TRANSACTIONS OF THE INSTITUTE OF AVIATION ISSN 0509-6669
No. 4 (245), pp. 189-198, Warsaw 2016 eISSN 2300-5408
DOI: 10.5604/05096669.1226888

IMPLEMENTATION OF MAGNETORHEOLOGICAL ELASTOMERS IN TRANSPORT

Paweł Skalski*, Klaudia Kalita**

* Zakład Transportu, Pion Transportu i Konwersji Energii, Instytut Lotnictwa, Al. Krakowska 110/114, 02-256 Warsaw, Poland
**Wydział Budowy Maszyn i Lotnictwa, Politechnika Rzeszowska imienia Ignacego Łukasiewicza, Al. Powstańców Warszawy 8, 35-959 Rzeszów, Poland
pawel.skalski@ilot.edu.pl, klaud14@gmail.com

Abstract

In the paper the comprehensive review of the research and development done on different potential applications of the magnetorheological elastomers in the automotive and aviation sector is presented. In the introduction part the magnetorheological materials are characterized. The composition of magnetorheological elastomers is described. Also, the magnetorheological fluids are mentioned. In the next part of this document the applications of the magnetorheological elastomers in the automotive sector are showed. The car suspension, the adaptive system of energy absorption, the releasable fasting system, the vibration reduction system of the car's drive shaft, the linear rod active hood lift mechanism are depicted. In the automotive industry, the new solution involving magnetorheological elastomer is described based on the Polish patent proposal.
Keywords: magnetorheological elastomers, transport, automotive, aviation, applications.

1. INTRODUCTION

With constantly increasing requirements towards modern devices and machines, especially aerial and automotive constructions, their production is becoming more difficult with the use of standard materials. The industry is still in need of new materials which will enable more advanced construction of (various) means of transport. Implementation of magnetorheological materials can increase efficiency and reliability of some systems, even allow designing systems which were never implemented in older generations of cars or aircraft.

The magnetorheological (MR) materials belong to a group of smart materials due to their rheological properties that are susceptible to a present magnetic field. The first magnetic materials were developed in 1948 by Rabinov – magnetorheological fluids. Currently, the following types of magnetorheological materials can be distinguished: MR fluids (MRF), MR foam, MR gel, MR paste, MR elastomer (MRE) [1÷3].

MRFs are stabilized dispersions of magnetic particles inside of a liquid, dispersive environment, best if it has a significant viscosity. When subjected to a magnetic field, the viscosity of the fluid changes, allowing it to reach a quasi-solid state. Due to the possibility of quick changes of the rheological properties in the magnetic field, MRFs have already been implemented in the automotive industry, for instance, LORD company has introduced brakes, clutches and dampers with controlled characteristics into the market. LORD is the leader in the MR fluid industry, with MR fluids that have properties of a very high quality, thanks to years of research done on them.

MR elastomers are constant MRF analogies and they can be the solution to some of the MRFs inconveniences, such as sedimentation. MR elastomers are composites in which the magnetic particles are scattered (dispersed) inside the elastomer matrix. Usually very soft elastomers, such as masticated rubbers or soft polyurethanes are used as the polymer matrix. In the majority, their volume consists of up to 30% magnetic particles (carbon iron particles), which is the cause of the significant deterioration of their mechanical properties – in the case of silicone elastomers the mechanical properties are already impaired. MREs based on soft silicone and polyurethanes have a considerable magnetic efficiency, however, it is achieved at poor mechanical properties. This prevents them from being used as real engineering solutions [3].

In order to get composites with good mechanical properties, work is being conducted on MRE composites based on retreading natural (India) rubbers. These composites are also filled with a great amount of magnetic particles, up to 50% volumetrically. In the case of composites based on natural rubber, a large volume of magnetic molecules does not cause a rapid decrease of their mechanical properties. Such materials are suitable for engineering solutions, such as building smart vibro isolators or objects of variable shape structure (morphing structures) used in aeronautical engineering. Morphing structures enable the change of aerodynamic properties of the wing and steering surfaces during flight, increasing the flight efficiency [4].

MR Elastomers are used not only in the aviation industry, but also in the car industry. Work is being conducted in FORD and General Motors. Due to the constantly increasing popularity of magnetorheological elastomers, the authors of the work have made a review of potential and already existing implementations of MRE in transport, taking into account the automotive and aviation industry. The paper identifies the challenges in this research area. In order to recognize the difficulties encountered in this field, this paper presents a timely state-of-the-art review of MRE in transport applications. The paper will summarize and comment on developments and applications of creative designs of MR elastomer devices to date and then discuss the challenges and opportunities to be addressed for future research in this area.

2. MR ELASTOMERS IN THE AUTOMOTIVE INDUSTRY

Magnetorheological elastomers have a big potential which can be used in the motorization industry. One of the solutions which includes MR elastomer is a patent [5] owned by Ford Motor Company, concerning the regulation of the suspension elements stiffness by implementing a sleeve with adjustable rigidity. In this solution, the magnetorheological elastomer is placed in between two sleeves: the one located inside is connected with the moving parts of the suspension, and the one on the outside is connected with the bodywork. An additional part of the system is a coil located in between the composite and the inside cylinder. The rigidity of the magnetorheological composite is regulated with the coil in which the magnetic field is induced. This solution can reduce the oversteer and understeer of a vehicle and can reduce the noise generated by the vibrations of a car body. The perspective view of a front suspension of a front wheel drive motor vehicle incorporating a variable stiffness busing in accordance with the present invention [5] is shown in fig. 1. The front wheel drive suspension includes a substantially transverse suspension member (10) and a lower control arm assembly interconnecting a wheel support member (14) to a chassis member (16). The longitudinal suspension member (12) is oriented substantially parallel to a longitudinal axis of the motor vehicle, which generally coincides with the center line of the vehicle front to rear. The chassis member (16) may include a subframe structure mounted on a unibody or it may simply be a component of the unibody structure. Additionally, chassis member 16 could also be a portion of the frame of a vehicle having a body on frame style structure [5].

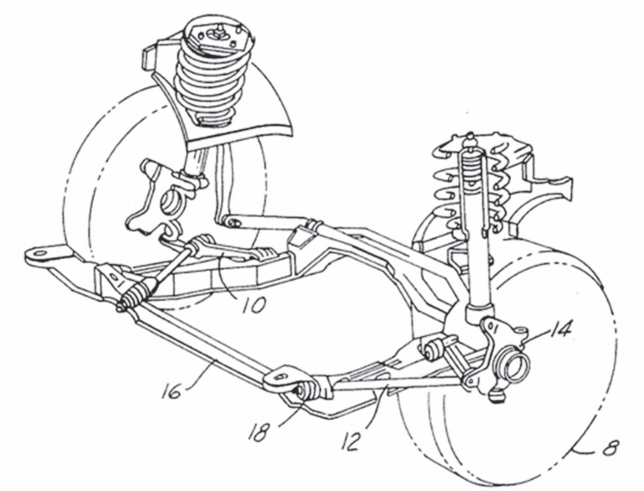

Fig. 1. Perspective view of a front suspension of a front wheel drive motor vehicle incorporating a variable stiffness bushing in accordance with the present invention [5]

A similar solution was used to eliminate the vibrations of brake discs [6]. The previously described element consisting of the two cylinders' discs with a layer of magnetorheological elastomer in between them was used in this method. Rigidity of the composite changes as the electric current going through the coil (which is reeled around the layer of elastomer) varies. The current value is set by the control system based on the data received from the sensor in the braking system.

A method of fast regulation of the physical properties of the elastomer elements in cars can be found in literature available on this topic [7]. In traditional solutions the elastomer parts, such as, sleeves in the suspension, parts of the engine fastening, the propulsion transfer system and exhaust system have unchangeable physical properties. By replacing them with magneto-rheological elastomer and adding a control system, it is possible to vary their rigidity, and therefore to adjust the level of noise and vibration, moreover to eliminate dipping of the car during braking, oversteer and understeer.

Thyssen Krupp AG company has developed a steering wheel column with an adaptive system of energy absorption in case of a crash, in which magnetorheological elastomer is applied to one of the elements [8]. This solution differs from the previous one which has a metal element responsible for energy absorption. Due to the implementation of MRE, the new solution accommodates factors such as the vehicle's velocity and driver's mass.

General Motors has developed a system which absorbs energy during a crash [9]. It can be installed inside headrests, seats, the dashboard, doors or over driver's and passengers' heads. This patented solution is composed of a rigid base and an elastic cover. In between them are the cylindrical elements made of magnetorheological elastomer with the coil reeled on them. The whole system is equipped with sensors and a control system. Fig. 2 illustrates the reversibly expandable energy absorbing assembly in a pre-deployed, i.e. a stowed or original configuration. An exemplary reversibly expandable energy absorbing assembly, generally indicated as (10), utilizing actively controlled and engineered materials comprises a flexible covering (12) attached to a rigid support structure 14 [9].

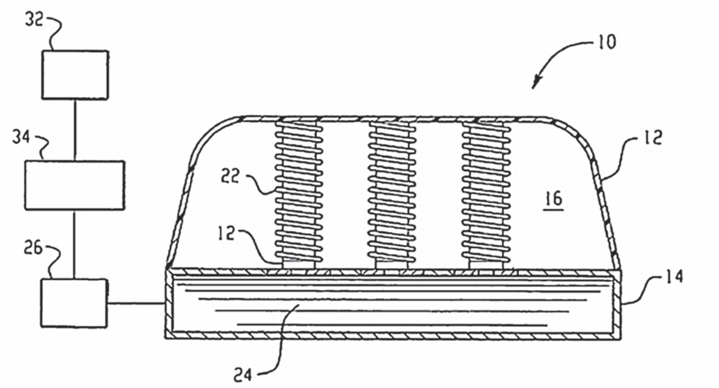

Fig. 2. A schematic illustrating an energy absorbing assembly in a stowed or pre-deployed configuration in accordance with the present disclosure [9]

Automotive companies have patented solutions which can have applications not only in the motorization industry, but in others as well. For instance, GM has developed a system of magnetically dissociable [hooks/detents/grips] which contains MR elastomer in its conformation [10]. This particular system can be used for vibration elimination.

Detents, which are opened and closed with the use of a magnetic field, were used to develop an entire system of separable securing of the various components of the car, for example closing the trunk lid or doors [10]. The proposed solution makes closing and opening of the lid easier, as well as absorbs more energy in the case of an accident than the traditional single-point locks. As shown in fig. 3 a releasable fastener system, generally indicated as (10), comprises a loop portion (12) and a hook portion (14). The loop portion (12) includes a support (16) and a loop material (18) disposed on one side thereof whereas the look portion (14) includes a support (20) and a plurality of closely spaced upstanding hook elements (22) extending from one side thereof. The hook elements (22) are formed of a magnetorheological elastomer that provides a shape changing and/or flexural modulus capability to the hook elements (22). More the description can be find in [10].

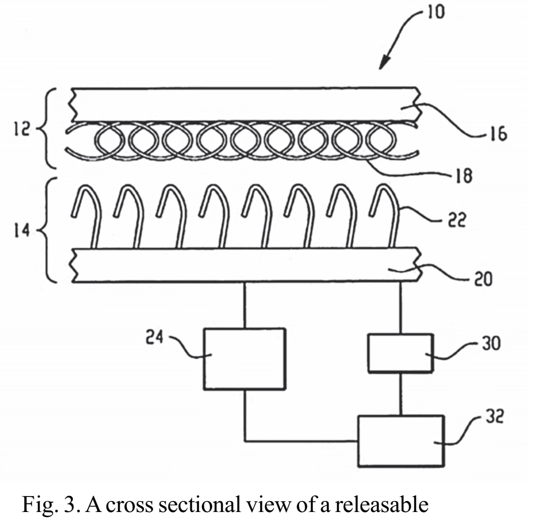

Fig. 3. A cross sectional view of a releasable fasting system [10]

Another embodiment of magnetorheological elastomers in the automotive industry is the vibration reduction system of the car's drive shaft [11]. In this solution, the damper limiting the transmission of vibrations from the drive shaft to the body is attached to the articulated joint. It is composed of two rings - external and internal, between which a ring made of magnetorheological elastomer is placed. The magnetic field that changes its rigidity is obtained by the use of screws made of a paramagnetic material. The change in the strength of the magnetic field induced in the magnetorheological elastomer is caused by the tightening or loosening of bolts, so as to adjust the damping to the natural frequency of the drive shaft. As shown in fig. 4, the driveshaft (12) is connected to a slip (16), preferably the driveshaft (12) is welded to the slip yoke assembly (16). Alternatively other suitable means may be employed to connect the slip yoke assembly (16) to the driveshaft (12). The slip yoke assembly (16) is conventional in the art and includes a yoke (18) and a universal cross joint (20). The yoke (18) is typically connected to a tubular end (17) that is attached to an engine shaft (not shown) [11].

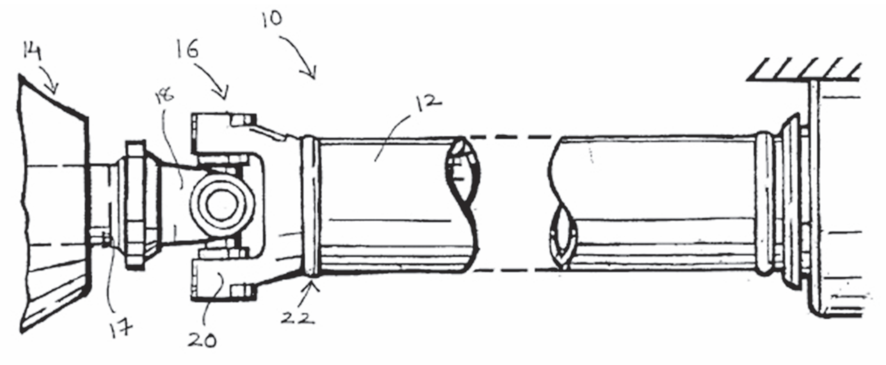

Fig. 4. A side view of the driveline assembly in accordance with the teachings of the present invention [11]

Adaptive vibration dampers are built with the use of magnetorheological elastomer [12]. The proposed device may be an intermediary solution between the dampers tuned to only a specific frequency and active damping systems, which, depending on the force, can provide power to the system. The response of the adaptive damper with magnetorheological elastomer can be adjusted in real time to the entering signal, so that it can find wider applicability than a device with constant characteristics, while maintaining a low price.

In the automotive industry, magnetorheological elastomers are used in the construction of engine covers or boots, for instance [13]. In the proposed solution developed by General Motors Corporation and the University of Michigan, the cover, which in normal operation is close to the engine or luggage, deforms in the instance of a crash in such a way that it increases energy absorption. Fig. 5 depicts an exemplary linear rod active hood lift mechanism (10) in the rest and lift positions. The hood (12) comprises a rotating pivot point (14) at one end. Pivot point (14) provides a means of attachment for hood (12) to a vehicle body (not shown). A lifting rod (24) is disposed on hood (12) on an end opposite to pivot point (14). An active material (18) is disposed on lifting rod (24). Connector (22) is coupled to and in operative communication with active material (18) on an end opposite to lifting rod (24). Connector (22) provides a means of attachment for active material (18) to an activation device (not shown), which is at a fixed location. A clearance distance (20) is defined as a distance between hood (12) and an under hood rigid body component (16), e.g. and engine. In the rest position, clearance distance (20) is at a minimum [13].

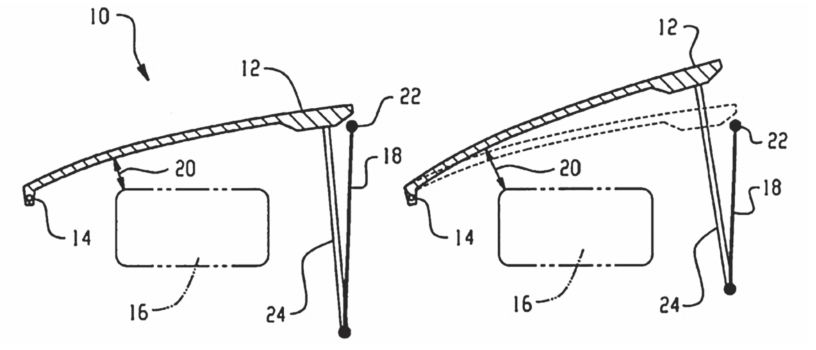

Fig. 5. A schematic representation of a cross-section of a linear rod active hood lift mechanismin rest and lift positions [13]

The solutions mentioned above are in the prototype phase, and some of them have already been implemented for specific applications.

3. MR ELASTOMERS IN THE AVIATION INDUSTRY

Aviation is an industrial branch where the newest and most modern materials and technologies are used. Using smart structures without a doubt benefits this industry. Increased passenger and crew comfort by reduction of vibrations and noise, an increasing amount of structural systems and elements of life, improvement of precise indication and uncovering of infrared and electro-optical sensors on airplanes, are the benefits of using intelligent structures, among other things. Structures containing smart materials are expected to monitor the state of the construction, detect any kind of damage, and be self-repairing. More information about such structures and materials can be found in papers [2, 4].

Composite materials presently have a wide range of applications. They offer much better benefits comparable to metal alloys, such as reduced weight, increased strength and improved corrosion resistance. However, composite materials react differently to stress and vibrations. Cracking of a metal component is gradual and predictable, while composite materials suffer significant impairment, as a result of accidental damage of an unforeseen and accidental nature. The solution to this problem could be the magnetorheological elastomer composite, due to its flexible nature and properties that are controlled by an applied magnetic field.

Fig. 6. F-14 Tomcat (www.airforce-technology.com)

Observation of the flight of birds has contributed to the creation of morphing technology. In aviation, morphing refers to the continuous change of shape, structural elements moving relatively to each other, and the whole structure deforming as a whole. For example, an aircraft wing can change its surface and convexity by morphing. This avoids gaps in the wing and sudden changes in the cross-section, which can cause significant aerodynamic losses, noise and vibrations in the aircraft. Breaking the sound barrier made engineers work on new wing forms. Changing the design of some plane parts in order to work properly in new conditions is very important because it concerns every flight phase. The aircraft F-14 Tomcat is a good example of adaptive wings (fig. 6).

Nowadays, two morphing technology types are considered: discrete morphing, like flaps or retractable landing gear, which are mature technologies, and 'continuous morphing', which is a single system that can provide multiple functions i.e. take-off, landing cruise [14], [15], in a continuous motion [16].

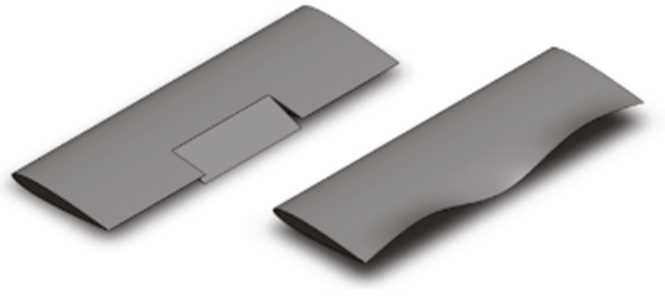

Fig. 7. Discrete (left) and continuous (right) wing changes

Showed in Fig. 7 a discrete and a continuous morphing technologies have been increasingly evolving during the last decades. Numerous projects are ongoing research. Elastic skins are frequently used as the layer covering the morphing structure. The intelligent layer should „feel" what is happening in the environment (collect information about the pressure, velocity, density or temperature changes) [4, 15].

A key challenge in the creation of morphing structures is to provide an appropriate smart skin, defined as a continuous layer of material, which extends over the morphing structure, forming a smooth surface. Magnetorheological elastomer, based on natural rubber, may be used as such a skin. Research is being done on the content of carbonyl iron particles, which are responsible for changing the rheology of the material in the presence of an external magnetic field. The first tests have shown that the properties of the material can be controlled by varying the external magnetic field (0÷0.5 T). The process is completely reversible and the magnetorheological material bodes well in constructional solutions made of morphing structures. Fig. 8 shows the new magnetorheological elastomer destined for use in aviation structures [4].

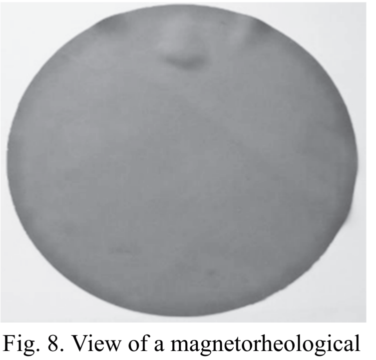

Fig. 8. View of a magnetorheological skin [4]

In the reported Polish patent proposal [17] an airfoil with a variable shape was described. It has an elastic coating made from an active material (magnetorheological elastomer) allowing to change the aerodynamic characteristics of an aircraft wing or a rotary blade during flight. In this solution [16] presented in fig. 9, a thin layer of magnetorheological elastomer (2) was placed on the upper side of the reversed wing (3). Magnets (1) were placed underneath this surface (12) in order to generate a strong magnetic field approximately 0.5 T that would attract the MR elastomer (2) and therefore change the overall profile of the wing. One end of the MR elastomer (2) is connected to a shaft (4), second end is fixed to the wing (3). A special mechanism (8) moves and controls the thin layer of magnetorheological elastomer in this structure [17].

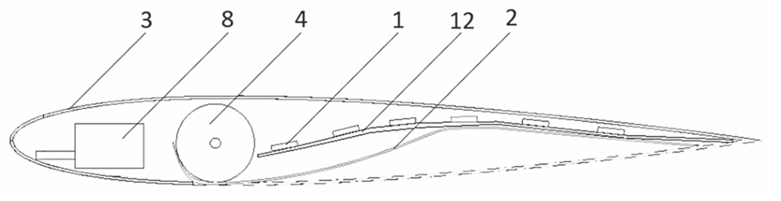

Fig. 9. A schematic view of the morphing structure with a magnetorheological elastomer [17]

Investigations of such a structure are performed in the Institute of Aviation. More information and results coming from experiments will be published.

4. CONCLUSIONS

To sum up, the comprehensive review of the research and development done on different potential applications of MR elastomer in the automotive and aviation sector was presented, has been successfully completed. Magnetorheological elastomers, belonging to the magnetorheological material family, is a composite material with magnetic-sensitive particles suspended or arranged within a non-magnetic elastomer matrix. Properties of the magnetorheological elastomer can be controlled by a magnetic field. Many magnetorheological materials have been invented over 30 years ago, but their development over the last few decades enables them to many different applications. Compared with magnetorheological fluids, magnetorheological elastomers overcome the applications problems, such as deposition, sealing issues and environmental contamination, etc. which makes the magnetorheological elastomer a favorable candidate for various vibration control applications. Due to their ability of dampening vibrations in the presence of a controlled magnetic field, have great potential application in transport. New solutions which regard implementing magnetorheological elastomer for automotive applications are constantly being patented, for example, the car suspension, the adaptive system of energy absorption, the releasable fasting system, the vibration reduction system of the car's drive shaft, the linear rod active hood lift mechanism.

In the aerospace industry magnetorheological elastomers are desirable for use in morphing structures. Morphing in aerospace applications is becoming more and more popular due to the possibility of increasing the productivity and efficiency of flight. With the magnetorheological elastomers, the development of new aircraft smart structures controlled by a magnetic field becomes possible. The main challenge for the next years and decades will be to adapt – at the industrial level – developments made in laboratories, like new structures with more flexibility and ability to distort in a controlled way.

Magnetorheological elastomers may also find use in innovatory elastic dampers with variable characteristics, or in the shipbuilding industry as a magnetic ballast.

BIBLIOGRAPHY

[1] Skorupka Z., 2010, "Magnetorheological fluids as method for active controlling of landing gear shock absorber characteristic", Transactions of the Institute of Aviation, No 207, pp. 36-48.

[2] Akhras G., 2000, "Smart Materials and Smart Systems for the Future", Canadian Military Journal, Autumn, pp. 25-32.

[3] Kaleta J., 2013, *Materiały magnetyczne SMART. Budowa, wytwarzanie, badanie właściwości, zastosowanie*, Oficyna Politechniki Wrocławskiej.

[4] Skalski P, 2014, "Morphing Structure with a Magnetorheological Material – Preliminary Approach", Mechatronics 2013 Recent Technological and Scientific Advanced, Springer International Publishing, pp. 219-226.

[5] Watson J.R., 1997, "Method and apparatus for varying the stiffness of a suspension busing", US patent 5.609.353.

[6] Stewart W.M., Ginder J.M., Ellie L.D., Nicholas M.E., 1998, "Method and apparatus for reducing brake shudder", US patent 5.816.587.

[7] Elie L.D., Ginder J.M., Mark J.S., Nichols M.E., Stewart W.M., 1999, "Method for allowing rapid evaluation of chassis elastomeric devices in motor vehicles", US patent 5.974.856.

[8] Klukowski C., 2009, "Steering column for a motor vehicle", US patent 20090033082 A1.

[9] Barvosa-Carter W., Johnson N.L., Browne A.L., 2006, "Reversibly expandable energy absorbing assembly utilizing actively controlled and engineered materials for impact management and methods for operating the same", US patent 7.140.478 B2.

[10] Ottaviani R.A., Ulicny J.C., Golden M.A., 2006, "Magnetorheological nanocomposite elastomer for releasable attachment applications", US patent 6.877.193 B2.

[11] Radolato A.R., Pawłowski R.P., 2003, "Tunable slip yoke damper assembly", US patent 6.623.364 B2.

[12] Lerner A.A., Cunefar K.A., 2006, "Adaptable vibration absorber employing a magnetorheological elastomer with a variable gap lenght and methods and systems therefor", US patent 7.102.474 B2.

[13] Brei D., Redmond J., Wilmont A.L., Browne N.A., Johnson N.L., Jones G.L., 2006, "Hood lift mechanisms utilizing active materials and methods of use", EU patent EP 1 617 022 A2.

[14] Barbarino S., Bilgen O., Ajaj R. M., Friswell M. I., Inman D. J., 2011, "A Review of Morphing Aircraft" , Journal of intelligent material systems and structures, Volume 22, pp. 823-877.

[15] Thill C., Etches J.A., Bond I.P., Potter K.D., Weaver P.M., 2008, Morphing skins, The Aeronautical Journal, Vol. 112 (1129), pp. 117 – 139.

[16] Ajaj R. M., Beaverstock C. S, Friswell M. I., 2016, "Morphing aircraft: The need for a new design philosophy", Aerospace Science and Technology 49, pp. 154-166.

[17] Skalski P., Parafiniak M., Wysokiński D., Bednarski M., 2014, „Profil lotniczy o zmiennym kształcie z powłoką z materiału aktywnego", P-409202.

IMPLEMENTACJA ELASTOMERÓW MAGNETOREOLOGICZNYCH W TRANSPORCIE

Streszczenie

W niniejszej publikacji przedstawiony jest kompleksowy przegląd zastosowań elastomerów magneto-reologicznych w przemyśle samochodowym i lotniczym. We wprowadzaniu scharakteryzowane są materiały magnetoreologiczne. Skład elastomerów magnetoreologicznych jest opisany. Wymieniono również ciecze magnetoreologiczne. W kolejnej części pracy prezentowane są aplikacje motoryzacyjne z wykorzystaniem elastomerów magnetoreologicznych. Zawieszenie samochodu, adaptacyjny system pochłaniania energii, szybki system rozłączania, system redukcji drgań wału napędowego, aktywny mechanizm siłownika to aplikacje zawierające w swojej budowie elastomery magnetoreologiczne. Następnie, nowe rozwiązanie z elastomerem magnetoreologicznym bazujące na polskim zgłoszeniu patentowym (P-409202), mogące zostać wykorzystane w przemyśle lotniczym, zostało przedstawione. Prace zakończono podsumowaniem i bibliografią.

Słowa kluczowe: elastomery magnetoreologiczne, transport, przemysł samochodowy, przemysł lotniczy, zastosowanie.