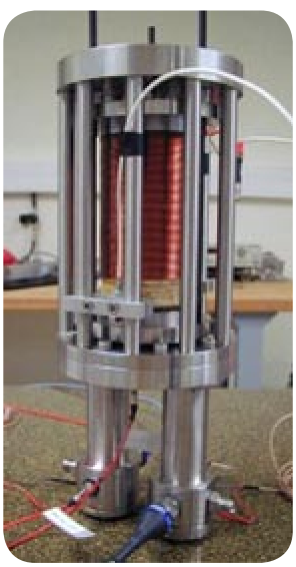
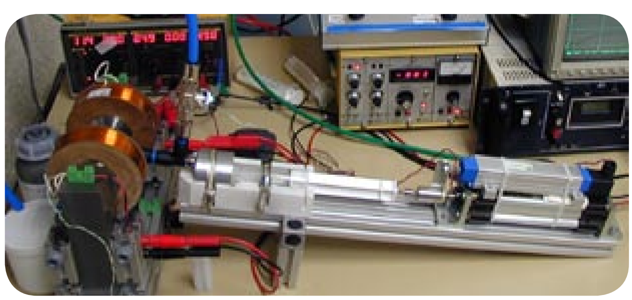
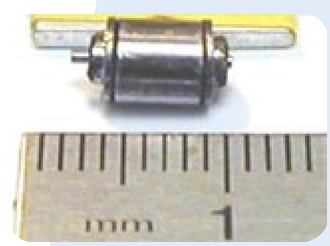
NEW LINEAR MAGNETIC ACTUATORS

Some Cedrat Technologies Design & Innovations ...







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INTRODUCTION

CEDRAT TECHNOLOGIES

CEDRAT TECHNOLOGIES SA is a high tech SME of CEDRAT Group involving 70 peoples located in 'Inovallée', the French Valley of Innovation, close to Grenoble.

CEDRAT TECHNOLOGIES develops and manufactures high performance Electro-Mechanical Components & Systems, especially Actuators & Electronics, which can meet needs from SME to prestigious customers as CNES, EADS, ESA, LG, NASA… :

- Piezo Actuators: Piezoelectric actuators can be developed as customized products. They are also available as off-the-shelf products : see separate documentation 'Piezo Actuators & Electronics' from CEDRAT TECHNOLOGIES or www.cedrat.com .
- New Magnetic Actuators: Magnetic actuators are developed by CEDRAT TECHNOLOGIES as customized products : Several examples of such developments are presented in this document.

What CEDRAT TECHNOLOGIES proposes through this document ?

This document presents several realisations of New Magnetic Actuators from CEDRAT TECHNOLOGIES and provides their technical performances. The presented technical characteristics reveal what the considered technology is able to achieve.

These actuators are not available as standard products, but as 'technological bricks'. So, if interested in such a technology, CEDRAT TECHNOLOGIES can develop similar products upon customer specification.

Developments of new Magnetic Actuators

Upon request, CEDRAT TECHNOLOGIES performs step-by-step developments in partnership with its customers:

- Analysis of customer specifications: A preliminary analysis by CEDRAT TECHNOLOGIES is free of charge. From this analysis, CEDRAT TECHNOLOGIES emits a formal proposal, including commitments, work programs, prices and delivery time.
- Design: A pre dimensioning or a feasibility analysis in case of very specific need, is realized using available design tools, before to perform the detail design. CEDRAT TECHNOLOGIES can apply Design Standards (for example ESA ECSS). At each stage, the customer gets the results, which generally a Detailed Design Report. CEDRAT TECHNOLOGIES accepts to perform such a Design work even if not in charge of the Prototyping, Testing and Manufacturing.

- Prototyping & testing: The prototyping & testing is performed according to specifications or following the defined work program. The test program can include a complete qualification. CEDRAT TECHNOLOGIES has already delivered several FLIGHT MODELS for space or aircraft applications. CEDRAT TECHNOLOGIES can apply Design Standards (for example ESA ECSS), a Quality Product Assurance Plan and a Configuration Management Plan. CEDRAT TECHNOLOGIES accepts to perform such a Prototyping & Testing works even if not in charge of the Manufacturing.

- Industrialisation & Manufacturing: CEDRAT TECHNOLOGIES can manufacture small or medium series of customized products. This can be performed applying a Quality Product Assurance Plan. In 2005, the number of manufactured actuators has reached 1000 units.

Cedrat Technologies Facilities

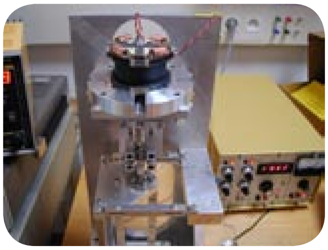
The R&D facilities used by CEDRAT to develop these technologies include advanced modeling CAD programs.

- FLUX 2D/3D is a standard Finite Element Method (FEM) software for the design of magnetic devices.
- ATILA 3D is a FEM software dedicated to the modeling of 2D/3D structures including active materials such as magnetostrictives and piezoelectrics.
- ADINA is a FEM software used for Computation of Flow Dynamics (CFD).
- I-DEAS is a CAD software used for the mechanical & thermal computation & design.
- MATLAB-SIMULINK, SPICE, DXP are software for the computation & design of driving & control electronics.

The R&D facilities include also workshop facilities and Test Equipment adapted to Electric Engineering and Electro-mechanics:

- 2D/3D metrology
- Clean assembly room
- Thermal-Vacuum chambers
- Vibration shakers
- PCs with LABVIEW
- Laboratory power supplies and amplifiers, including lock-in amplifier
- Impedance analyzer
- Spectrum analyzer
- Gaussmeters, permeameter
- Laser interferometers / vibrometers

Thermal-Vacuum Test Chamber.



Force Measurement of the VC-1 moving coil.

Electromechanical labs : Class 100 Clean assembly, Supplys & Vibrometers bench.

Moving Coil Actuators

Principle

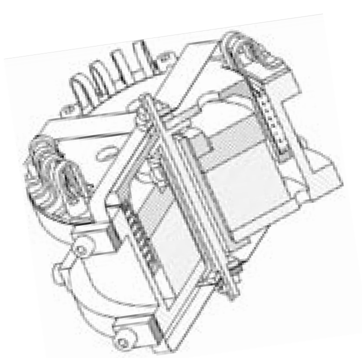
The Moving Coil Actuators are based on the Laplace (or Lorentz) force, which is strictly proportional to the applied current. A coil is placed into a magnetic field perpendicular to the coil winding. Applying a current into the coil produces a magnetic force to coil winding along the third direction. They have no blocking force at rest.

Moving Coil Actuators are also called Voice Coil or Lorentz actuators.

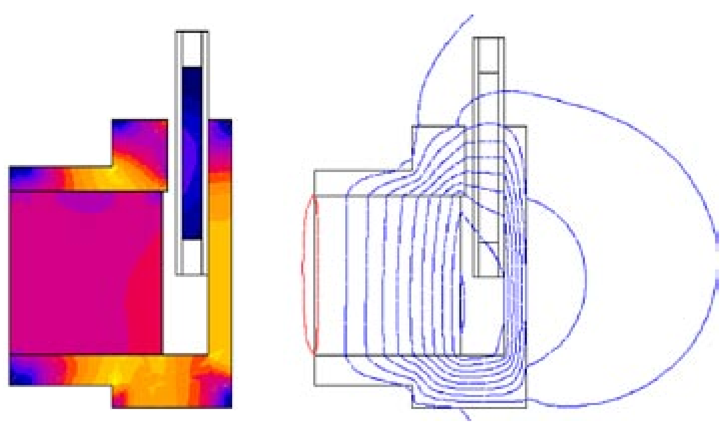
Design issues

Although Moving Coil Actuators are rather simple structures, their design can be customized thanks to following parameters:

- Magnetic Force: It is determined by the product of the coil current and the magnetic field. The magnetic circuit including a permanent magnet produces such a field. If the power dissipation need to be reduced, the magnetic field should be enlarged, which can be done to the price a larger magnetic circuit. If the actuator mass should be optimized, the current should be increased, which can be done to the price of a larger heating. A trade-off is generally performed between these two ways. Note that force is proportional to the applied current, but it depends on the position.
- Thermics: The thermics of a moving coil results not only of the previous trade-off but also of design of the heat exchange. As the coil is not in contact with iron, the heat exchange is difficult especially in vacuum application. In this case thermal drains should be considered.
- Guiding: The guiding can take benefit of the absence of transverse forces in a moving coil to use an elastic guiding. This is interesting to get a wear-free & hysteresis-free actuator.
- Environment: CEDRAT TECHNOLOGIES has developed voice coil actuators for specific environments such as Vacuum for space and instruments applications.



Structure of the VC-1 Moving Coil.



FLUX Magnetic Design.

Performances

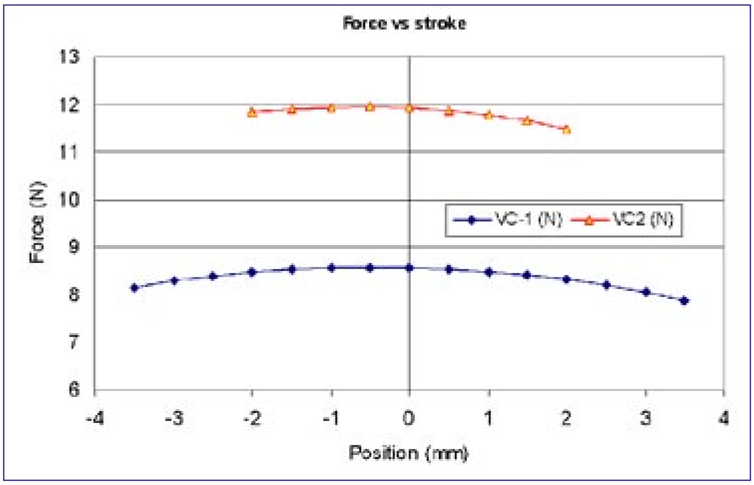
Typical performances are given in the following table. This table is not exhaustive as many other actuators can be rapidly designed by Cedrat Technologies using its design tools, lab facilities and technological know-how.

References	Unit	VC-1	VC-2
Notes		Space product	Preliminary
Stroke	mm	3	3
Maximal force in air	N	30	42
Peak force in air	N	90	127
Maximal force in vacuum	N	13	18
Maximal current in air	A	16	16
Maximal current in vacuum	A	7	7
Peak current	A	50	50
Dissipated power in air	W	28	28
Dissipated power in vacuum	W	5,5	5,5
Dissipated peak power	W	280	280
Mass	g	500	500
Moving mass	g	50	50
Stiffness	N/mm	1.8	1.8
Eigen frequency	Hz	30	30
Dimensions	mm	71 * 71 * 49	71 * 71 * 47
Mechanical interface		Housing : 4 * M3	Housing : 4 * M3
Electrical interface		2 wires AWG	2 wires AWG

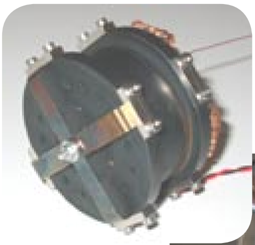
Applications

Moving Coil Actuators find applications as loudspeakers, vibration generators, micro/nano positioning, proof-mass dampers for active control of vibrations. They are used in Instrumentation and space, but are also considered in automotive industry.

For short stokes, Moving Coil Actuators are in competition with Amplified Piezoelectric Actuators from CEDRAT TECHNOLOGIES. For long stroke, they are in competition with Moving Iron Controllable Actuators, a new technologies from CEDRAT TECHNOLOGIES.



Force vs stroke @constant current.



VC-1 Voice Coil Actuator.

Thermal-Vacuum Test of the VC-1

Moving Magnet Actuators

Principle

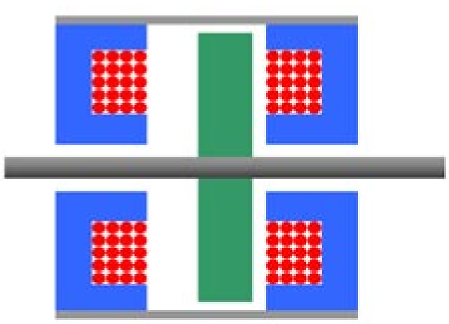
The Moving Magnet Actuators are based on a permanent magnet moving between to opposite electromagnets. They provide two stable positions at rest. Supplying one electromagnet to provide a magnetic field pulse adding to the permanent magnet field and making the opposite with the second electro magnet allows the permanent magnet to move toward the first electromagnet, and vice-versa.

For this reason, they are also called bi-stable actuators or flip-flop actuators.

Design issues

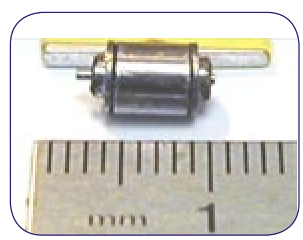
Moving Magnet Actuators are rather complex structures needing a careful design, which can benefit of FLUX FEM software from CEDRAT S.A.:

- Magnetic Forces: The static force at rest is determined by the permanent magnet size. The actuation force depends of the stroke and varies a lot along the strokes. The actuation force is minimum when the moving magnet is leaving its initial position. Design should take care of this issue in combination with the load. In addition, transversal forces are not negligible as soon as there are some play in the guiding, which may damage bearings.
- Thermics: There is no power at rest, so no heating at rest. Heating is meet only in operation when the switching frequency is going up.
- Miniaturization: For specific applications, CEDRAT TECHNOLOGIES has investigated the possibility of miniaturizing Moving Magnet Actuators leading to Micro Bistable Linear Moving Magnets BLMM.

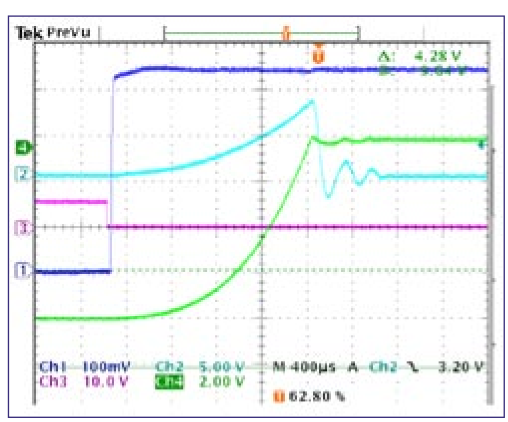


Principle of a moving magnet actuator.

BLMM-1Micro bistable Actuator.



BLMM1-1 Micro Actuator response [Current : 1A = 100mV]; [position : 80µm = 1V]; [Speed : 125mm/s = 1V];



Performances

Typical performances are given in the following table. This table is not exhaustive as many other actuators can be rapidly designed by Cedrat Technologies using its design tools, lab facilities and technological know-how.

References	Unit	BLMM-1	BLMM-2
Notes			*preliminary*
Stroke	*mm*	*0,62*	*3*
Holding force at rest (Fh)	*N*	*0,093*	*50*
Actuation force at start stroke (Fs) for I_{npc}	*N*	*0,033*	*10*
Actuation force at end stroke (Fe) for I_{npc}	*N*	*0,6*	*> 100*
Electrical interface		*2 wires*	*2 wires*
Nominal pulse voltage	*V*	*+/- 2,6*	*TBD*
Nominal pulse current I_{npc}	*A*	*+/- 5,4*	*TBD*
Pulse width	*ms*	*0,63*	*TBD*
Switch response time	*ms*	*2,7*	*10*
Maximal speed	*mm.s-1*	*437*	*TBD*
Impact speed	*mm.s-1*	*265*	*TBD*
Winding resistance	*ohm*	*0,48*	*TBD*
Temperature rise for 10 switch/s	*°C*	*3,5*	*TBD*
Moving mass	*mg*	*76*	*15*
Total mass	*g*	*0,8*	*50*
Diameter	*mm*	*5*	*25*
Height	*mm*	*6,7*	*20*
Usefull force Fs/ mass / curent	*mN/g/A*	*7,64*	*TBD*
Usefull force Fe/ mass / curent	*mN/g/A*	*138,19*	*TBD*

Applications

Moving Magnet Actuators find applications as bi-stable actuators, locking actuators, electro-valves vibration generators, ...

They are used in electric industry, production industry, air&space industry, and are considered for Braille application, ink jet printers...

Collaborations, Supports

CEDRAT TECHNOLOGIES is supported by Oseo French Innovation Agency.

Moving Iron Actuators

Principle

The Moving Iron Actuators are more generally called electromagnets. They use the magnetic attraction force that exists between two soft magnetic parts in presence of a magnetic field. This force is due to a minimization of the system magnetic reluctance. It is generally much higher than Laplace force used in Moving Coil Actuators.

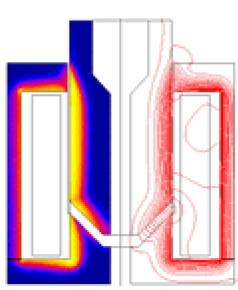
In principle, the magnetic force is intrinsically quadratic meaning that only attraction forces can be produced. To get it back, a return spring is added, leading to one fixed position at rest. Such an actuator is generally not able to perform control functions (like accelerating/breaking for fast positioning, all along the stroke).

However New Moving Iron Controllable Actuators, called MICA, allow to circumvent this limitation and to get high forces controllable actuators.

Design issues

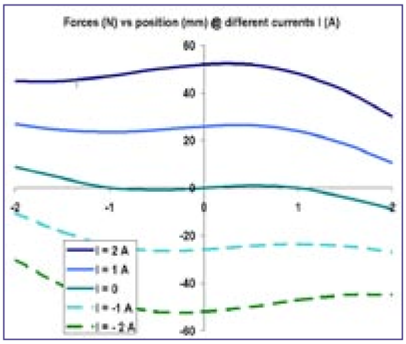
Moving Iron Actuators are rather complex structures needing a careful design, which can benefit of FLUX FEM software from CEDRAT S.A. This software allows combining magnetic analysis and mechanical effects such as return springs:

- Magnetic Forces: In usual cases, the static force at rest is determined by the spring force. The magnetic force varies with the position. In the rest position, the magnetic force is the smallest as this force increase when the air gap decreases. To get a more constant force along the stroke, a usual way consists in conic air gap.
- High Forces Controllable Actuators (MICA): For applications requiring high forces long stroke controllable actuators, CEDRAT TECHNOLOGIES has investigated new concept of Moving Iron Controllable Actuators (MICA). Such new actuators can provide both positive and negative forces all along the stroke, depending on the applied current sign. For this reason, MICA can compete with Moving Coil Actuators and can address mechatronic applications.
- MICA compared to Moving Coil Actuators: Compared to Moving Coil Actuators, MICA offers much higher forces, are less sensitive to heating and are more robust. Wires are fixed. The moving part is stiff and can drive heavy loads.



FEM FLUX magnetic design of standard Moving Iron Actuator.

Standard Moving Iron Actuator with a conic air gap and a return spring.

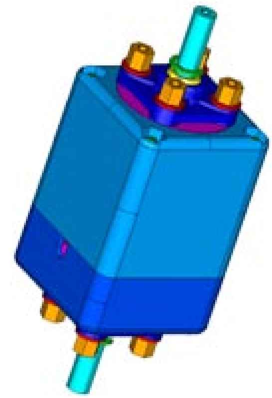


Force vs stroke for the MICA50-4 for positive to negative currents.

Performances

Typical performances are given in the following table. This table is not exhaustive as many other actuators can be rapidly designed by Cedrat Technologies using its design tools, lab facilities and technological know-how.

References	Unit	MICA40-3	MICA170-4
Notes		*Preliminary*	*Preliminary*
Stroke	*mm*	*3*	*4*
Maximal force in air	*N*	*+/- 40*	*+/- 172*
Peak current density	*A/mm²*	*8*	*10*
Dissipated peak power	*W*	*8*	*52*
Side	*mm*	*39*39*	*60*
Height	*mm*	*80*	*55*
Mass	*g*	*360*	*716*
Moving mass	*g*	*100*	*300*
Force / mass	*N/kg*	*111*	*240*
Force / power $^{1/2}$	*N/W* $^{1/2}$	*14*	*24*
Electrical interface		*2 wires AWG*	*2 wires AWG*



CAD Assembly of the MICA40.

Applications

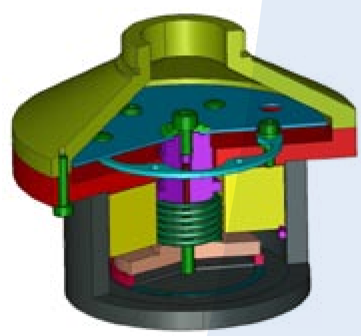
Moving Iron Actuators find applications as circuit breakers, on-off electro valves, locking actuators, ...

They are used in electric industry, air & space industry, car industry, ... New controllable actuators are considered for high vibration generation, high power loud-speaker, active damping applications, smart circuit breakers...

Collaborations, Supports

CEDRAT TECHNOLOGIES is supported by Oseo French Innovation Agency. CEDRAT TECHNOLOGIES is the laboratory managing SCHNEIDER ELECTRIC Thesis 'Controllable Linear Magnetic Actuators for circuit breakers'.

High power loud-speaker based on MICA concept (right) compared to the initial moving-coil loud-speaker (left). In this application, MICA offer 3 times more forces, twice more displacement, while requesting twice less power and being much smaller
Courtesy of MADE.



Design of a High Power loud-speaker based on a MICA Moving Iron Controllable Actuator.

Magnetostrictive Actuators

Principle

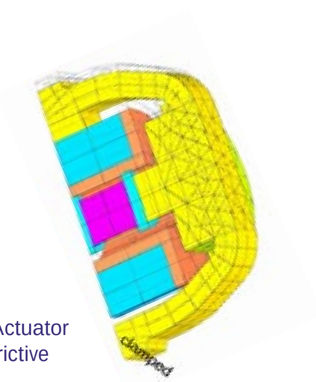
The Magnetostrictive Actuators are solid state magnetic actuators. A current-driven coil surrounding the magnetostrictive rod generates the expansion of the rod. Magnetostrictive Actuators need a magnetic bias to present a linearised response, which can performed either by a DC current in the coil or permanent magnets.

Magnetic field induced strain materials are classically represented by Giant Magnetostrictive Materials (GMM) such as Rare earth-iron discovered by A.E.Clark. These materials feature magnetostrains which are two orders of magnitude larger than Nickel. Among them, bulk Tb0.3Dy0.7Fe1.9, called Terfenol-D, is commercially available since 1987 and presents the best compromise between a large magnetostrain and a low magnetic field, at room temperature. Positive magnetostrains of 1000 to 2000 ppm (0.1-0.2%) obtained with fields of 50 to 200 kA/m are reported for bulk materials, opening the possibility of building high power transducers and low voltage high force density actuators. More recently, the family of smart magnetic materials has been extended with Magnetic Shape Memory Materials (MSM) such as NiMnGa alloys offering a magnetostrain of up to 6%. These materials basically behave as Giant Magnetostrictive Materials.

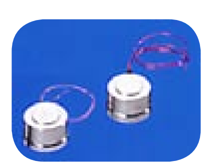
Design issues

Magnetostrictive Actuators are complex structures needing a careful design, which can benefit of ATILA FEM for magnetostrictive and piezoelectric devices, from CEDRAT S.A. and of FLUX FEM software for magnetics. ATILA software allows 3D computation of the structure strain vs applied electric current accounting for magnetoelastic coupling:

- Forces: Magnetostrictive actuators can offer large forces because of high coupled stresses (up to 50Mpa) and availability of rods with large section (more than 50mm in diameter).
- Stroke: Stroke is governed by the expansion of the active rod and by its length (up to 200mm). Stroke can be amplified using a mechanical amplified such as a shell.
- Voltage: The excitation voltage can be adjusted using the coil number of turns. With high current and large section wires, the required magnetic field can be produced with a low voltage (less than 12V if needed).



Miniature Direct Magnetostrictive Actuator DMA XSLarge Direct Magnetostrictive Actuator DMA L.



Amplified Magnetostrictive Actuator AMA Modeling of the AMA magnetostrain with ATILA FEM.

Performances

Typical performances are given in the following table. This table is not exhaustive as many other actuators can be rapidly designed by Cedrat Technologies using its design tools, lab facilities and technological know-how.

References	Unit	DMA XS	DMA L	DMA XL
Notes				
Stroke	µm	2	110	100
Maximal force	N	250	1570	21000
Maximal frequency	kHz	5	2	1
Voltage	V	12	12	12
Dissipated DC power	W	10	10	20
Diameter	mm	8	115	130
Height	mm	5	180	180
Mass	g	10	9300	12000
Electrical interface		2 wires AWG	2 wires AWG	2 wires AWG

Applications

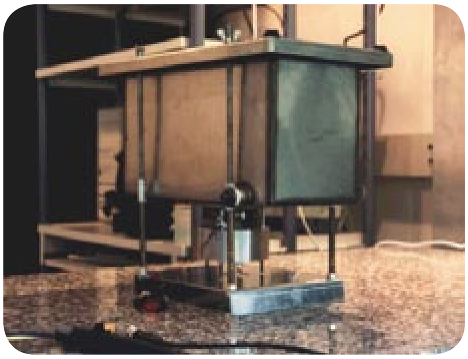
Magnetostrictive Actuators are in strong competition with the standard piezo electric actuators such as PPAs and APAs (see catalogue http://www.cedrat.com/hardware/piezo_actuators/piezo_actuators.htm) from CEDRAT TECHNOLOGIES.

They find applications as sound generators (sonars), proportional valves, high forces generators or low voltage actuators (it can be less than 12V) ...

They are used in machine tools, gas & petroleum industry, and are considered for medical, military and space industries...

Collaborations, Supports

CEDRAT TECHNOLOGIES is partner of the FP6 EC MESEMA project with ALENIA, EADS, TACT, U.Naples, ZIP-LPA, ZFL.



High power (3kW) magnetostrictive sonar transducer TRIPODE.

Magnetostrictive transducerfor ultrasonic cleaning.

Magnetostrictive actuator for making an aircraft hydraulic pump in an Electro Hydraulic Actuator (EHA).

MRF Actuators

Principle

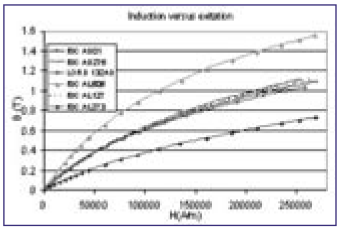
The MRF Actuators are new electromechanical components using Magneto Rheological Fluids (MRF). These smart fluids are characterized by their capability to change their rheological properties, especially their viscosity, versus applied magnetic field. With high enough field, they can switch from a liquid to almost solid body. This effect is reversible. It operates in few milliseconds.

This effect can be used for generating controllable damping or braking capabilities, which can be used for making special electro-fluidic actuators.

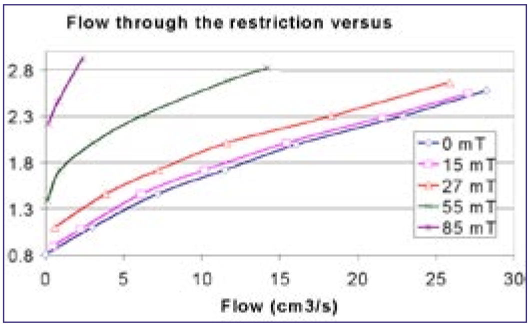
Design issues

Magneto Rheological Fluid (MRF) Actuators are complex structures needing a careful design, which can benefit of FLUX FEM software for magnetics and CFD FEM for computing flow dynamics. Selecting the MRF and performing an appropriate devices design implies also a good characterization of the MRF magnetic and rheological properties. There are several ways of using MRF:

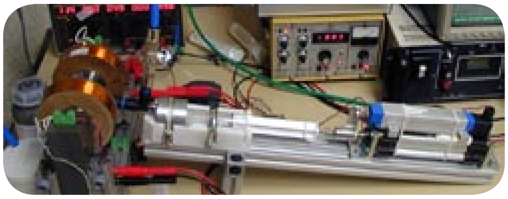
- Flow mode : In flow mode, the MRF fluid is flowing in a restriction. Applying a magnetic field in the restriction reduces the flow because of increased viscous forces. With high enough field, there is no more flow. This is used for making controllable flow valves without moving parts.
- Shear mode : In shear mode, the MRF fluid is static and placed between two surfaces with a relative motion. Applying a magnetic field in the MRF fluid increases the tangential forces between the two surfaces because of increased viscous force. This is typically used in clutches.
- Damping effects : Thanks to these properties, MRF may be used to provide controllable damping forces that require only a relatively small amount of magnetic energy. Typically the damping coefficient can be increased by 3 to 5 when the field is applied. This is called semi active damping. These possibilities are used in semi-active dampers and controllable shock absorbers.



Magnetization curves B(H) of various MRF fluids.



Pressure vs Flow @ different B-field of a MRF.



CEDRAT TECHNOLOGIES test bench of MRF in a flow mode (active valve mode).

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