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SOME PROBLEMS CONNECTED WITH DESIGNING OF MAGNETORHEOLOGICAL FLUIDS AND DAMPERS

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ABSTRACT: In the currently presented paper, the main problems which could be encountered by designers of MRF dampers and scientists have been presented. The MRF dampers work on the basis of the magnetorheological fluid, which belongs to the group of the non-Newtonian, rheostable liquids. They are characterized by the "flow" limit and are able to change their rheological properties in a very short time. The control factor in this case is a magnetic field intensity.

The structure of the magnetorheological fluids is quite simple with a comparison to the other group of well known smart structures such as piezoelectric or a shape memory alloys. Although, the controlling process of the exploitation of the previously mentioned devices is rather complex.

Formerly discussed problems influence on the construction and exploitation of machines, having implemented parts consisting of MRF devices. Taking into considerations reach experimental experiences of authors in considered field, some, previously selected problems will be presented, analysed and particularly discussed. Such problems are observable in each step of MRF devices designing.

They are connected with the evaluation of the influence of the current intensity, the magnetic field saturation, the size and shape of the working fluid gap, the coil parameters and its material, a temperature etc. on the dampers working conditions.

KEYWORDS: MRF fluid, magnetorheological dampers, laboratory tests, smart structures.

1. INTRODUCTION

In the family of materials which could be classified to the "smart structures" group, having particular properties which give possibilities of the integration of sense, control and steering processes, rheologic fluids are one of the most important cells creating those group of materials.

On account of lower, in proportion to other groups of "smart structures", demanding connected to the steering process, also in many cases due to lower importance against other sorts of steering fluids, technical demanding concerning manufacturing of this group of materials, recently increase of interest in magnetorheological fluids field, could be observed. They won recognition in a different sorts of applications, particularly as a fundamental constructive element of different sorts of dampers, shock absorbers, clutches, brakes etc..

Besides applications in very advanced technical experiments, such as space technologies, commonly cited examples of mostly mentioned fields, where previously presented MR constructions could be applied are inter alia:

- cars: Cadillac Stabilitrak, Corvette (1999), presented for the first time in Geneva car salon in 2000 year, model of the Imaj roadster Cadillac, and prototype model Sevilla STS 2002, car chassis dampers of well known Delphi [281,358] company, also in model Cadillac Corvette 2003, GM production dampers such as RPO F55 and RPO F45,

- increasing driver comfort, applied for the first time in 1998 by Western Star and Freighliner companies, driver's seats steered dampers of eighteen-wheel trucks,
- applied inter alia in washing-machines, magnetorheological dampers made by LORD company,
- applied since 2000 MR dampers in hip-prosthesis,
- vibro-insulators with MR fluid, used for a long time as a building protections against earthquakes,
- vibration dampers of machines and devices,
- mining machinery sealing,

micro MR clutches précising movements of robots etc..

2. BASIC KNOWLEDGE ABOUT PROPERTIES OF FLUIDS AND DESIGNING OF MAGNETORHEOLOGICAL SHOCK ABSORBERS AND DAMPERS

Magnetorheological fluids belong to the rheo-stable group of liquids, so they are fluids, which rheological properties depend on shearing time; they prove also flowing border; so they are liquids characterizing plastic-viscous properties.

In the magnetorheological fluid group, two sub domain groups could be defined:

- ferrofluids-FF,
- magnetorheological fluids-MRF.

Previously mentioned kinds of fluid are characterized by one, very important common feature. It is ability do the fundamental change of visco-plastic properties in a very short, few milliseconds order time. Its possible because of appropriate magnetic field, which is generated by the passage of current through the solenoid. Tank's to that feature, steering of fluid properties is extremely simple and effective.

Being main field of presented part of this paper interest, magnetorheological fluids (MRF) are colloidal suspension ,which proves magnetic properties, of particles having sizes from 0,5 [μm] to 8 [μm]. Content of those particles in the main liquid, which is most frequently ponyphenylether, perfluoropolyether or cyclopentan, is about 20%. The value of saturation induction in engineering applications is in order of 1,2 [*T*], and the range of unchangeable working conditions, is temperature dependent and is defined by values from 50^{O}[*C*] to 150^{o}[*C*]. Viscosity of the MRF fluid is defined in the range of 5 [*cP*] to 25000 [*cP*].

The main advantage of the magnetorheological fluid is, that it reveals a big magnetization. It's viscous, due to magnetic field action, changes a lot and in a very short time. Basing on information presented in catalogues, viscous of MRF fluids is about 700 [*P*] in 200 [kA/m] magnetic field intensity. It causes, that shear stress for this type of fluids, assuming previously mentioned field intensity, is about 100 [kPa]

In Tab. 1, parameters of the MRF-132AD fluid, which fills shown in the **Fig. 1**, most popular among researchers, damper made by LORD corporation, signed as Rheonetic^{TM} MR Damper RD-1005-3, have been presented.

Tab. 1 Typical values of the magnetorheological fluid parameters

Fluid signature	Rheonetic Fluid MRF-132 AD
Basic fluid	Hydrocarbon
Working temperature	-40 - 130°C
Typical viscosity	
Destination	Universal (dampers, brakes, connections)

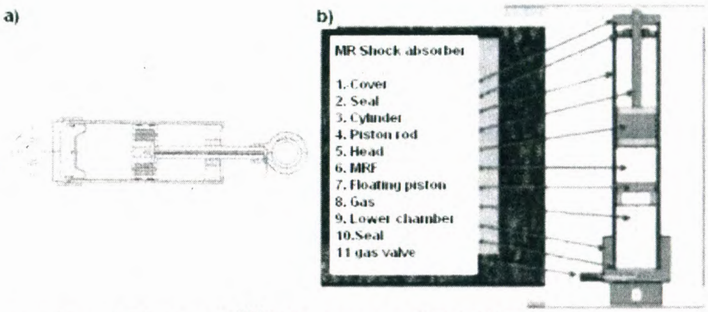

Fig. 1: a) Intersection of Rheonetic™ MR Damper RD-1005-3 and b) pictorial scheme with assemblies selection

In Fig. 2a, designed by the Institute of Machines Design Fundamental of Warsaw University of Technology, MR shock absorbers and dampers have been illustrated. In the **Fig. 2b**, four differences of constructional solutions of the MR fluid flow from the one working chamber to another, have been explained.

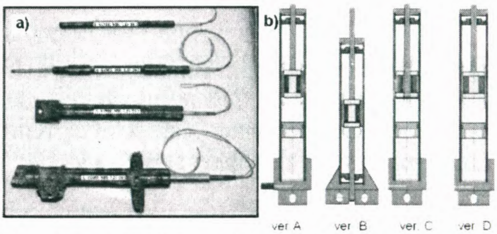

Fig. 2: a) Designed by the Institute of Machines Design Fundamental of Warsaw University of Technology, MR shock absorbers and dampers; b) Four differences of constructional solutions of the MR fluid flow from the one working chamber to another

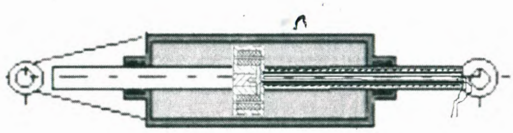

Fig. 3: Design scheme of the magnetoreological shock absorber

Analyzing presented in Fig. 1b pictorial scheme which illustrates main assemblies of previously mentioned device, extraordinary constructional simplicity have been found. Classical linear MR damper consists of following assemblies:

- suitable cylinder, which is a casing of a damper or a shock absorber; in shock absorber case, it consists of separating MR fluid and a gas chamber, independent, free flowing piston or membrane,
- suitable sealed in a casing, moving together with steering electric wires, piston rod, mounted at the end of a piston rod and moving inside the chamber with MR fluid, complete piston.

Considering damper (Fig. 3), previously mentioned constructional assemblies are similar to the shock absorber case. This type of device has always quite different solution, it is mostly bilateral guidance of the piston rod, and according to it, additional constructional possibility of a fluid flowing holes solution; it also does not have an elastic element.

Constituent elements of each, previously discussed assemblies, from the constructional point of view, are also not too complicated. Their number, corresponding to the construction solution could be however significant. In the fig. 4, constituent parts of a one of dampers made by the Institute of the Machinery Design Fundamentals of Warsaw University of Technology, damper A-SiMR-MR-LD-203, have been illustrated.

The main constructional assembly of described MR shock absorber (Fig. 1 and 4) consists of: having circular cross-section guiding cylinder, suitable designed leak stopper of a piston rod with a cylinder's upper cover and a lover cover equipped with a valve for a gas supply and a fasten hole. Gas is supplied from outside by a compressor; thanks it, unbounded forming of an elastic characteristic of a damper is possible.

The fundamental element of the second damper's (Fig. 1a) assembly is a piston rod. On the one end of it, being outside the cylinder, fixing handle which fastens a shock absorber to the external device, is mounted. On the other end, placed inside the cylinder, representing separate assembly, complete piston of a shock absorber. Mostly, in drilled on the whole length of the piston rod hole, electric wires, which supply the current to placed, in the damper's piston, head are situated.

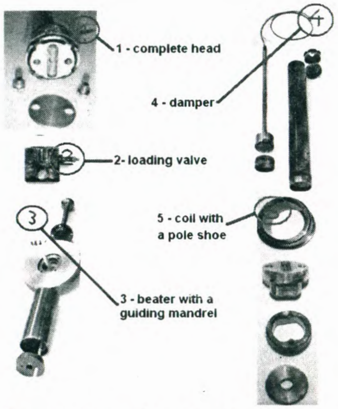

Fig. 4: Constituent elements of the A-SiMR-MR-LD-203 damper

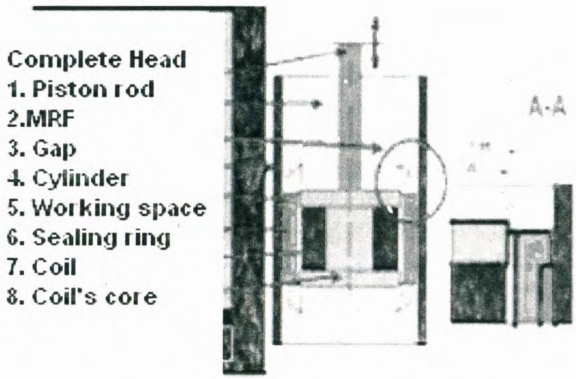

Fig. 5: Example of the constructional solution of MR damper's and shock absorber's piston

According to the MR damper, illustrated in Fig. 3 case, previously mentioned assembly has a piston rod which is symmetrically situated against the head of a shock absorber and doesn't have internal hole. In this kind of device, also a gas chamber and elements connected to it, such as gas valve, piston or membrane, do not exist.

The next discussed assembly is a piston (Fig. 1). In the shock absorber case, it has to be also the piston rod guiding element. Mostly used, typical solution of this constructional problem has been illustrated in Fig. 2b.

The main element of the piston is it's "heart", so head (Fig. 4 and 5), which consists of: placed on the suitable metal core solenoid; mounted by the piston rod cover, and fastened to the solenoid's core external metal ring of the head, witch placed on the external surface sealing ring (teflon). As was previously mentioned, presented constructional solution is mostly applied in shock absorbers construction. Due to use of a difference between internal diameter of the external ring enclosing head and external head and solenoid diameter, gap occurs, through which the flow of, filling the casing, MR fluid is possible.

According to the damper case, piston doesn't have to play the guiding role. Mostly, guiding is ensured in casing covers of devices. Thanks such a solution, to the fluid flow the space between internal casing diameter and external head diameter could be used (Fig. 2b and Fig. 3). Undoubtedly forming a MR fluid flowing gap problem could be solved in the multifarious way. Task, from the mechanical point of view, is extremely easy to solve. Very serious problems occur, when magnetic problems are taken into account.

3. MAIN PROBLEMS IN CONSTRUCTION AND TECHNOLOGY OF THE MR DAMPER

Described in section 2 of presented work, rules of construction and functioning of dampers or shock absorbers appear as from mechanical point of view, discussed device is unusually simple and the functioning rule is well known from the traditional solutions of shock absorbers and dampers. In point of fact, widely conducted experiments show how such a judgment could lead to wrong affirmations. It turns out that, in complex solutions of this type of devices, many different types of problems exist which haven't been solved in copasetic way even by the main companies designing such devices. Thereinafter matters connected to previously mentioned group of devices remain undeveloped. They could be divided into two groups:

- connected to determining of the optimal magnetorheological fluid,
- connected to selection of proper materials, especially for the core of solenoid, in a shock absorber case, external piston's ring, resistant on the high temperature insulation lacquer for a covering of the solenoid's wire, suitable steel for a casing etc.,
- matter connected to designing of fluid flow channel's shape, piston rod and frame of a solenoid sealing, current wires connections to the solenoid, holes execution on a length of the piston rod, gas chamber sealing etc.,
- connected to the set of problems concerning damper's or shock absorber's current steering.

3.1 Problem of MR fluid proper selection

Possibilities of choosing kind of the magnetorheological fluid for a construction of the MR device are very limited. Actually, at the world market, four kinds of a high quality MR fluids, which are used by Lord and Delphi companies producing MR dampers and shock absorbers, are available. Those are fluids having following signatures: *MRF-132AD* or *MRF-132LD, MRF-240BS* or *MRF-241ES, MRF-122-2ED* and *MR 100* Taken in many countries, also in Poland, probes of developing of own MR fluid composition aren't so far fruitful enough. Obtained properties of MR fluids could not be comparable with those previously mentioned. Closest to the indubitable success which would be developing of European MR fluid is the Frauhofer Institute in Wurtzburg. In this research unit, lately, on the basis of the engine oil, three different kinds of fluids (signatured: *AD 57, MRF ISC, AD 27*) have been developed. Their visco-plastic properties in the magnetic field and the reaction time could be comparable to the American ones. Still, the fundamental problem is how to overcome delamination and ageing of it's components. Developing of the MR fluid, having good visco-plastic features and at the same time fulfilling possibly large amount of exploitation demanding, is still an open problem.

3.2 Constructional materials selection, fluid flow channels forming, connections and sealing of wires and the piston rod

Selection of constructional materials properties of a MR damper or shock absorber, is a very complex task. It turns out, that although the shape of constituent elements is not so complicated, to the construction at least four different kinds of metal materials, with suitable bond and insulation properties, have to be applied.

The main element of previously mentioned devices is doubtless the casing of a damper or shock absorber. It is mostly a appropriate pipe having a circular cross-section area. Fact of what kind of material it is made of, is significant for a proper functioning of a device. This influence would be different for a different constructional solutions of a fluid flow through the piston's gaps.

In a shock absorber case, forcing through the MR fluid from the one part of a chamber to the other is realizing by a proper shaping of the piston's gap. They could be holes, directly drilled in a piston's part or a free space obtained as a result of a difference between external diameter of a piston and internal diameter of a ring which encloses the piston to which this external ring is fastened (welded in most cases). This part of a piston is always at the same time a core on which solenoid is mounted. Additional ring is made of plastics and is placed on the external diameter of a metal ring. It fulfills the sealing, and guidance of a piston and connected to it piston rod, roles. In this type of solutions, closure of the magnetic field occurs around the external ring or through holes, drilled in a core of a piston's head (carcass). In a constructional solution with holes, acting on a fluid magnetic field consists of many closing loops. In this case, the power of the magnetic field corresponding to previously discussed solution with a gap, is lower because a part of magnetic field's lines is closing directly in a steel. Therefore during designing of a piston's head process, ones should ensure that lines of a magnetic field should close in possibly large space. A simple treatment, in a constructional solution case with an external ring enclosing a core of a head with a solenoid is mounting it to the core using a brass for example.

Material the head's core is made of, on which a solenoid is put on, has also an important influence on the behavior of the MR fluid in a shock absorber. In steel with increased carbon case, effects of reactions are significantly reduced comparing to the identical elements made of low-carbon steel. Of course the most advantageous results are obtained in case when the core of a solenoid is made of ARMCO iron. Applying of this product of material engineering have a beneficial effect on the magnetic behavior of a shock absorber. The time of arising of the magnetic field shortens more than twice corresponding to for example case when a solenoid is made of St3 steel; this material also guarantee a practical lack of residual magnetism in the while of turning the current on.

Very important thing for the efficiency of a damper or a shock absorber acting is a size of the gap for a MR fluid flow. In the fig. 5, experimental results of influence of a gap size on absorption and dissipation of an energy, have been illustrated. Experiments focused on *SiMR A-MR-LD-206* showed that, the most efficient is a shock absorber whose gap size, measured on a radius is 0,5 mm. In increasing of this value to 1,5 mm case, the efficiency of a shock absorber decreases more than six times. When the gap size decreases to the 0,25 mm value, the stiffening of the shock absorber occurs and fluid flow from the one chamber to another is restricted, and steering process is noninspectable.

During designing of MR damper's or shock absorber's head process, very important thing is to provide a high quality insulation materials, which have to be applied for covering of the solenoid's muff wires supplying current. In such kind of solutions, the insulation lacquer should provide work possibilities of solenoid in the temperature range at least 200°C. Similar demanding are connected to the wire insulation security, providing current to the solenoid. It turns out, that from the technological point of view, this task is not so simple to realization. Difficult constructional element in the head is a precise connection of current wires with the end of solenoid's conductors. In the structure illustrated in fig. 4, this problem has been solved by applying miniature pin connections.

Akin constructional task is a suitable damage protection of solenoid. Depending on the constructional solution concerning the fluid flow, its external surface could be loaded by very large friction forces. Best protection in such situations could be applying the proper class, high-temperature resistant epoxide; after induration, adequate surfaces are treated by machining.

From the research point of view it is inconvenient when the sealing of wires, supplying a current to the solenoid, is "hard"; there isn't a possibility of another applying in the next version of the device. This problem is very important, because during working time, internal pressure causes floating of too weak resins, applied in previously discussed constructional node.

Another technological problem is drilling the hole, for conductors supplying current to the solenoid, in the piston rod. In small constructions case it is not a big problem; in constructions where piston rods are quite long, special gun drills have to be applied.

3.3 Controlling of the damper's properties problems

Problem of steering of a MR damper's and shock absorber's properties is a very complex task, which has to be solved in global constructional problems. The main aim in this group of acting is achievement of such current steering parameters, to minimize the time of arising of the magnetic field, ipso facto minimize the time of magnetorheological fluid feature's change. At the same time always, regardless of the MR fluid conditions, its instantaneous activation and immediate availability to the normal work conditions, have to be caused. Independently after work is finished, steering activities ought to provide possibly small value of the residual magnetism field. It turns out, that applying constant values of the current intensity causes changes of MR fluid properties, but it do not have to be optimal values. Achievement of the full MR fluid ability in the situation when even if a small delamination of it has occurred, for example when a device has stayed for a long time in a standstill, demands an activation in such a case. It could be realized in several ways, for example applying the current intensity. The state after work finishing is at the same importance and also demands careful steering activities. Always in such cases, residual magnetism of the device is observed. Such a state plays an important role especially when we have to deal with discontinuous work of a damper or shock absorber. In this situation the magnetic rest is difficult to estimation and increases after each part of the work.

Previously mentioned problems could be considerably minimized by such a design of steering changes of the direct current, in order to at the beginning of each work cycle, applying currents activating the MR fluid, steering impulses having the high intensity of a current, in the second phase, the value of the current intensity should be constant and in the third, again alternate impulses which demagnetize discussed system should occur. Presented in such a way steering of the MR device philosophy has been realized in the *MR-3002-1* controller of an American Lord company by using a suitable processor realizing described course of current changing. Although plenty of good experimental results have been achieved, especially concerning set of the *Rheonetic^{TM} MR Damper RD-1005-3* and *RD-3002-1* controller, they show that the demagnetization of a device is not the same, and after each cycle of the work its value is different.

4. CONCLUSION

Previously mentioned considerations connected to the construction and its manufacturing of smilingly simple devices, working on the basis of magnetorheological fluids, although in very simplified way, clearly shows, how big problems in achievement of the full success in this technical branch occur. Certainly they caused, that the development of MR fluids applying, after strong initial increase in 50's and 60's, have been stopped to rise again in splendid expansion of electronics, especially computer techniques and connected to it development of steering.

Although serious development of products, being on the basis of magnetorheological fluids, could be observed on the world market, still problems concerning this type of devices will be a passionate topic of researching works and experiments. Still products based on the previously mentioned working rule, due to lack of the competition on the market, will be very expensive.

5. REFERENCES

[1] ŁAWNICZAK, A. MILECKI; *Ciecze elektro i magnetoreologiczne oraz ich zastosowania w technice*, wyd. P.P., 1999,

[2] B. SAPIŃSKI, J. FILUŚ, *Analysis of parametric models of MR linear damper*,

[3] H. GAVIN, J. HAAGG, M. DOBOSSY; *Optimal design of MR Dampers,* U.S.-Japan Workshop on Smart Structures for Improved Seismic Performance in Urban Regions, 2001,

[4] BAJKOWSKI M., GRZESIKIEWICZ W. KNAP L. Etudes des amortisseurs magnetorheologiques. Cahier de Mécanique 1-03; -9^{-eme} Seminaire Franco-Polonais de Mecanique, Polytech'Lille, 2002.