MAGNETOREOLOGICAL FLUIDS AS METHOD FOR ACTIVE CONTROLLING OF LANDING GEAR SHOCK ABSORBER CHARACTERISTIC

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Summary

Smart materials are being used in much larger scale in mechanical solutions. Aviation usage of these materials seems to be natural because of interest in new technologies use in this industry. In this article authors discuss characteristics of magnetoreological fluids as a smart materials, examples of its industrial usage, requirements on landing gear characteristics, design and laboratory tests of model shock absorber in which MRF was used as damping fluid.

1. MAGNETOREOLOGICAL FLUID

Magnetoreological fluids (MRF) are qualified as smart materials, which are controlled by magnetic field. Every MRF consists of two fractions liquid and solid. Liquid fraction is mostly an oil (can be both synthetic or natural), which is responsible for MRF density when magnetic field is not applied. Viscosity of liquid fraction also has also limited interaction with speed of MRF response to magnetic field. Solid fraction of MRF is basically particles of ferromagnetic material mixed with liquid fraction. Solid fraction can be made in different sizes and different susceptibility to magnetic field. Generally MRF because of the composition (mixture of oil and ferromagnetic particles) has the tendency to sedimentation. Depending on the substance used as liquid fraction and the grains sizes of solid fraction sedimentation can be different in the same period of time and be less or more permanent. Some MRF can sediment in such manner that later mixing is impossible what makes their use in constructions (e.g. airplane shock absorbers) impossible.

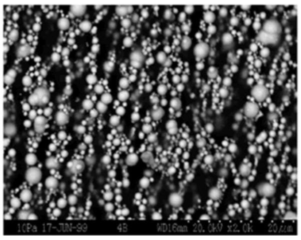


Fig. 1. Picture of the particles of the ferromagnetic substance, after applying the magnetic field (picture: http://www.matint.pl/materialy-magnetoreologiczne.php)

The change of the property of the MRF consists in the change of the solid fraction particles arrangement in surrounding them liquid fraction. When no magnetic field is applied, the particles of solid fraction are arranged randomly in liquid fraction. When magnetic field is applied particles try to arrange according to lines of the magnetic field creating long chains (fig. 1, fig . 2). This results in the increase of density and shear strength.

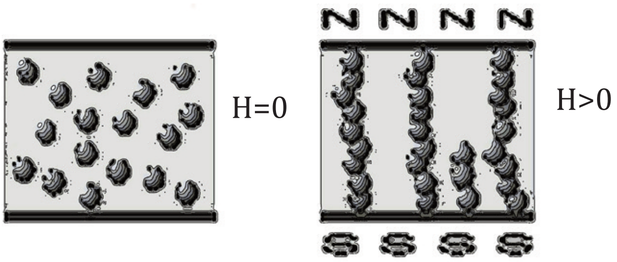


Fig. 2. Pattern of the magnetic field influence on the MRF. Dots represents ferromagnetic particles, background represents flui. (source of picture as in Fig 1.)

Magnetic field, which is used to control the MRF, can be generated by any source from the permanent magnet to the coil. Controlling the behavior of MRF follows through the magnetic field value change. MRF reaction to changes in the magnetic field is immediate and allows to use MRF in applications where short times of the reaction are required.
MRFs are offered as the trade product by many companies. The largest and the most well known manufacturer of the MRF and MRF based devices is LORD Corporation.

Tab. 1. Examples of Magnetoreological Fluids parameters by LORD Corporation [3]

		MRF-336AG	MRF-140CG	MRF-132DG	MRF-122EG
Base Fluid		Silicone Oil	Mineral Oil	Mineral Oil	Mineral Oil
Viscosity Pa-s	40°C	0,115±0,015	0.280 ± 0.070	0.092 ± 0.015	0.042 ± 0.020
Density	g/cm3	3,32-3,44	3.54-3.74	2.98-3.18	2.28-2.48
Solids Content by Weight	%	% 82.02	% 85.44	% 80.98	% 72
Flash Point	°C	>150	>150	>150	>150
Operating Temperature	°C	-40 to +150	-40 to +130	-40 to +130	-40 to +130

2. USE OF MAGNETOREOLOGICAL FLUID

Unique properties of MRF create the possibilities of application in actively controlled energy dissipation devices. Example applications of MRF include:

- car suspension systems (fig. 3) ex. vibration dampers
- in pneumatic systems as the speed and position controller
- vibration damping and stiffness systems car seats
- devices reducing the results of strong wind and quakes (fig. 4)
- in artificial limbs for improved comfort

Fig. 3. Example MRF based automotive shock absorber (picture: Lord Corp.)

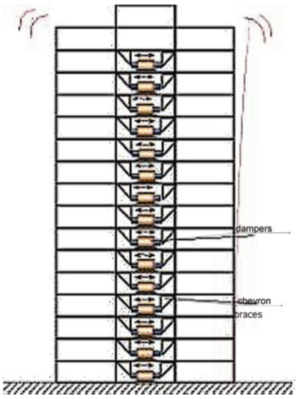


Fig. 4. Example of building seismic vibration damping (picture:Lord Corp.)

3. REQUIREMENTS FOR AIRPLANE LANDING GEAR AND SHOCK ABSORBERS

The main functions of the landing gear are:
-to absorb the kinetic energy of the vertical velocity
-to provide elastic suspension during taxiing and ground maneuvers
-to assure safety and comfort for passengers and transported goods during ground maneuvers, start and landing of the airplane.

These requirements are fulfilled in landing gear by properly designed shock absorbers and correctly chosen wheels.

There are some different landing gear designs that fulfill above criteria. In light airplanes dissipation of the energy can be achieved in different ways:
- spring L/G (in aeronautics L/G is an abbreviation for landing gear) made as a spring beam is both shock absorber and L/G strut (fig. 5)
- flexible elements the most often rubber or different elastomers built-up in the L/G structure
- steel ring springs
- oleo-pneumatic shock absorbers (fig. 6)

Fig. 5. Spring beam L/G for AT airplane (photo:internet)

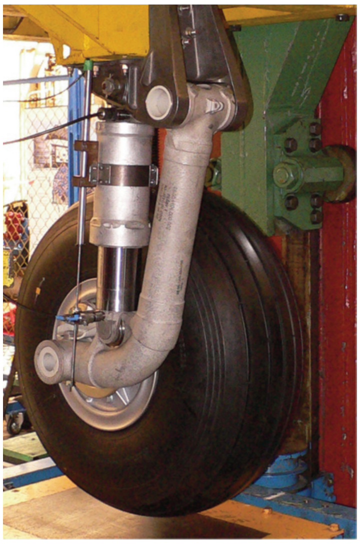


Fig. 6. M-28˝Skytruck˝main L/G with oleo-pneumatic shock absorber (design Institute of Aviation L/G Department, photo: IA archive)

The first three solutions are preferred in light airplanes because of their low cost in connection with high efficiency rates and low weight. Yet use of the oleo-pneumatic shock absorber is the most effective solution.

Because of the largest efficiency in energy dissipation use of oleo-pneumatic shock absorbers is general in military and commercial airplanes where cost of the construction is not the most important criterion.

Oleo-pneumatic shock absorber absorbs energy by "pushing" a volume of hydraulic fluid against volume of gas (usually nitrogen but can be dry air.)

Oleo-pneumatic shock absorbers carry out two functions:

-a spring or stiffness function, which provides the elastic suspension by the compression of a gas volume

-a damping function, which dissipates energy by forcing hydraulic fluid through one or more small orifices

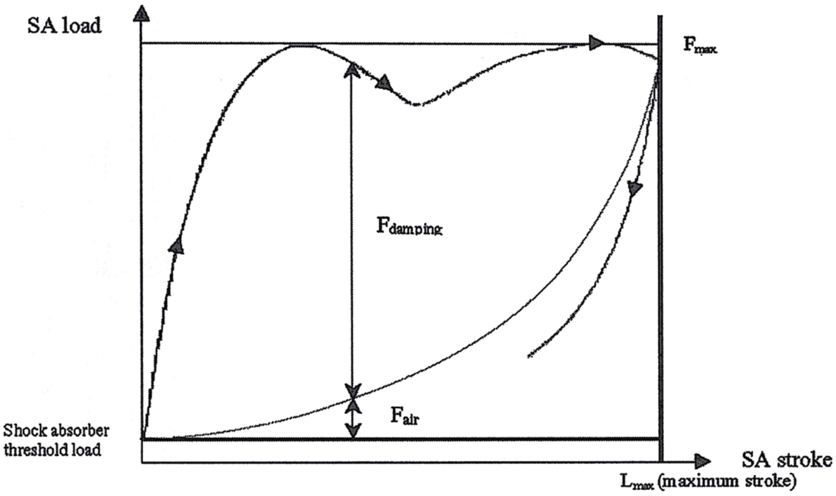


Fig. 7 Examplary shock asorber load versus stroke characterisc [1]

4. EXPECTATIONS OF MRF AS SHOCK ABSORBER FLUID EXPECTATIONS AND MRF CONTROLLING SYSTEMS

Use of MRF carries necessity of certain; quite serious changes in current shock absorbers or design new device initially capable of MRF use. In the case of the modernization of the older solution, there should be put special attention to different consistency of magnetoreological fluid. Also existence of solid fraction (iron particles) can be destructive for shock absorber parts (particularly seals). Another necessary change in shock absorber is to add one or more coils for MRF control. Design of entirely new shock absorber which is initially optimized for MRF use eliminates these problems, however this is not always possible.

Main goal of MRF use in airplane landing gear is possibility to correct shock absorber characteristics in order to achieve optimal energy dissipation in every landing condition. Naturally obtaining of the ideal profile is not possible for every landing because of general shock absorber design limits. Range of the possible L/G control is also limited by the safety reasons especially by requirement that landing must be safe even during MRF control power supply failure.

There are three methods of MRF based damping control.

First one is to put fixed damping characteristics into steering module (it can be both programmable computer or fixed hardware based logic). During landing phase, on board computer execute shock absorbers damping characteristic in order to achieve previously defined damping. Reference characteristic (put into MRF control system) is developed during laboratory tests of the shock absorber. That way of damping control enables two state steering:

- Without powered/executed MRF control system. In this case damping characteristic is only via mechanical systems built into shock absorber – passive damping

- With powered/executed MRF control system. In this case dumping characteristic is the one defined in electronic control system.

Main advantage of this control method is simplicity of MRF steering system, but there are only two damping characteristics available and energy absorption process is far from optimal. It is also ineffective because almost the same effect can be achieved by using standard well optimized hydraulic shock absorber.

Second way of MRF control (let's call it semi-smart) is to create several damping characteristics optimized for different landing scenarios. Control system itself is more complicated than in first method because it has to act as databank for several characteristics and has to enable execution of right one. This can be achieved by onboard computer trigger based on existing instruments (without need to put external flight condition measuring systems). Semi-smart control system is better optimized than fixed one but still it is not the best solution.

Third and most advanced method of MRF control (let's call it smart) is to enable real time control of shock absorber characteristic. This type of control enables full optimization of energy dissipation based on actual landing conditions. In order to achieve correct MRF steering it is need to provide fast computer system for damping characteristic calculation and set of high accuracy sensors which will measure parameters need to characteristic calculations. In most of the cases sensors for MRF control systems will be independent from airplane built-in sensors because of safety reasons (interferences, not enough accuracy, etc.). Execution of MRF steering is automatic and is performed by onboard computer, rest of the process is carried on by MRF control system. Smart system is most accurate of all three systems described but it is also most complicated and costly.

It can be assumed that for now semi-smart control system can be widely used in MRF based damping control due to reasonable cost/performance ratio.

5. MRF BASED SHOCK ABSORBER DESIGN

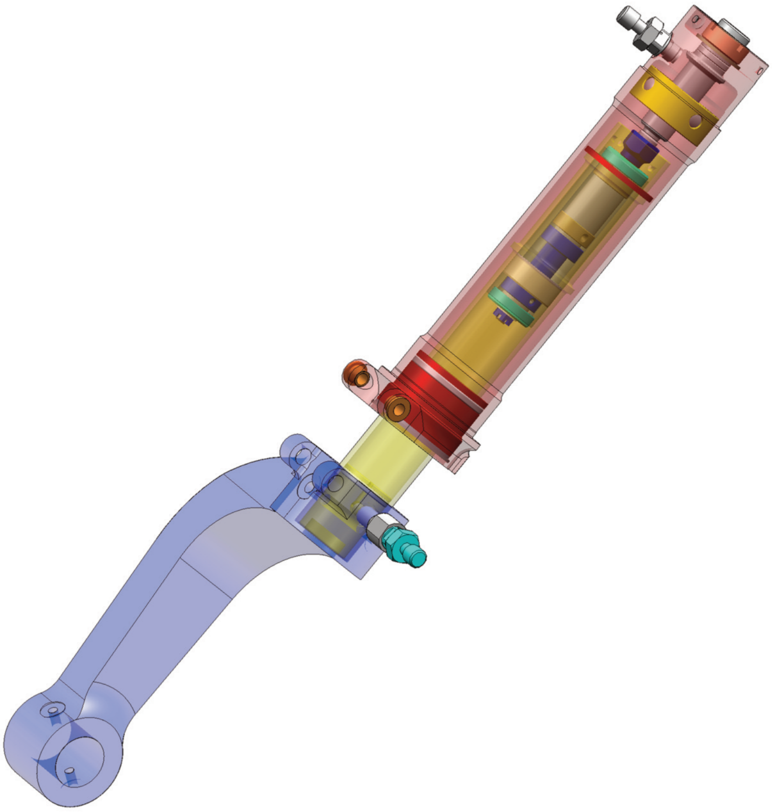


Fig. 8 3D shock absorber model (picture: IA archive)

MRF based landing gear shock absorber was created by Warsaw Institute of Aviation Landing Gear Department within the project PBZ-KBN-115/T08/04 titled "Metallic, ceramic and polymer smart materials (design – obtainment – properties – use)". MRF based shock absorber is a developed version of existing I-23 “Manager” small airplane front L/G. Necessary modifications were made to the existing design in order to use MRF but modifications didn’t change L/G layout.

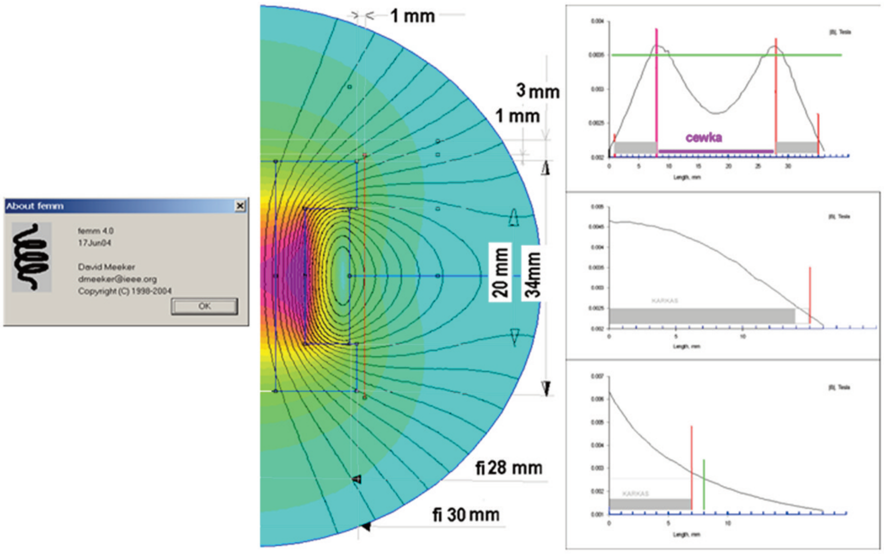
First stage of the design change was to build MRF control coils. Coils were calculated using Finite Element Method (FEM) (fig. 9) by the FEMM [4] software.

After preliminary calculations of coils, which were crucial for shape of the rest of the design, it was 3D modeled. The design process was made by the use of the SolidEdge [5] software for 3D (fig. 8) modeling and flat drawing. 3D modeling software was used in order to avoid structural mistakes and to speed up design process.

Shock absorber design process was aided by strength analysis using Femap (with Nastran calculating module) Finite Element Method (FEM) software.

That type of software significantly speed up design process and gives the chance of optimization before actual manufacture of the product.

Finally prototype of MRF shock absorber was built (fig. 10). LORD MRF-336AG was used in design as a working fluid. Chosen MRF meets hydraulic oil flow requirements and can be easily mixed when sedimentation occurs.



Rys. 9 Example of FEMM programme based coil magnetic field analysis

Fig. 10 Prototype of MRF based shock absorber – internal parts

6. MRF BASED SHOCK ABSORBER LABORATORY TESTS

The tests of MRF shock absorber took place in Institute of Aviation Landing Gear Department Laboratory. Both static and dynamic test were made. Static tests were conducted in order to make shock absorber static characteristic. Dynamic tests were made in order to check shock absorber behavior in similar to actual conditions.

Static tests were conducted at 40T hydraulic press (fig. 11), dynamic tests were made on 10T drop machine (fig. 12).

Fig. 11. 40 T press for L/G static tests (picture:IA archive)

Fig. 12. 10 T drop machine for L/G dynamic tests (picture IA: archive)

During static tests shock absorber was optimized in order to obtain the best possible profile for MRF flow control.

The dynamic tests of the shock absorber were executed on the object which static profile is showed on the graph below (profile Pr_810, fig. 13).

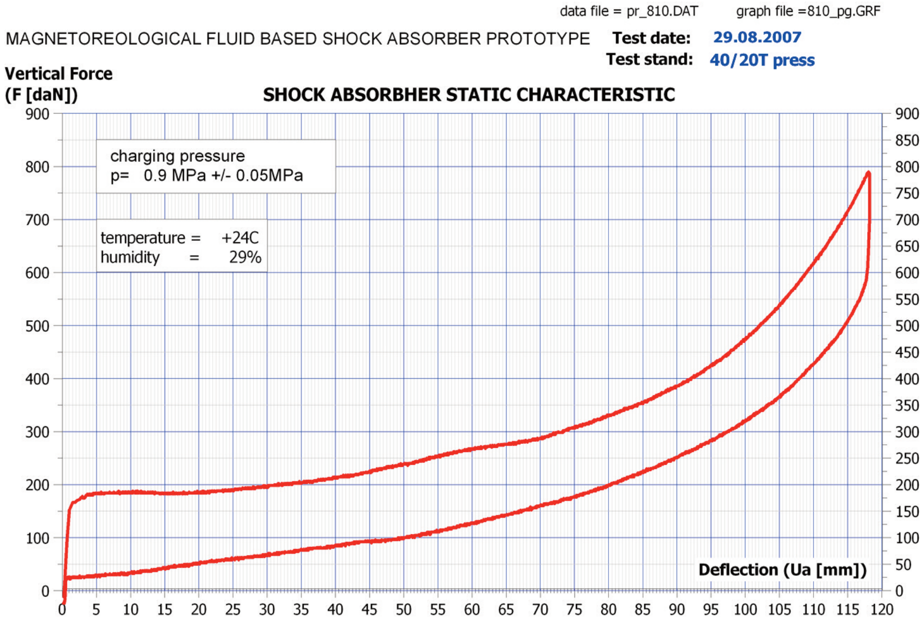


Fig. 13. Static characteristic of MRF shock absorber (picture: IA archive)

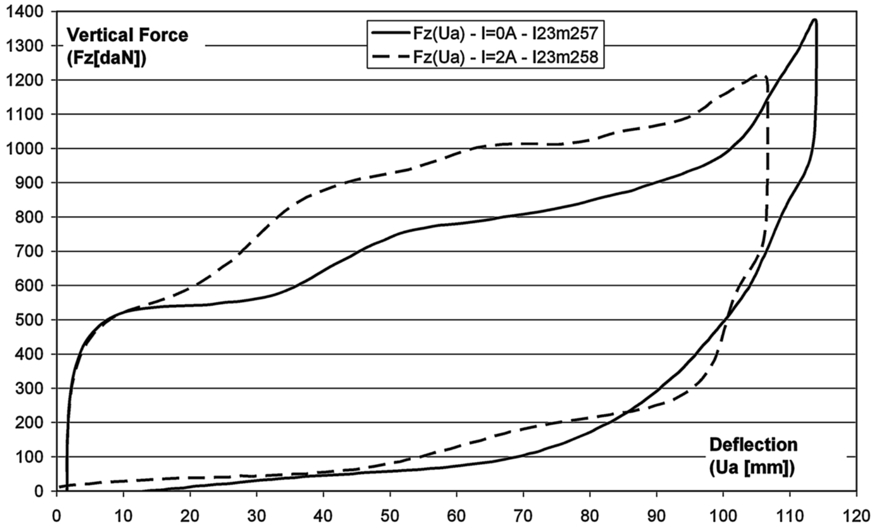


Fig. 14. Vertical force versus shock absorber deflection for dynamic tests made with two control currents (both tests made with the same energy) (picture: IA archive)

Dynamic test of L/G is a free drop of defined mass from fixed height in order to achieve desired landing energy.

Dynamic tests I23m257 (fig. 14) and I23m258 (fig. 14) were executed for the same reduced mass and L/G fall (the same energy), with relief of 2/3 dropped mass weight. During first dynamic test coils were not powered, current I=0[A]. In this case (I=0[A]) shock absorber design provide only hydraulic damping by pumping MRF through damping holes as in classic shock absorber solution. Shock absorber hydraulic damping was optimized in order to achieve the same damping value as in standard (non MRF based) I23 shock absorber.

During second dynamic test coils were powered by the current I =2[A]. Maximal L/G load decreased from 1376 [daN] in case of lack of current to 1218 [daN] in case of the 2[A] powered coils. There was about 11,5% decrease in load compared to the hydraulic damping itself (I=0[A]). Load change is a result of increased damping without change in other parameters of dynamic test.

7. SUMMARY AND CONCLUSIONS

Design of MRF based is no more complex than today’s standard solutions. There is no need of using additional control system because every modern airplane is equipped in on board power sources and computers that can be used as control electronics.

11,8% load reduction was achieved as the result of MRF use in shock absorber. Reduction was enough to conclude that shock absorber designs based on MRF could be made in future. Achieved effect was promising in spite of current was constant during drop tests. Active control of current can enlarge desired effect.

Use of proposed design can result in making, more reliable and better fatigue resistant landing gears. However high cost of MRF used during tests can put design to the economical test. But when one look at long term advantages of MRF based L/G such as improved safety and comfort designer should consider MRF based design as future of landing gear system.

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Streszczenie

Materiały inteligentne (ang. smart materials) znajdują coraz większe zastosowanie w konstrukcjach inżynierskich. Wykorzystanie ich w lotnictwie jako jednej z najbardziej nastawionej na nowoczesne rozwiązania gałęzi inżynierii jest jak najbardziej naturalne. Praca zawiera krótką charakterystykę cieczy magnetoreologicznej jako materiału inteligentnego, wymagania stawiane podwoziom lotniczym, opis konstrukcji oraz badań modelowego amortyzatora wykorzystującego MRF jako czynnik roboczy .