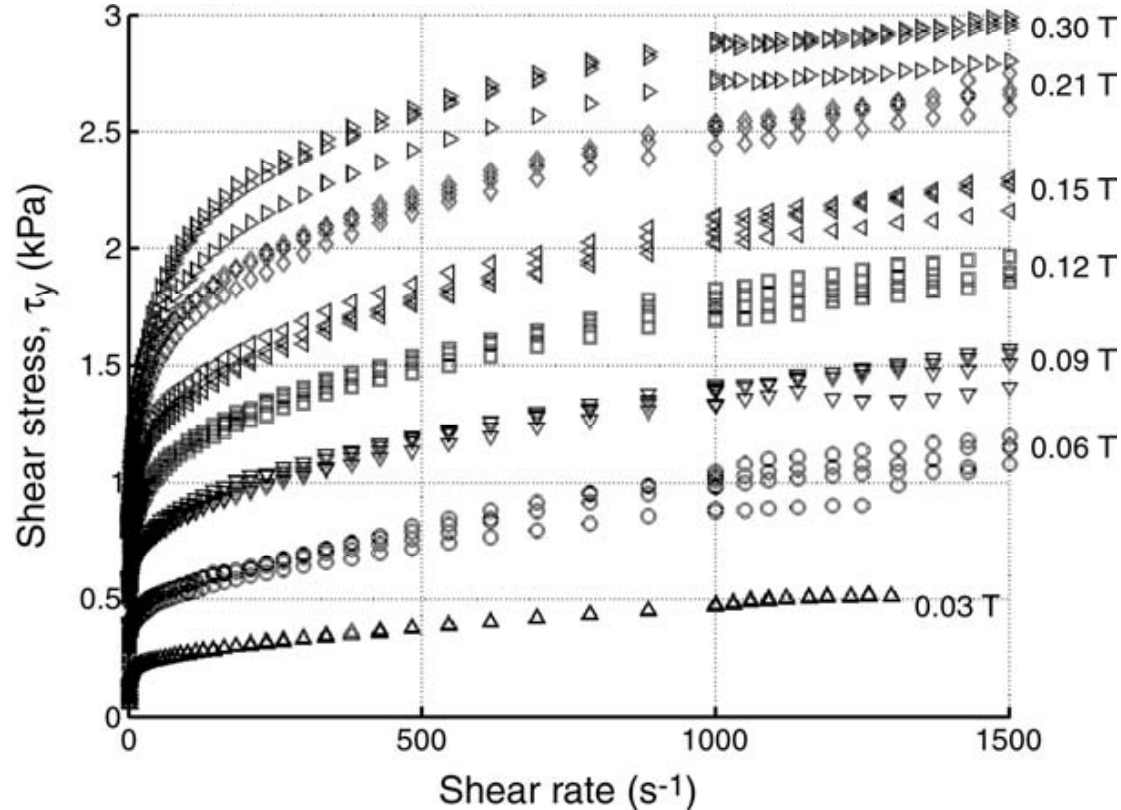


Biviscous Model

τ : Shear stress
 μ : Shear viscosity
 $\frac{du}{dy}$: the derivative of the velocity

(Dimitrios, A., 2011)

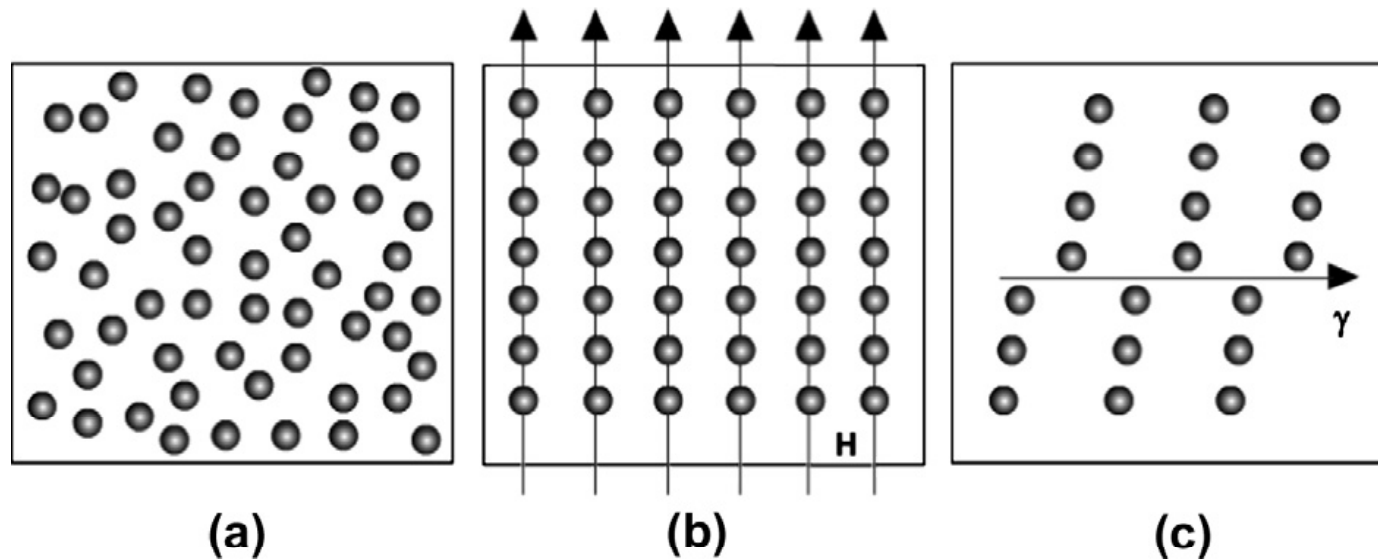
Experimentally observed behavior of MRF



(Chaudhuri, A., 2006)

Micro-scale behavior of the MRF

- When a magnetic field is applied, however, the microscopic particles (usually in the 0.1–10 μm range) align themselves along the lines of magnetic flux.
- The particles in a ferrofluid primarily consist of nanoparticles



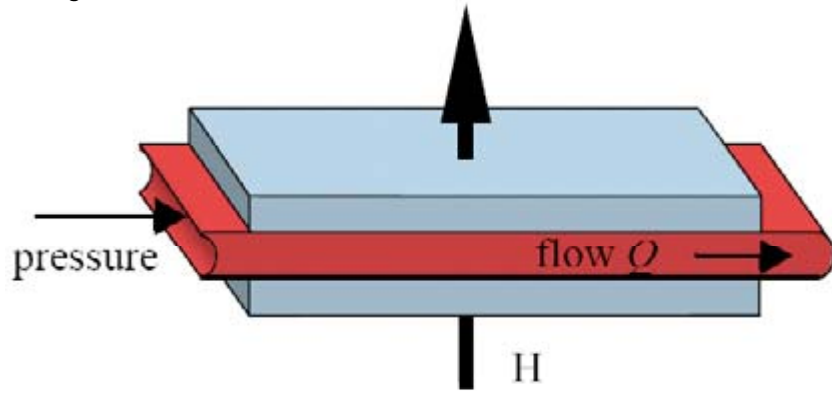
(Parlak, Z., 2012)

Properties of MRF/ERF

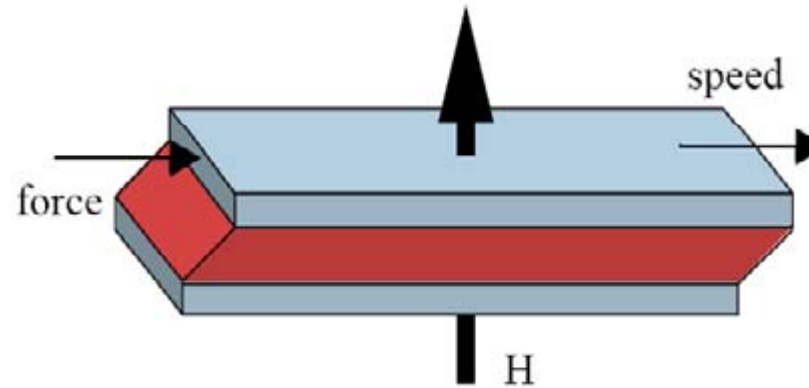
■ (Butz, T., 2002)

| Property | ERF | MRF |
|----------------------------|---|-----------------------------------|
| Response | milliseconds | milliseconds |
| Plastic viscosity | 0.2 to 0.3 Pa·s | 0.2 to 0.3 Pa·s |
| Operable temperature range | +10 to +90 °C (ionic, DC) -25 to +125 °C (non-ionic, AC) | -40 to 150 °C |
| Power supply | 2 to 5 kV 1 to 10 mA | 2 to 25 V 1 to 2 A |
| Maximum yield stress | 2 to 5 kPa(at 3 to 5kV/mm) | 50 to 100 kPa(at 150 to 250 kA/m) |
| Maximum field | ca. 4 kV/mm | ca. 250 kA/m |

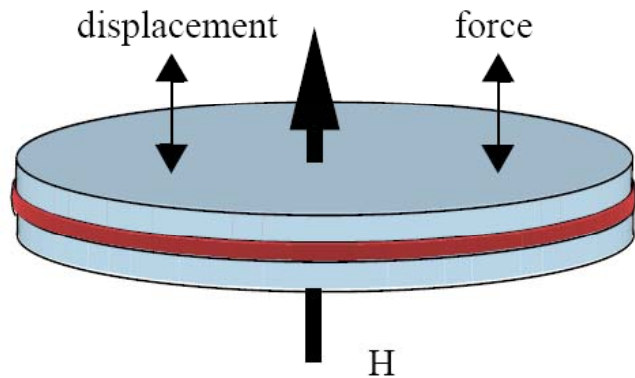
Operational Models of MRFs



(a)



(b)

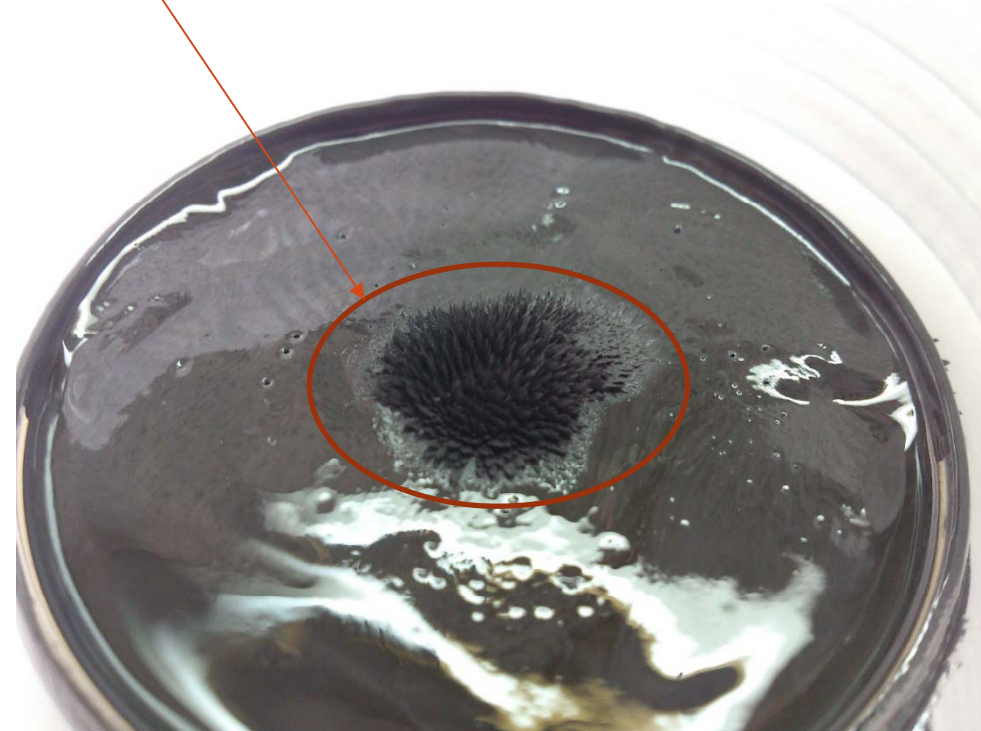


(c)

(a) The flow mode, (b) The direct shear mode and (c) The squeeze mode(Wang, D. H., 2011)

MR Fluid (MRF-132DG)

施加磁場區域



MR Fluid (MRF-132DG)



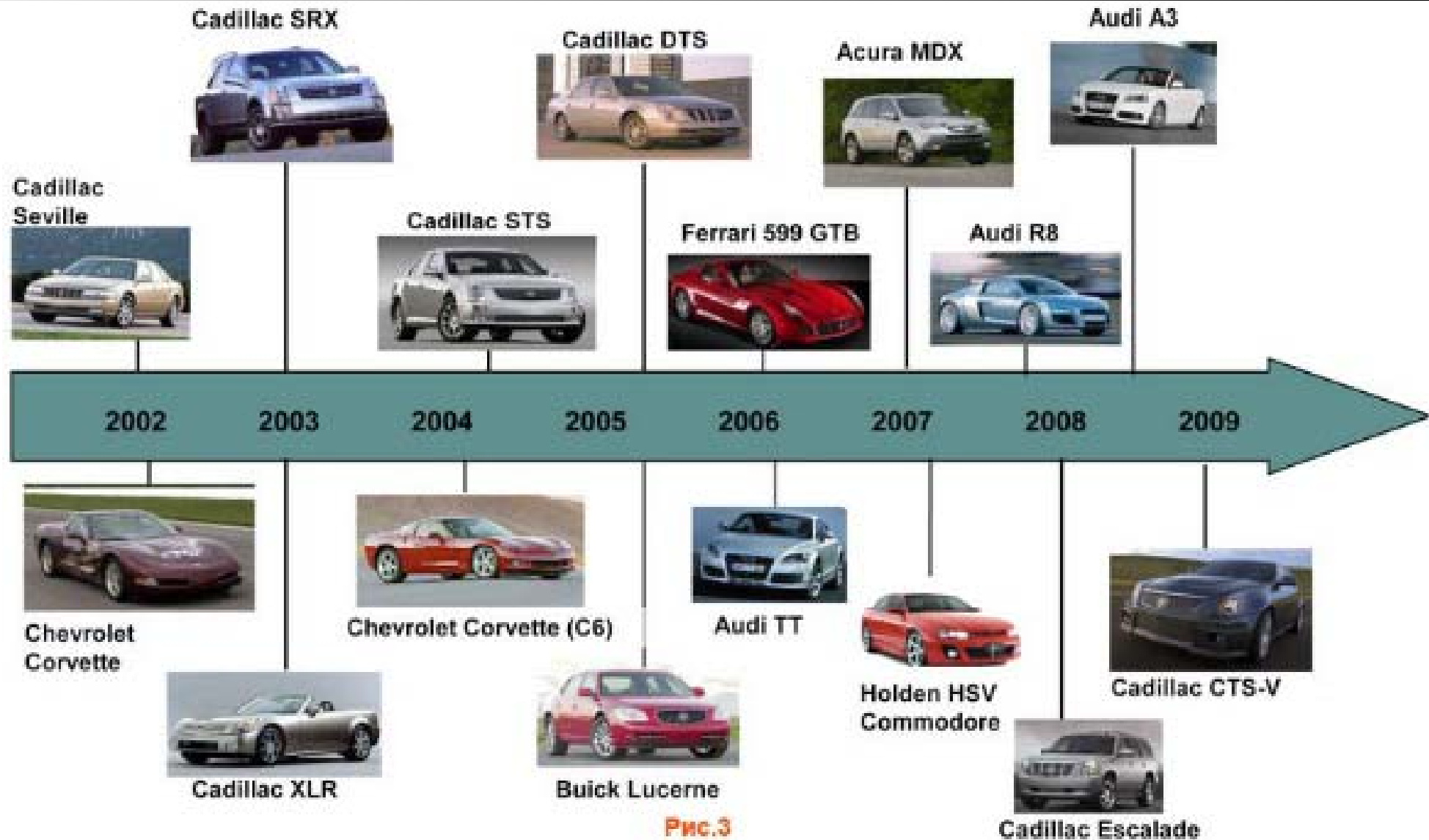
Magnetorheological Fluid Applications

Introduction

- The first model of magnetorheological fluid has been developed by *Yakov Rabinov* who was born in a city of Kharkov (Ukraine) in 1910.
- Later he has started fruitful work in the scope of science, and in 1948 Rabinov has developed first models of magnetorheological fluids and couplings that use magnetorheological fluids.
- The early 90th the **LORD company** stakes on commercialization of the magnetorheological fluids and devices with their application. The project has been started by a group of scientists, mechanical engineers and chemical engineers under the leadership of *David Carlson*. Thus in the middle 90th the first commercially successful couplings and brakes have appeared; some of them have been placed to the fans' drives in the Chevrolet Suburban stock cars and other cars of the **General Motors** make.

Introduction

- The early 1999-2000 an active suspension **Delphi MagneRide™** with the magnetorheological dampers has been announced. It has been developed in cooperation with the *Delphi* company. And this active suspension has been placed on many expensive stock cars since 2002.



There are the stock cars on which the Delphi MagneRide™ system has been placed.

<http://mrfengineering.com.ua/magnytoreologicheskaya-zhydkost/ystoryya-sozdanyya?lang=en>



Corvette



Audi R8



Ferrari 599

<http://mrfengineering.com.ua/magnytoreologicheskaya-zhydkost/oblasty-prymeneniyya?lang=en>

Applications

Poynor, J. C., 2001, "Innovative Designs for Magneo-Rheological Dampers," MS. Thesis, Virginia.

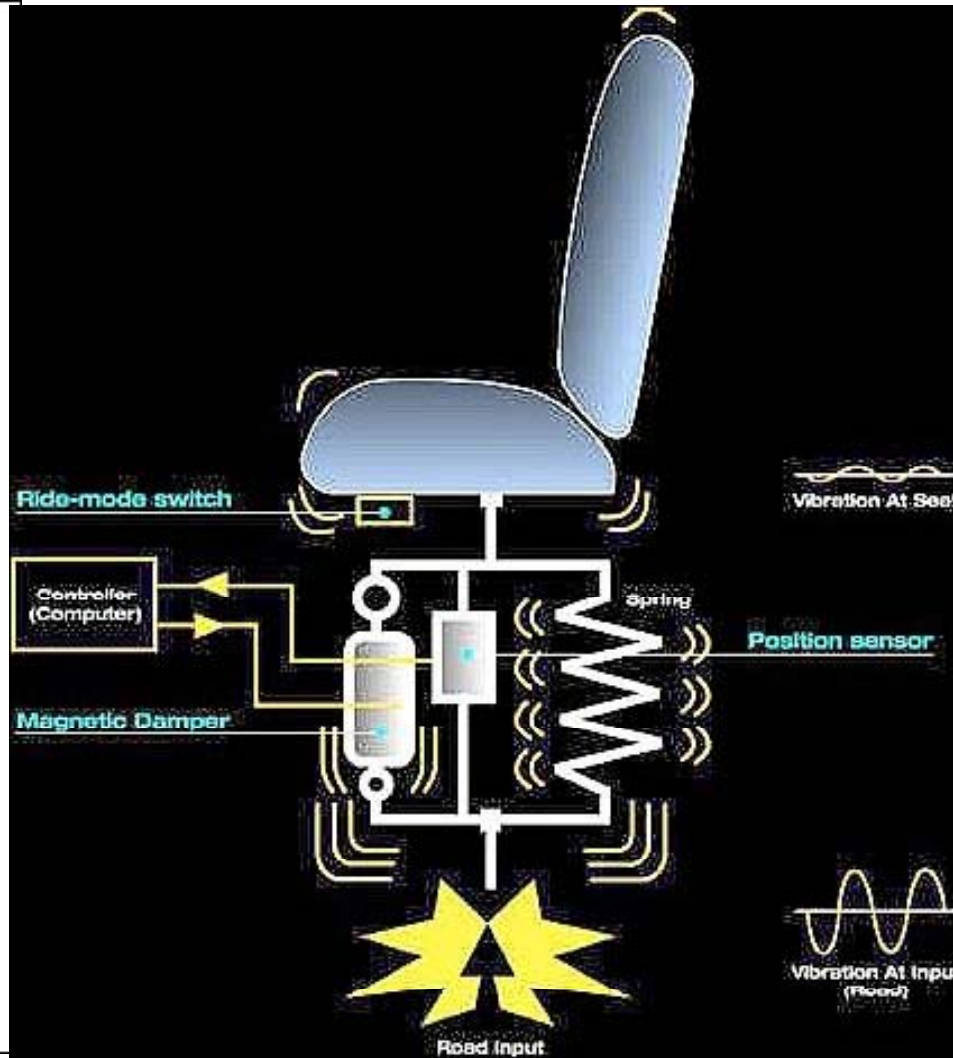
- In the mid 1990's, Lord Corporation began manufacturing an MR damper line called "Motion Master". These dampers have found their way into truck seat suspensions and prosthetic legs.
- Lord Corporation also produces Steering Sensor, Force Feedback Unit - Steer-By-Wire.
- General Motor's announcement that an MR damper suspension system will be available on certain 2003 Cadillac models.
- The military has shown interest in using MR dampers to control gun recoil on Naval gun turrets and on field artillery.

Applications

Poynor, J. C., 2001, "Innovative Designs for Magneo-Rheological Dampers," MS. Thesis, Virginia.

- has incorporated MR dampers is the [stabilization of buildings](#) during earthquakes.
- Two unusual applications
 - The first is an [optical polishing machine](#) that uses a slurry-like mixture of MR fluid and abrasive particles. This slurry-like mixture of MR fluid and abrasives is ideal since it will conform to the surface of the lens being polished and its stiffness can be controlled through the use of a magnetic field.
 - The other unusual application for MR fluids involves its use for fixturing fragile components such as turbine blades so that they can be machined without damage.
- [And more...](#)

LORD Co. Motion Master®



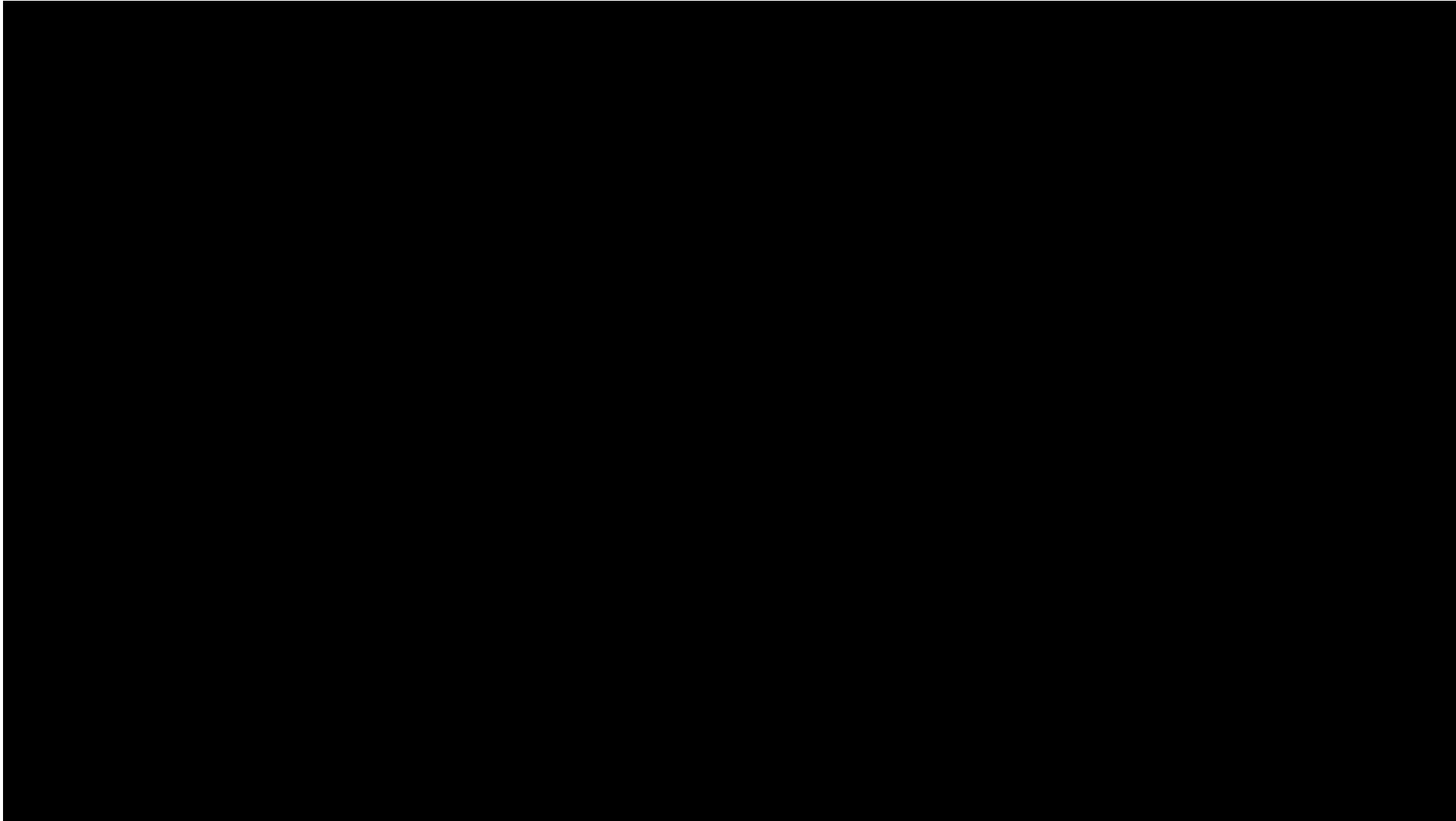
They have developed and marketed a number of MR items, with the most successful at this stage being **Motion Master®** suspension seat mechanism. Designed to be retrofitted to the suspension seats **widely used in trucks and buses**, the **Motion Master®** uses a **controllable damper filled with MR fluid**, a sensor arm that measures the position of the seat, and a controller that adjusts the damping force in response to changes in seat position. **The system adjusts the damping force 500 times a second** and includes a ride mode switch selectable between firm, medium and soft settings.

Exoskeletons with the magnetorheological liquids, brakes and couplings

The first commercially successful exoskeletons have been created in 2006 by Japanese company *Cyberdyne Inc.* Exoskeleton is a complex symbiosis of a human nervous system, biomechanics, electronics and mechanics. The magnetorheological couplings in all the socket joints are a part of the most important actuators of the exoskeleton. Magnetorheological clutch is a shock absorber in knee and elbow joints of the exoskeleton. Also these exoskeletons advance human physical capacity.



At HCR 2010, Hashimoto Artificial Limb Manufacture exhibited, for reference, a leg brace that uses an MR brake.



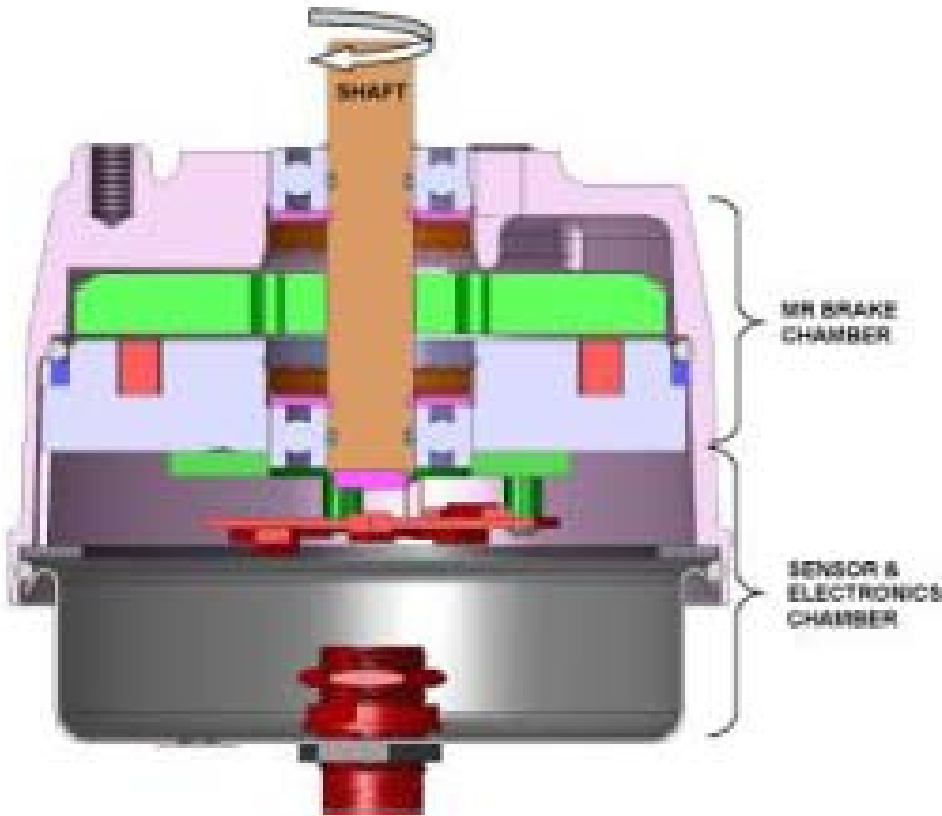
"This leg brace is designed for hemiplegics, or other people who don't have much control of their leg joints. In particular, it can be used by people with a type of paralysis known as "drooping foot." The brake makes this product effective for severe hemiplegics with the drooping foot condition."



LORD TFD® Steering Sensor, Force Feedback Unit

The LORD TFD Steer-By-Wire is a cost-effective and design-efficient feedback solution for improving by-wire control and safety.

- Produces continuously variable resistive steering torque
- Delivers high-fidelity "feel" and maximum control to their operator
- Available in standard 12 Nm and 5 Nm torque configurations
- Offers compact, energy efficient design and high torque density per unit volume
- Turnkey, integrated solution providing steering wheel attachment, earing supports, sensing and force feedback
- Scalable to your production needs



Magnetic sensors for steer-by-wire

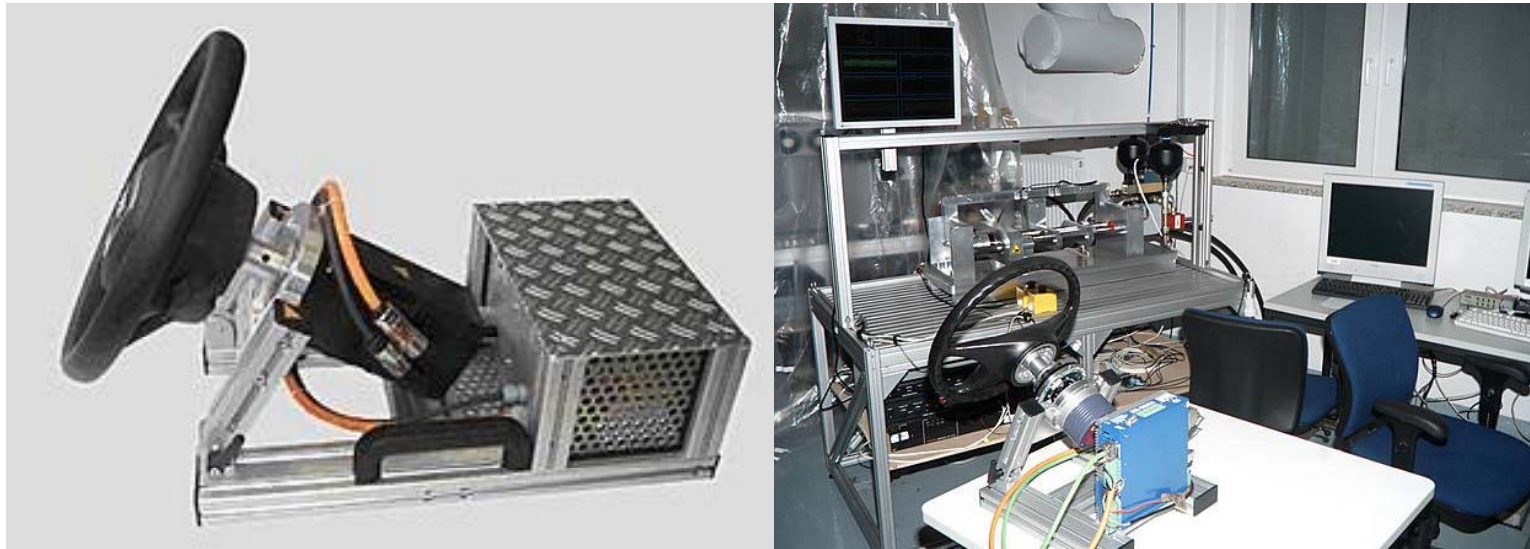
<http://www.sae.org/mags/sohe/NEWS/6592>



[http://www.lord.com/products-and-solutions/magneto-rheological-\(mr\)/steer-by-wire.xml](http://www.lord.com/products-and-solutions/magneto-rheological-(mr)/steer-by-wire.xml)

Steer-by-Wire

Vehicle steering technology is evolving by substituting the mechanical and hydraulic subsystems with electrical equivalents to boost performance and enhance safety. by a steer-by-wire controller to provide the driver a desired steering feeling and the vehicle a desired steering response.



http://www.dlr.de/rm/en/desktopdefault.aspx/tabid-5313/8906_read-16108

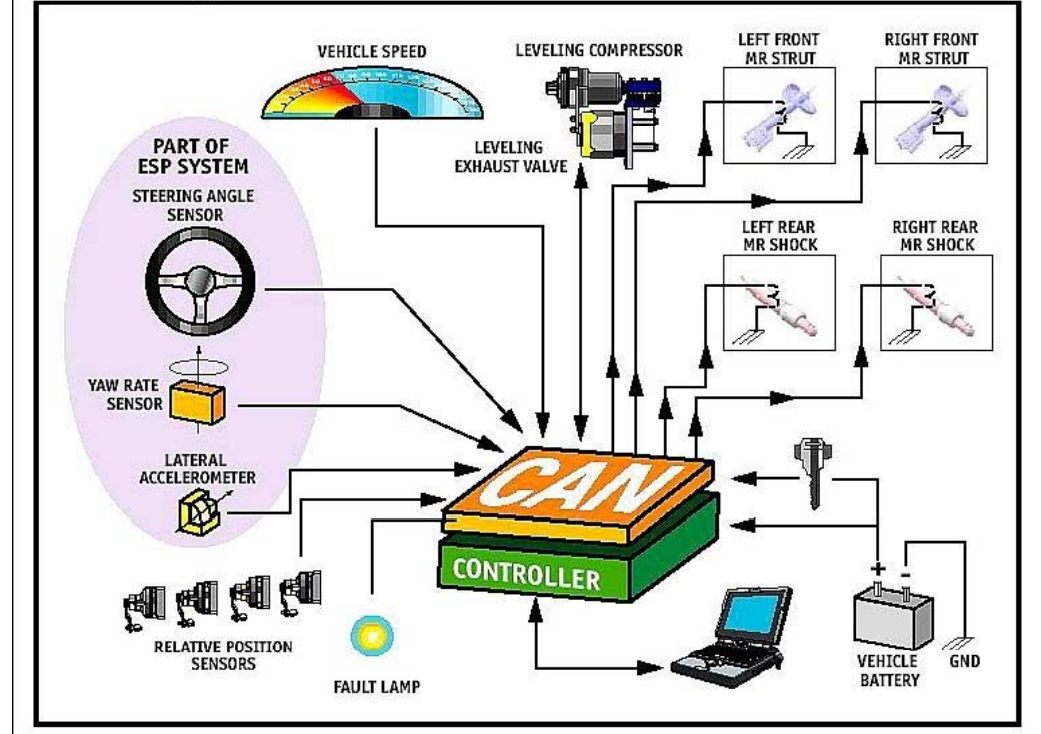
The most important use of MR dampers will occur in 2003, when GM in the US launches a Cadillac equipped not just with MR dampers, but with a complete ride control system based around them. The Magneride system includes the following input sensors:

- Steering angle
- Vehicle yaw
- Vehicle speed
- Four damper position sensors
- Lateral accelerometer



<http://upload.wikimedia.org/wikipedia/commons/thumb/b/b8/Cadillac-CTS.jpg/1280px-Cadillac-CTS.jpg>

Control System Architecture



http://www.autospeed.com/cms/A_110995/article.html

Outputs comprise the four MR dampers and also an air compressor that will drive a self-levelling system (implying that the springing will be very soft indeed!). Rear dampers will feature a 46mm bore and be used together with front struts (36mm bore), with both front and rear dampers packaged within existing suspension architectures. **The system will have a 15-millisecond response time.**

And More.....

GM Promotional Video - *Corvette C5* Magnetic Ride



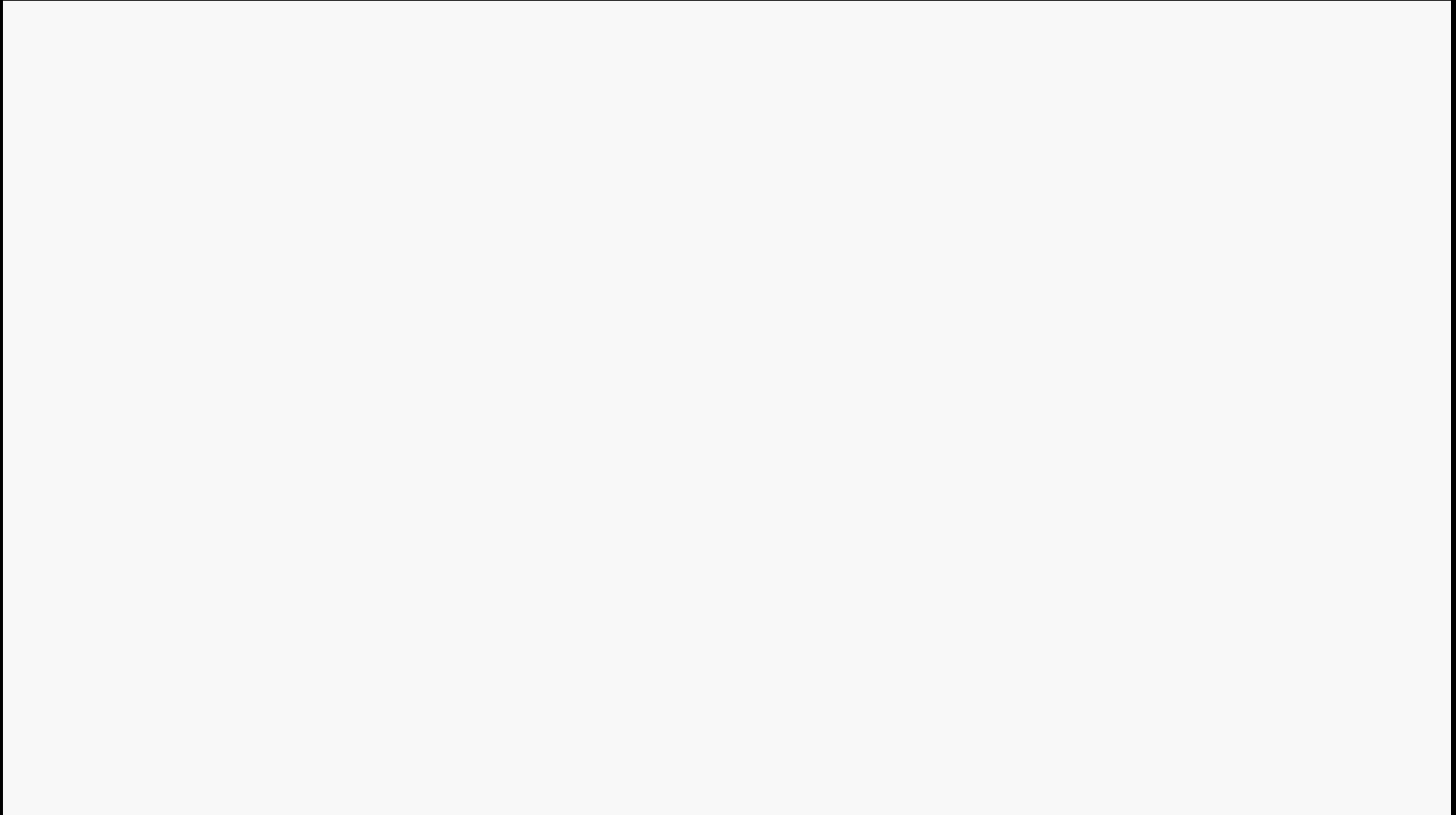
GM Magnetic Ride Control & Performance Traction Management *Camaro ZL1*



http://www.karoto.gr/static/media/2009/10/audir8_magnetic-ride_resize.jpg

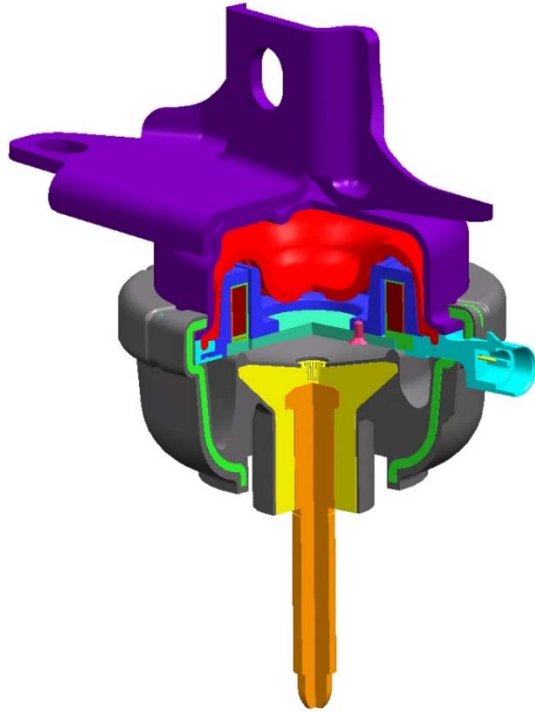
Audi R8 Active Suspension Systems

Audi RS7 Active Suspension Systems



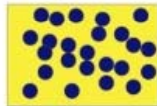
The same magneto rheological damping technology that allows [Chevrolet](#), [Cadillac](#) and [Ferrari](#) to control 500-plus horsepower in a car that's comfortable to drive on city streets will soon make its way to the engine bay of the 2010 Porsche 911 GT3.

...
Benefits include improvements in powertrain isolation, vehicle stability and traction. "The level of sound and vibration transfer can be greatly reduced," says Schlangen. "It also opens new opportunities for brand-specific tuning and vehicles whose character changes depending on the driver's requirement, perhaps linked to other active systems such as dampers and a sports exhaust to transform the noise and feel at the flick of a switch." ...



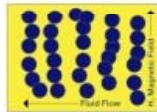
Delphi develops MagneRide engine mounts for Porsche 911 GT3

MagnetoRheological (MR) Fluid is a suspension of magnetically soft particles in a synthetic hydrocarbon fluid.



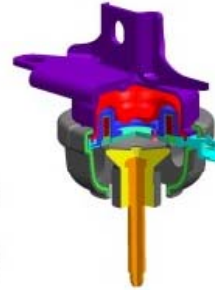
MR Fluid in the "Off" State

Random dispersion of magnetizable particles exhibits Newtonian-like rheological behavior (Shear stress = viscosity x shear rate)



MR Fluid in the "On" State

Applied field aligns particles into fibrous structures MR fluid rheology changes from Newtonian to a Bingham plastic (Shear stress = viscosity x shear rate + yield shear stress) Yield shear stress is controlled by the applied field viscosity is not affected by the applied field



By [Jeremy Korzeniewski](#)
Posted Jul 11th 2009 3:28PM



Comments 35

[Delphi MagneRide Engine Mounts - Click above for high-res image gallery](#)

The same magneto rheological damping technology that allows [Chevrolet](#), [Cadillac](#) and [Ferrari](#) to control 500-plus horsepower in a car that's comfortable to drive on city streets will soon make its way to the engine bay of the 2010 Porsche 911 GT3. In this latest application, Delphi's engineers have made it possible to fine-tune the way engine mounts react to the various situations presented when driving a car.

For instance, these MagneRide engine mounts can automatically adjust their stiffness when the engine is



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The Ford Mondeo is new in many ways. It comes with a new design, new 2.3 liter petrol engine and six-speed automatic transmission. And now it is also available with a new active suspension set-up, called *Interactive Vehicle Dynamic Control (IVDC)*.

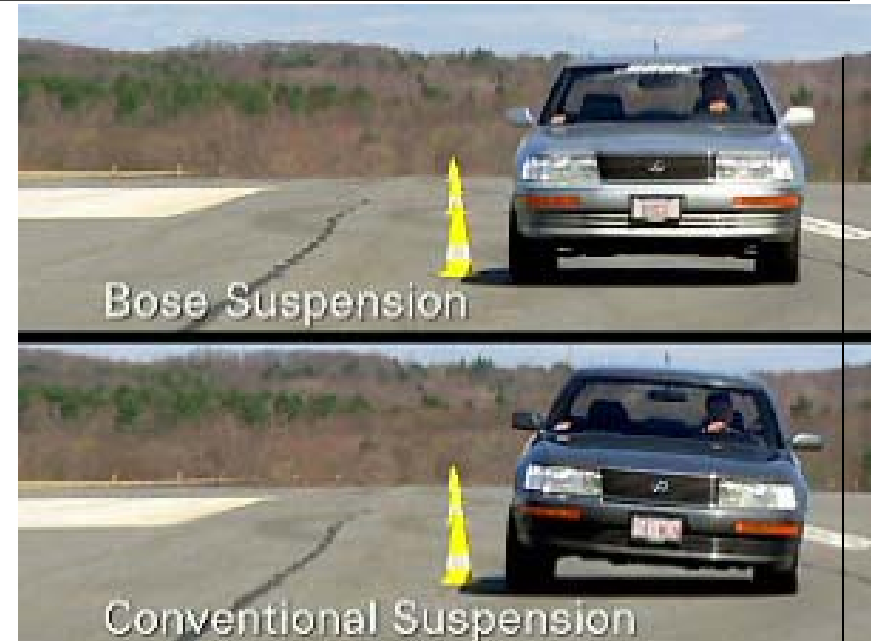
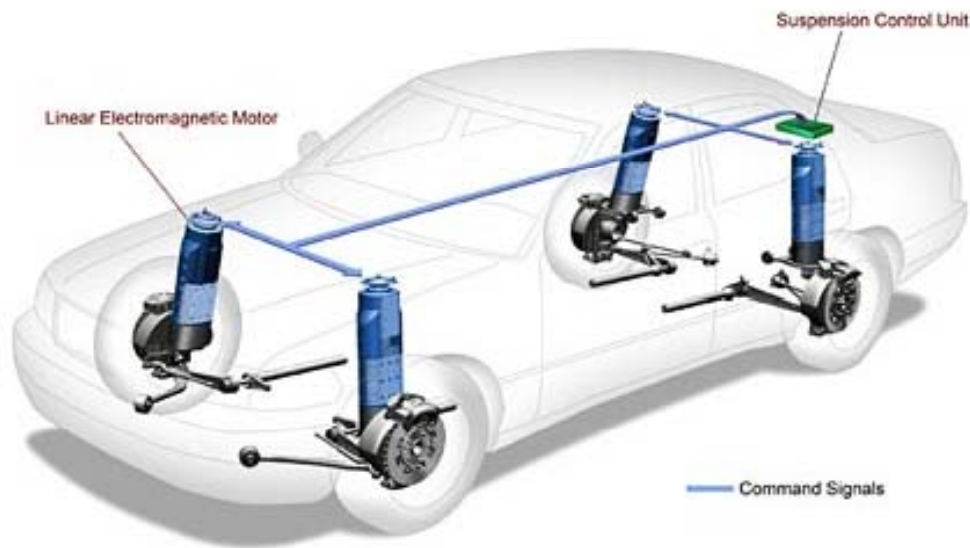


Norbert Kessing, Ford vehicle dynamics manager: **"An active suspension system makes particular sense in larger cars like the new Mondeo. It enhances dynamic stability, particularly under critical driving conditions, and works with the car's other safety systems to reduce braking distances by up to 10 per cent on rough roads."**

"This is the first time a suspension system is the same for a sports car and for a luxury car", said its creator, Dr Amar Bose, chairman and head of technical design. The result is a ride that is level and bump free over incredibly rough terrain and when the vehicle turns in to corners.

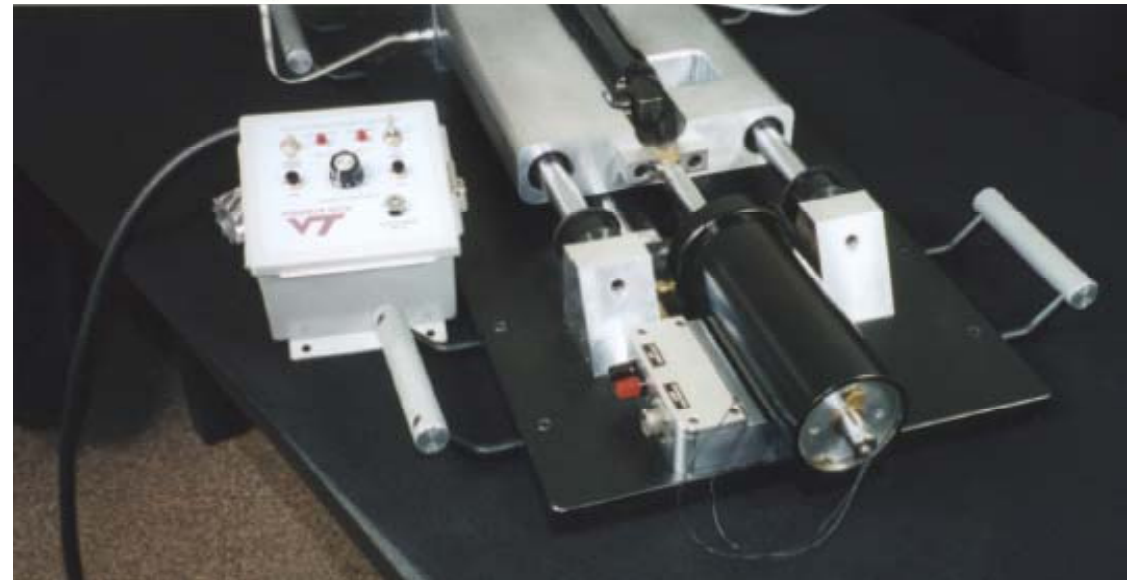
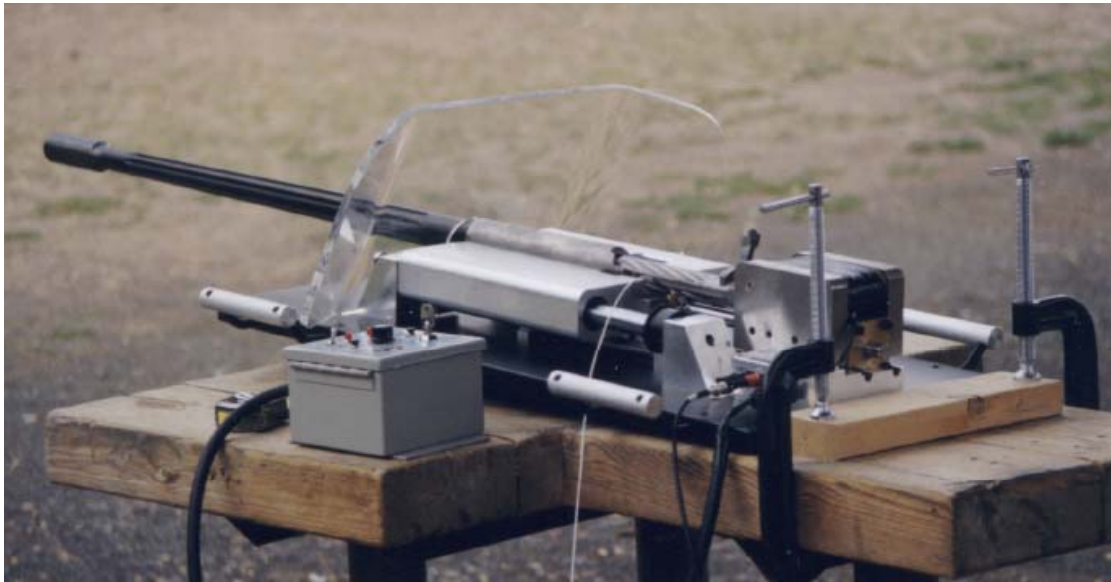
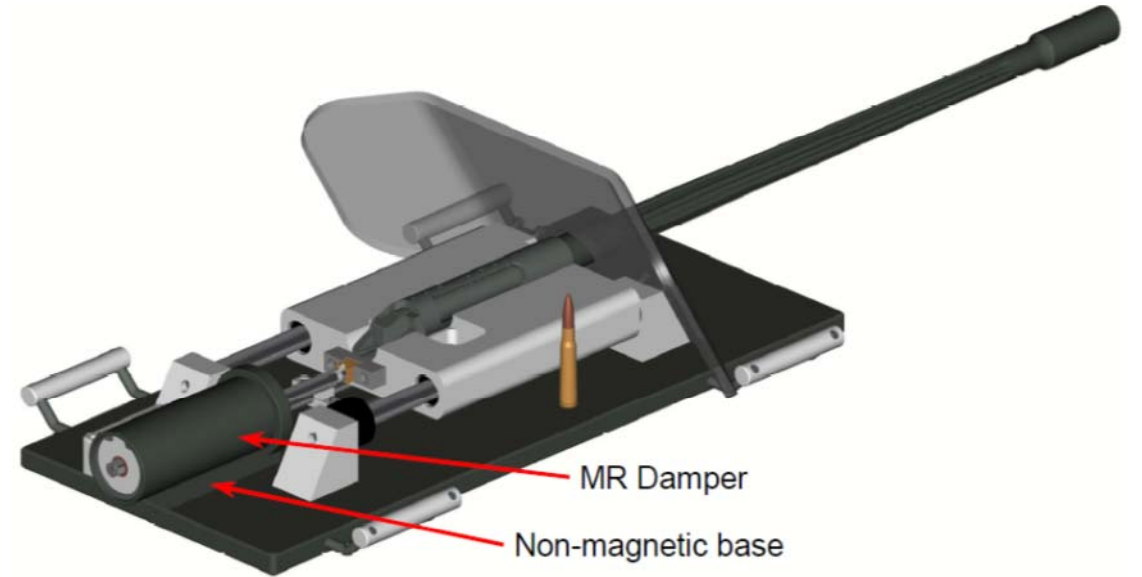
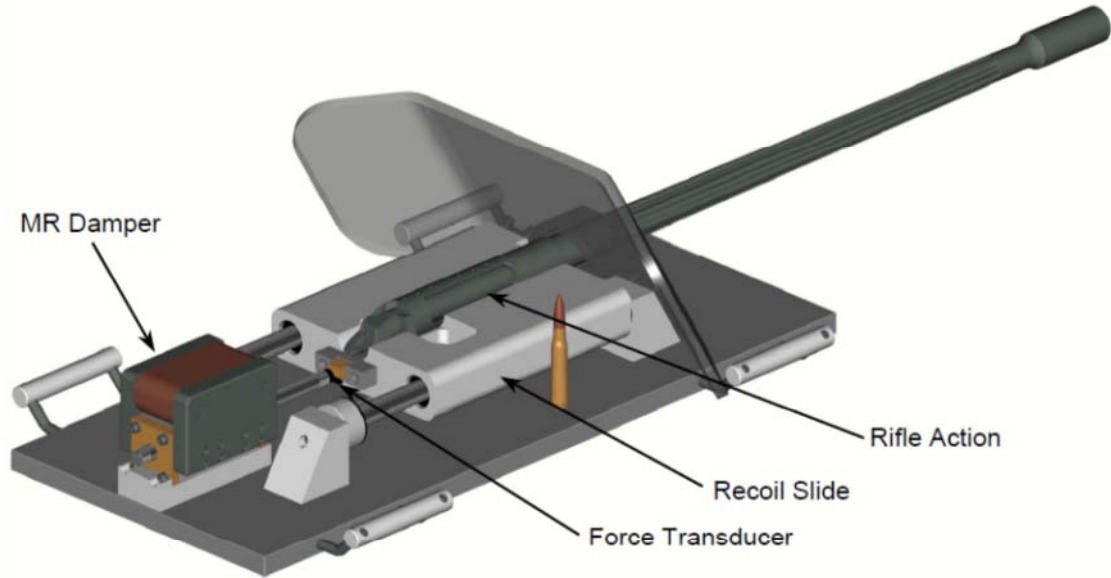
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The purpose of an automobile's suspension system is two-fold: **passenger comfort and vehicle control**. Comfort is provided by isolating the vehicle's passengers from road disturbances. Control is achieved by keeping the car body from rolling and pitching excessively, and maintaining good contact between the tire and the road.



Bose Redefines Automobile Suspension Systems on *Lexus LS 400*





50-caliber Browning machine gun (50BMG) cartridge with 1st generation MR damper design

50-caliber Browning machine gun (50BMG) cartridge with 2nd generation MR damper design



U.S. M1985 field Howitzer



U.S. Mk45 5-inch Naval gun turret

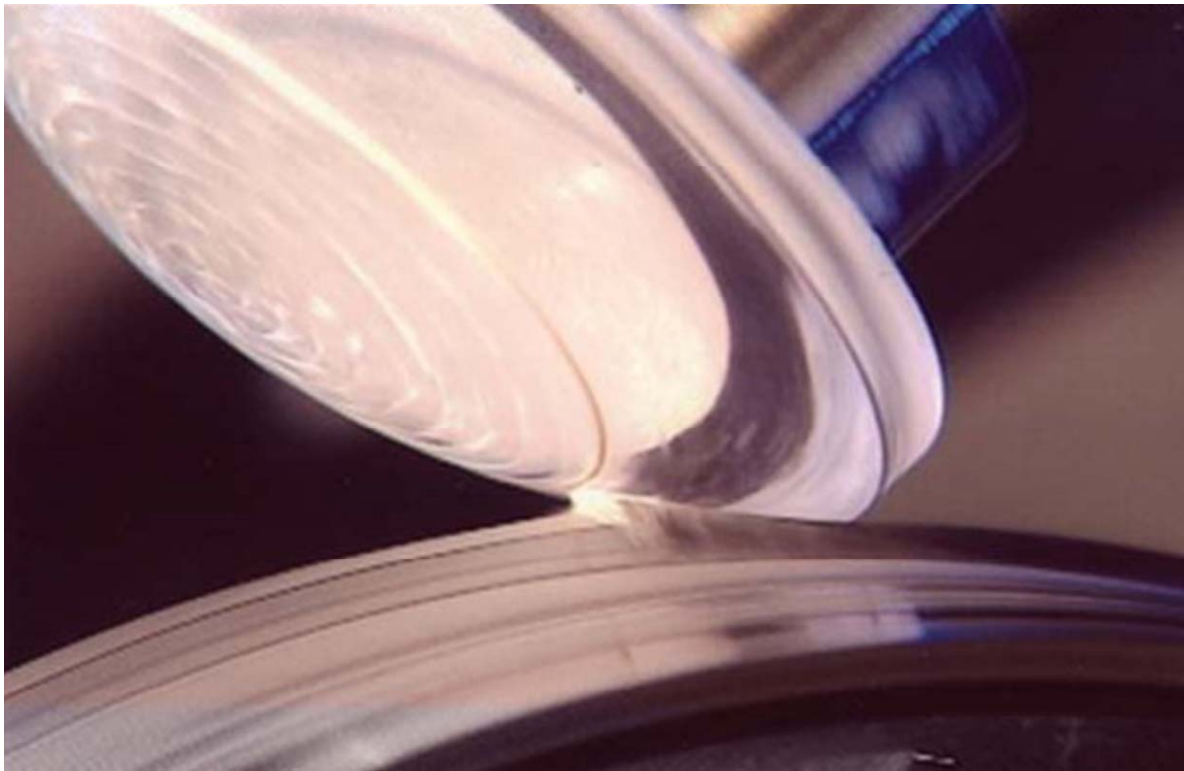




In building and architecture mainly the magnetorheological dampers are used to quench oscillation. They are mostly spread in Japan (house footings, tightening bridges, tower buildings) where a seismic problem is urgent. However these antihunts can also be used for buildings situated next to a subway, street railway or railway lines.



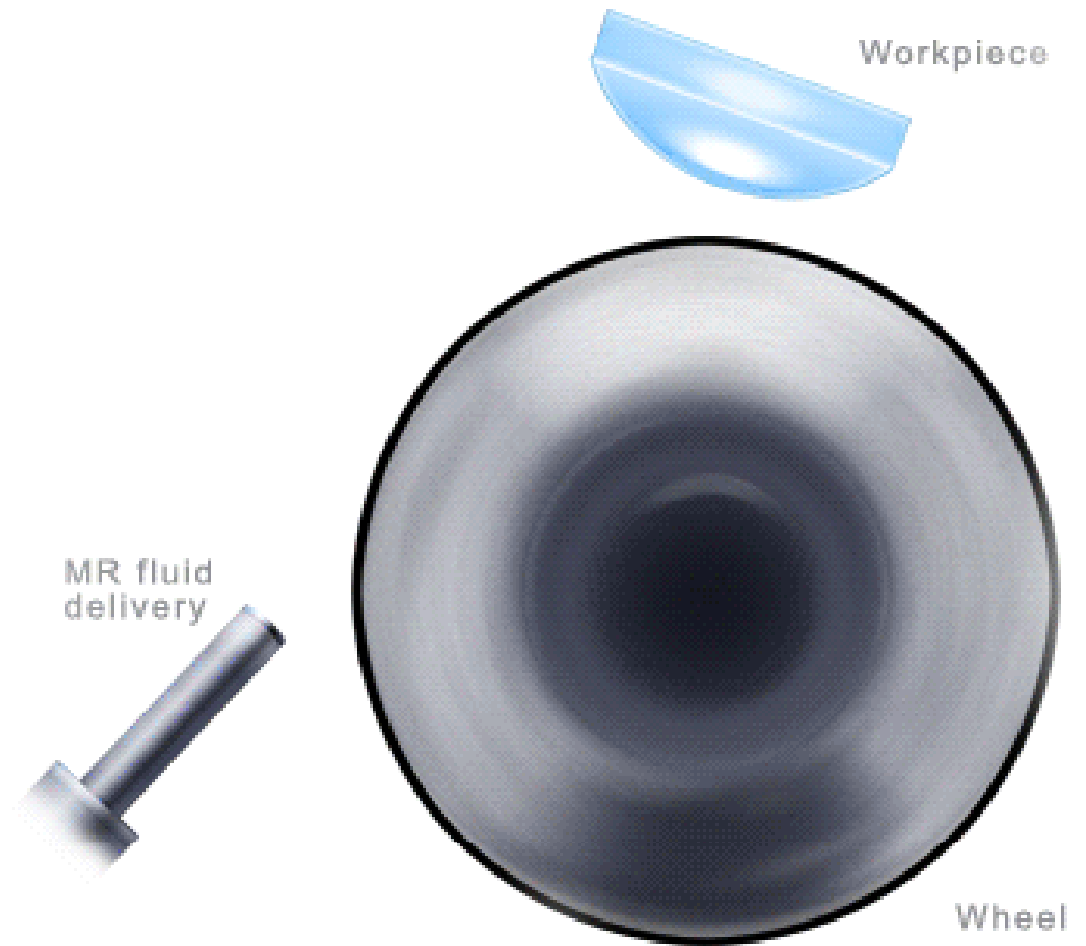
<http://mrfengineering.com.ua/magnytoreologicheskaya-zhydkost/oblasty-prymeneniya/stroytelstvo-y-arxytektura?lang=en>



Polishing and finish operations with a help of the magnetorheological liquid.

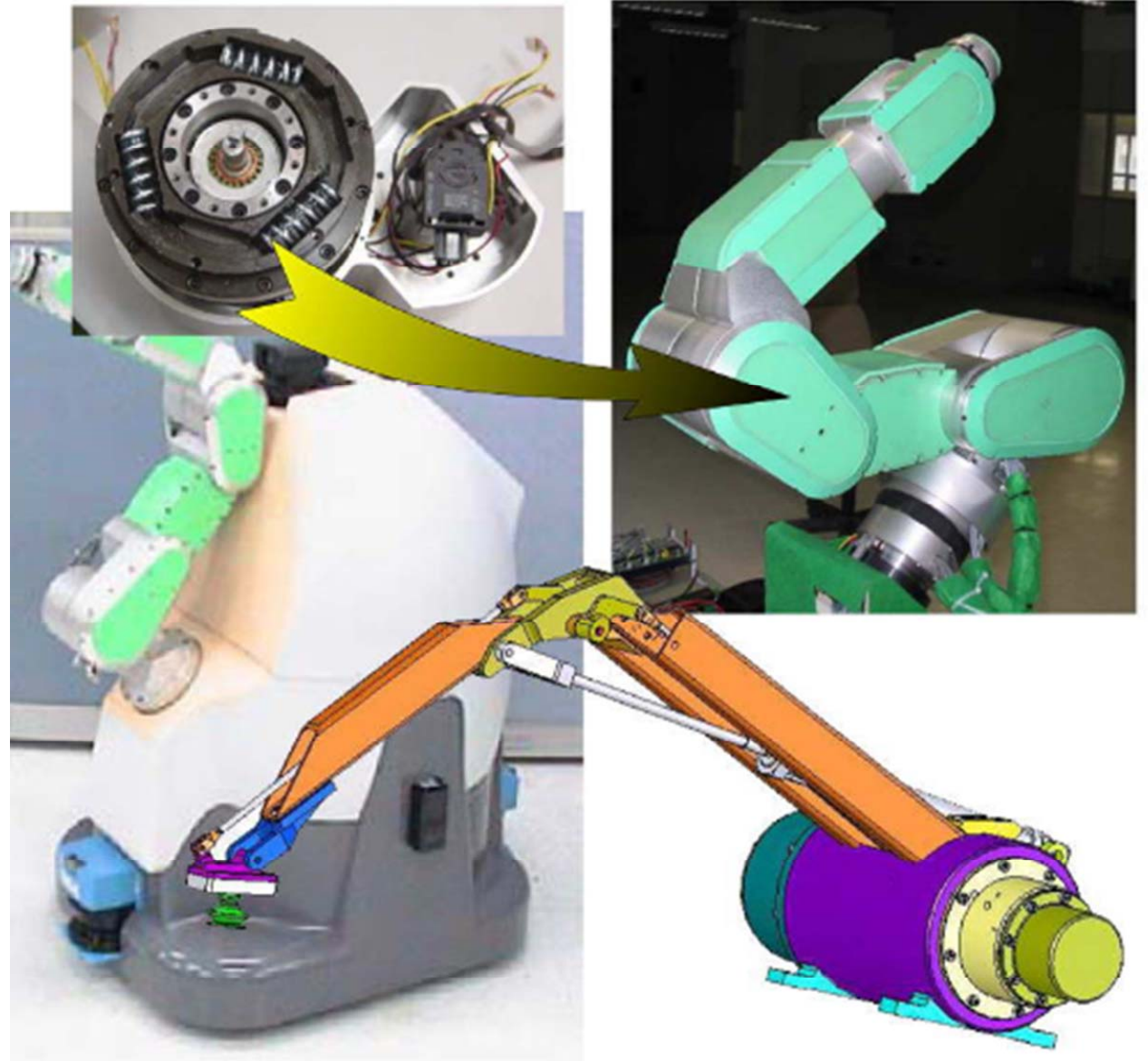
Abrasive particles are added into the magnetorheological liquid, and with a help of the magnetic field they are brought to a detail that is to be machined. Even the most difficult polysurfaces can be machined with a help of the magnetorheological liquids.

MRF

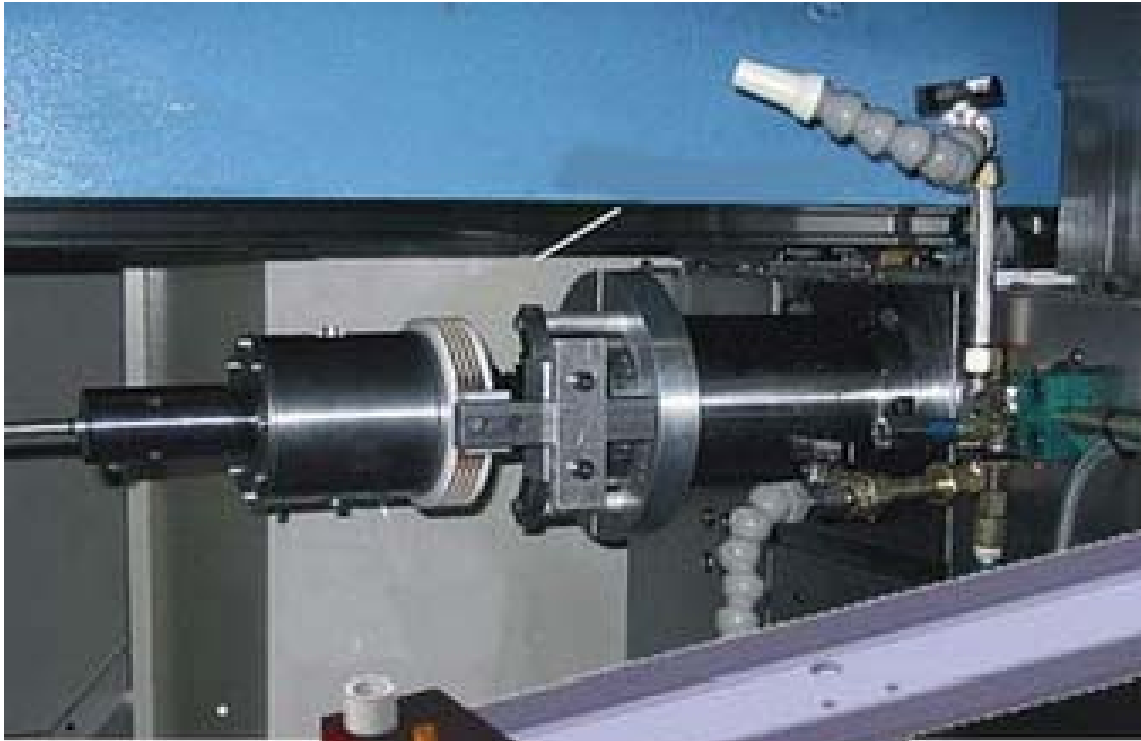


Using the magnetorheological liquids, brakes and couplings in industrial robots.

A robot that has been developed by Japanese engineers for a part presentation and a blanks supply in machining centers. The magnetorheological brake functions as a controlling unit. In a case of damage or an emergency the magnetorheological brake locks the robot out.

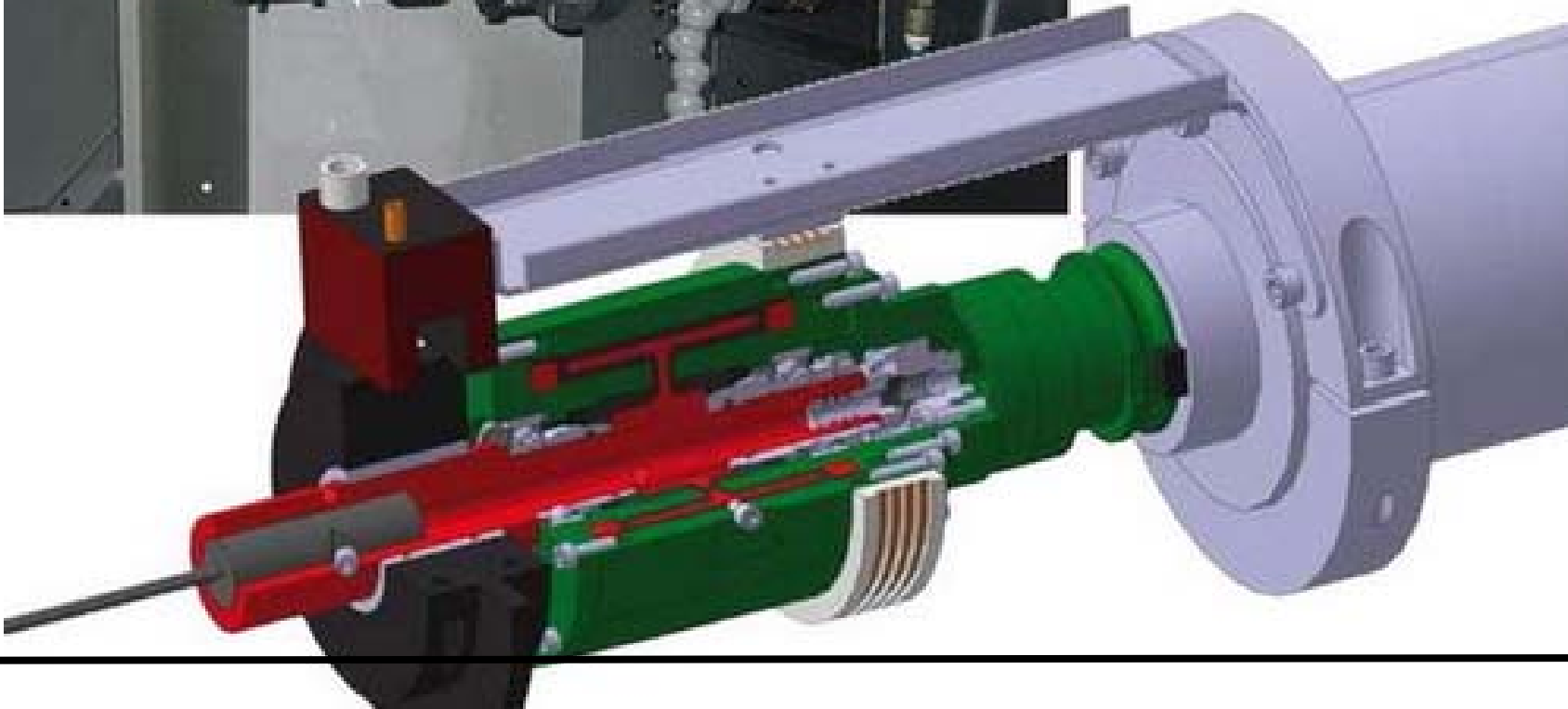


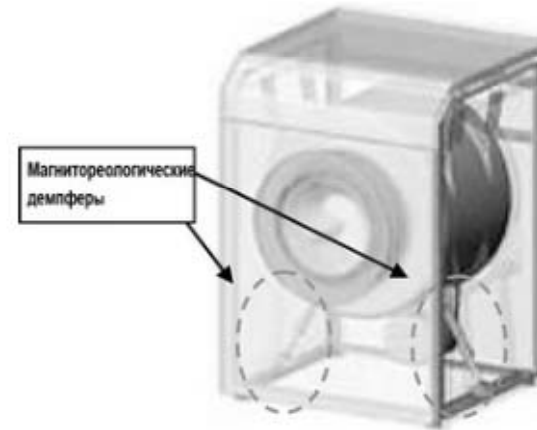
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An adaptive vibration control during boring and gun drill boring. Using the magnetorheological liquids in the adaptive systems of vibration control is one of the areas of development that is taking place abroad.

<http://mrfengineering.com.ua/magnytoreologicheskaya-zhydkost/oblasty-prymenyaya/mashynostroenye-y-stankostroenye?lang=en>





Magnetorheological dampers with active control of vibration in the domestic and industrial washing machines

**Thank You
for your attention!**