ISSN 2229-5518

Research Trends in Controllable Fluids for Landing Gear Applications

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Abstract— Landing gears are an important element in an aircraft to facilitate safe takeoff and landing by protecting both passengers and aircraft structure. The efficiency of landing gear depends on the damping characteristics of shock absorber which will convert shock loads into heat energy. The landing gears are designed for a particular landing conditions. Any deviation in landing conditions will influence landing gear performance. In order to make to perform efficiently in the entire permissible landing conditions there is a need to develop a new class of landing gears which are adaptive to the landing conditions. The continual development of controllable fluid devices such as, electrorheological (ER) and magenetorheological (MR) shock absorbers will be one of the novel technologies leading to the development of smart landing gears. The present study brings out the research trends towards development of landing gears based on controllable fluids.

Index Terms— Aircraft landing gear, Electrorheological , Magnetorheological, semi-active damping, shock absorber, smart fluids, shock absorber, shimmy damper, adaptive impact absorption

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1 Introduction

Aircraft landing gears are intended to support the craft while at rest, taxiing, take-off and landing without any damage to the craft or passengers. Present day landing gears are built in various configurations, sizes and designs. How ever all landing gears are aimed to meet the stringent requirements of the flight regulations and competitive requirements. Various designs schemes are illustrated in [1],[2],[3]. During take-off and landing, an aircraft landing gear and parts of an airframe will experience high dynamic loading. In extreme conditions even damages and loss of the stability of an airplane may be expected. To have a safe touchdown while landing, the airframe load factors should be kept in the prescribed range [4],[5]. Many accidents have occurred due to failures of landing gear. Though there were may reasons for this, designers are always concerned about the development of landing gears to achieve best performance. To achieve the same various research activities are initiated. Though no unique solution exists at present, development of shock absorber based on controllable fluids, such as electrorheological (ER) and magnetorheological (MR) are exhibiting promising results for many problems of landing gear and associated systems. There are may forms of landing gears available in the market starting from, spring, rubber, air, liquid spring, oleo-pneumatic. In military and commercial aircraft where efficiency is the highest priority, only the oleo pneumatic shock absorbers are used. This shock absorber type has the highest efficiency and best energy dissipation. Its role is to limit the impact loads by transmitting the lowest and most bearable acceleration level to the aircraft structure and passengers. An oleo-pneumatic shock absorber absorbs energy by "pushing" a volume of hydraulic fluid against a volume of gas (nitrogen or dry air) and compressing it.

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Oleo-pneumatic shock absorbers carry out two functions: (i) a spring or stiffness function, which provides the elastic suspension by the compression of a gas volume and (ii) a damping function, which dissipates energy by forcing hydraulic fluid through one or more small orifices.

Industries engaed in the supply of landing gear are continuing to extend their efforts to introduce more sensors and monitoring devices in to the landing gear system to assess the health condition and also to have an insight view of operational life of the system. Further research is extended to consider the possibility of introduction of controlled landing gears into airplanes. Military companies were also interested in introduction of controlled landing gears inito their aircraft. The most basic motivation for military purposes were obtaining a more versatile device, which would be capable of landing onpartly destroyed or repaired landing fields and introduce less loads into the aircraft structure. Various schemes and ideas were developed to achieve the desired goals. At present it is understood that the use of controlled fluids in place of hydraulic fluids and controlling them either electrically or magnetically will be a potential solution. In consideration to this the potential benefits of controlled fluids are studied to utilize them in the development of landing gear.

2 Introduction to Controllable Fluids

2.1 Smart materials

Smart fluids, including electro-rheological (ER), Magnetorheological (MR) fluids and Magnetorheological grease (MRG) are special suspensions which consists of large amounts of solid particles dispersed in a carrier fluid. When subjected to a strong electric or magnetic field, the flow properties of these liquids can be changed and the process is reversible. Due to the fast response of the fluids smart fluids have attracted greater attention of researchers and engineers since their invention. The use of smart materials in the development of var-

ISSN 2229-5518

ious devices for landing gear application was already investigated. The advantages of these materials are discussed in subsequent sections.

2.2 ER Fluids

About sixty years ago, in the 1940s, W.Wuski was discovered the Electro-rheological fluid (ERF). ER fluids experience a significant change in their magnetic, electric, thermal, acoustical and optical properties upon exposure to an electric field. The most important change, however, takes place in their microstructure and with that in their rheological behavior: the resistance to flow increases with increasing electic field. The change in the structure and rheological properties of a liquid under the application of external electric field is called the ER effect as shown in Figure. 1. The liquid or the dispersed system is generally called an ER fluid.

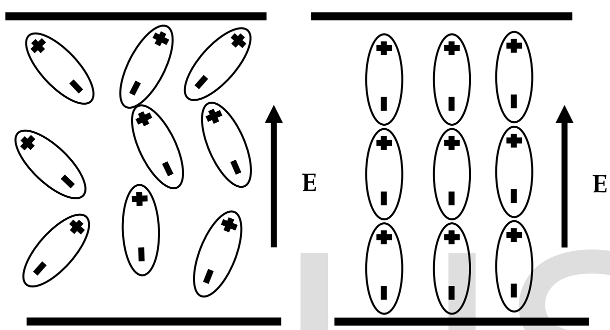

Fig. 1. Change in structure under electrical field-ER effect

ER fluids that have solidified under influence of electric field will flow back again by removing the electric field or by applying a shear stress that exceeds a certain critical value also called as yield stress. Table 1 shows some of the important values of ER fluid.

TABLE 1
Typical properties of ER fluid

Maximum Yield Stress τ	2-5 $[kPa]$
Maximum Field Strength E	4 $[kV/mm]$ (Limited by breakdown)
Viscosity η	0.1-1.0 $[Pa.s]$
Operable Temp. Range:	+10 $[^oC]$ to +90 $[^oC]$ (ionic,DC) -25 $[^oC]$ to +125 $[^oC]$ (non-ionic, AC)
Stability	Cannot tolerate impurities
Response Time	$<$ a few milliseconds
Density	1-2 $[g/cm^3]$
Active Volume Figure of Merit (η_p/τ_y^2)	$10^{-7} - 10^{-8}$ $[s/Pa]$
Maximum Energy Density	10^1 $[J/m^3]$
Power Supply	2-5 $[kV]$ at 1-10 $[mA]$ $(2-50[W])$

ER fluids are not available as large scale commercial devices due to its low yield stress.

2.3 MR Fluids

MR fluids(MRF) are also developed parallel at the same time of ER fluids. The discovery and development of MR fluids and devices can be credited to Jacob Rabinow at the US National the late 1940s. Similar to ER fluids, MR fluids exhibits change in properties under the magnetic field. The magnetorheological response of MR fluids results from the polarization induced in the suspended particles by application of external field. The interaction between the resulting induced dipoles causes the particles to form columnar structures, parallel to applied field. The chain like structures restrict the motion of the fluid, thereby increasing the viscous characteristics of the suspension. The MR effect is shown under the influence of magnetic field in figure 2.

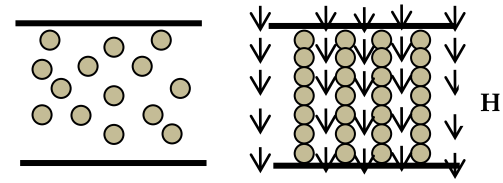

Fig. 2. Change in structure under electrical field-MR effect

The mechanical energy needed to yield these chain-like structures increases as the applied field increases resulting in field dependent yield stress. In the absence of an applied field, MR fluids exhibit Newtonian-like behavior. Table 2 shows some of the important properties of MR fluid.

TABLE 2
Typical properties of MR fluid

Maximum Yield Stress τ	10-100 $[kPa]$
Maximum Field Strength H	250 $[kA/m]$ (Limited by saturation)
Base Viscosity η	0.3 $[Pa.s]$
Operable Temp. Range	-40 $[^oC]$ to +150 $[^oC]$
Stability	Unaffected by most impurities
Response Time	$<$ a few milliseconds
Density	3-4 $[g/cm^3]$
Active Volume Figure of Merit (η_p/τ_y^2)	$10^{-10} - 10^{-11}$ $[s/Pa]$
Maximum Energy Density	10^3 $[J/m^3]$
Power Supply	2-25 $[V]$ at 1-2 $[A]$ $(2-50[W])$

Considerable progress has been made in the development of MR fluid based devices in comparision to ER fluid. This is due to the achievement of high yield stress with small voltages. As the voltage and current requirement are very small with less power consumption, MR fluid finds many areas of application.

2.4 MR Grease

Magnetorheological grease (MRG) has been developed to overcome the settling of ferro particles in both ER/MR fluids. Due to settling, the performance of devices will degrade over a a period and not suitable for devices used for long term application, such as aircraft landing gears. The synthesis and magneto mechanical properties of MR grease are brought out in [7]. The MR characteristics of MRG are similar to MRF. Some of the properties of MRG are tabulated in table 3.

TABLE 3
Typical Values of MRG fluid

Max. Yield Strength, τ_y	50-80kPa
Maximum field	Tested up to 1.2 T
Plastic viscosity, η	5-90Pa s
Operable Temp range	-65^o-170^{o}C
Response time	< milliseconds
Density	3-4 g/cm^3

The development of MRG based devices are in initial stage and much efforts are needed in developing and evaluation of the MRG based devices.

2.5 MRF - Operation modes

The modes of operation of MR fluid devices are flow mode (fixed plate mode, valve mode), shear mode (clutch mode), squeeze mode (compression mode)and any combination of these three as illustred in [8]. Diagrams of the three basic modes of operation are shown in Figure 3. In flow mode, MR fluid is made to flow between static plates by a pressure drop, and the flow resistance can be controlled by the magnetic field which runs normal to the flow direction. The flow mode is used in devices such as servo valves, dampers, shock absorbers and actuators. In the shear mode MR fluid is located between surfaces moving (sliding or rotating) in relation to each other with the magnetic field flowing perpendicularly to the direction of motion of these shear surfaces. The characteristic of shear stress versus shear rate can be controlled by the magnetic field. Clutches, brakes, chucking and locking devices, dampers and structural composites works on the shear mode principle. In squeeze mode, the distance between the parallel pole plates changes, which causes a squeeze flow. In this mode relatively high forces can be achieved and the mode is suitable for damping of vibrations with low amplitudes and high dynamic forces.

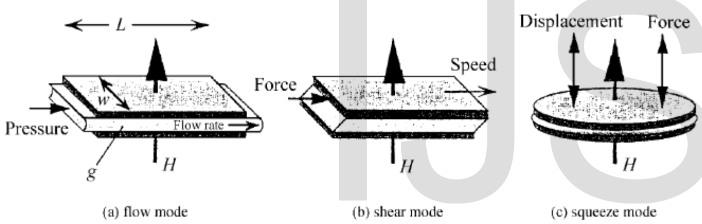

Fig. 3. Basic modes of operation of MR fluid devices

3 MR FLUID DEVICES

Many MRF devices are developed for varied field of applications. In automobile industry the MR shock absorbers are introduced to improve the ride quality. A semi active conrol of car suspension with MR damper was demonstrated [9]. Delphi corporation already markeing the magnetorheological damper under the brand name “MagneRide”[10]. Vibration control of passenger seats using MR fluid damper is one the research topic. Many research articles are publiched on the above topic.   In civil engineering, the seismic control of large buildings and bridges make use of MR fluid dampers.

In mechanical industry[11], MR dampers, clutches, brakes, polishing devices and hydraulic valves etc. are being developed and commercialized. Efforts are still continuing to imporove the systems and design new devices.

In consumer goods, the MR damper is used in washing machines for vibration control and MRF clutch in exercise machines.
Research is also extended to military equipments such as dampers heavy guns, shock absorbers in military vehicles. Recent trend towards the application of aerospace industry, specifically in aircraft landing gear dampers, shimmy controls and lead-lag dampers in helicopters. The study focus on the research initiatives on the development of MR fluid based landing gears.

4 MR LANDING GEARS

MR landing gears comprise more or less same modules in comparision to conventional oleo-pneumatic landing gear. The change being in the design of shock strut. In place of oil flow the MR fluid will flow in a controlled way to obtain maximum efficiency. Studies revealed that 11.8% in load reduction was achieved as a result of MRF use in shock absorber[12]. Many research articles are appearing with different titles such as semi active control of landing gear, Improved impact absorption of landing gear, Active control of landing gear etc. Some of the research carried out are discussed in subsequent paragraphs.

5 MR LANDING GEAR DEVELOPMENT

Magnetorheological landing gear design and validation has been carried out by many institutes and organizations. One among them is ADLAND [13]. The design methodology for MR landing gear shock strut illustrated in [14]. The design methodology aimed at packaging, optimizing magnetic design and to produce desirable behavior for wide range of impact conditions unlike passive device. A 2DOF simulation study e performed to simulate the exact drop test facility. A widely adjustabale valve control ratio resulted in damping levels to accommodate large range impact conditions. The study helped to demonstrate the feasibility of an MR landing gear. The manufacture and testing was illustred in the studies made by the same group [15]. It is emphasized that to validate the design, a quasi-steady MR valve function must be formulated analytically, without the need to update the yield stress and viscosity parameters. The study is performed at low velocities. There is a need to carryout the same with higher velocities.

Landing gears are also designed for improved impact absorption [16]. Two technologies (piezoelectric and magnetorheological fluid)for adaptive landing gear have been investigaeted. The piezoelectric valve can control the shock force and adapt the stiffness of the shock absorber depending on several landing conditions. Scaling is required for developing the bigger shock absorber for large aircrafts.

Several numerical simulation studies for predicting the performance and control issues are studied [17]. Many prototypes are developed and validated for performance test byusing drop tests [18]. Dynamic loads and vibrations resulting from runway and taxiway unevenness are serious concern for fatigue life. The experimental investigation reveals the feasibility of reducing loads by using active control gear. Such gear is effective in reducing the loads transmitted to the airframe. A non flying prototype of semi-active landing gear built by MR fluid shosck absorber for a general aviation airfraft was tested for performance [19]. The results revealed that proper control, the ground loads can be significantly reduced. Similar drop test studies were also carried by Zhu et.al[20]. The studies served to understand the MRF damper for aircraft landing gear application.

There are many studies carried out by academia and industries for the development of MRF based landing gear. Still it is not evident that any real usage of the MRF landing gear in commercial application. This is due to stringent reliability and certification issues. However the research will soon realize the product in commercial market.

4 Conclusion

The study gave an insight in to the benefits of MRF based landing gear development activities and the importance of research for further improvement. This will help the researchers to design, develop and evaluate the “Adaptive Landing Gear “ or “Smart Landing Gear”.

Acknowledgment

The authors are indebted to Shri P Srikkumar, Outstanding Scientist and Director, ADE for his continued guidance, support and according permission for publishing paper. We record our grateful thanks to Dr ACR Pillai, Group Director, ADE and KG Rammanohar, Group Director for their unstinted support and guidance.

References

[1] Daniel P Raymer, *Aircraft Design: A Conceptual Approach*, 2nd Edn, AIAA Education series, pp. 229-252, 1992.

[2] Jan Roskam, *Part-IV Layout Design of Landing Gear and Systems*, Roskam Aviation and Engineering Coorporation, pp 1-123, 1985.

[3] Norman S Curry, *Aircraft Landing Gear Design: Principles and Practices*, AIAA, Education series Edition, 1988.

[4] Joint Aviation Requirements, JAR-25, Large Aeroplanes, 1996

[5] Lomax T L, *Structural Loads Analysis for Commercial Transport Aircraft: Theory and Practice*, AIAA, Educational series edition, 1996.

[6] Rutten, S.H.L.A, Smart Materials in Automotive Applications – How to improve vehicle crashworthiness by incorporating smart materials. Report, Eindhoven University of Technology, Department of Mechanical Engineering, June 2003

[7] M. Hari Prasad, K V Gangadharan,”Synthesis and Magneto Mechanical Properties of MR Grease”,International Journal of Engineering Research & Technology(IJERT), Vol 3 Issue 5, May 2014.

[8] Bolter, R. and Janocha, H. Design rules for MR fuid actuators in different working modes. In Proceedings of theSPIE Conference of the International Society for Optical Engineers (Ed. L. P. Davis), 1997, Vol. 3045, pp. 148–159(SPIE, Washington).

[9] H.F.Lam, C.Y.Lui and W.H.Liao, “Automobile Suspension systems with MR Dampers”, Dept of Mechanical Engg, The Chinese University, Hong Kong.

[10] www.formula1-directory.net/damper_magnetorheological.html

[11] J Wang and G Meng, “ Magnetorheologial fluid devices:Principles,l characteristics and applications in mechanical engineering”, pp165-174 , Proc Instn Mech Engrs Vol 215 Part L

[12] Zhingniew Skorupka, “Magnetorelogical fluids as method for active controlling of landing gear shock absorber characteristic”, Transaction of the Institute of Aviation No.207,Warszwa.

[13] Adaptive Landing Gears for Improved Impact absorptioin (ADLAND), Project No.IST-FP6-2002-Aero 1-502793-STREP, EU Research project.

[14] D C Batteerbee, N D Sims, R Stanway and Zbigniew Wolejsza, “Magnetorheological Landing Gear, Part 1: Design Methodology”, Dept of Mech. Engg,, The University of Sheffield, Sheffield, S1 3JD, UK

[15] D C Batteerbee, N D Sims, R Stanway and Zbigniew Wolejsza, “Magnetorheological Landing Gear, Part 2: Validation using Experimental Data”, Dept of Mech. Engg,, The University of Sheffield, Sheffield, S1 3JD, UK

[16] G. Mikulowski, “Advaned Landing Gears for Improved Impact Absorption”, 11th International Conference on New Actuators, Bremen,Germany, 8-11 June 2008.

[17] Gian Luca Ghiringhelli, Stefania Gualdi, “Evaluation of Landing gear semi-active control system for complete aircraft landing”.

[18] William E Howell, et. al, “F-106B Airplane Active Control landing Gear Drop Test Performance”, NASA Technical Memorandum 102741, 1990.

[19] Gian Luca Ghiringhelli, “testing of a semi-active landing gear control for a general aviation aircraft”, Poloitechnico di Miland, Italy.

[20] Zhu et.al, “Experimental Research on Aircraft Landing Gear Drop Test Based on MRF Damper”, Procedia Engineering 15(2011)4712-4717.