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MAGNETOSTRICTIVE SMART MATERIALS REVIEW FOR MORPHING AIRCRAFT

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ABSTRACT

The applications of magnetostrictive materials can be found in various disciplines. Due to their excellent actuation performance characteristics, magnetostrictive materials are employed as smart actuators in aerospace applications. As the technology of adaptive structures is favoring the use of smart actuators and sensors, magnetostrictive smart materials have justified their employment in morphing applications. The morphing aircraft technology presents new challenges in terms of actuation characteristics; these material actuators provide higher frequency and higher actuation efficiency. Also, the magnetostrictive materials can provide mechanisms both for actuation and sensing due to their property of bidirectional energy exchange between magnetic and elastic states. This paper presents an overview of magnetostrictive materials, their characteristic features and the applications with the aim to inspire morphing structures in aircraft. The challenges and trends in the applications of magnetostrictive materials have also been discussed.

Keywords: magnetostrictive, morphing aircraft, smart actuator, piezoelectric.

1. INTRODUCTION

Magnetostrictive materials seem ready to assume an undeniably essential part in applications going from dynamic vibration control, control surface deployment and energy harvesting to stress and torque detecting. Magnetostriction was initially detailed by James Prescott Joule in the mid-1840s. He detected that iron particles changed their dimensional length when their polarization was changed. Next, Villari found that under stress loading condition magnetostrictive materials changes their polarity, which empowers the utilization of these materials as stress/force sensors. In any case, magnetostrictive materials were not utilized as actuators or sensors for long time (Atulasimha & Flatau, 2011). Amid World War II, magnetostrictive nickel-based composites of 50 ppm were utilized in building transducers for sonar applications. In the 1960s, it was watched that uncommon earths, for example, terbium (Clark, DeSavage, & Bozorth, 1965) and dysprosium (Mayergoyz & Engdahl, 1999) displayed substantial magnetostriction of ~10000 ppm at low temperatures.

Despite of this, they don't exhibit huge magnetostriction at room temperature because of their low Curie temperature. While trying to deliver expansive magnetostriction at room temperatures, rare earths were alloyed with 3D transition elements like iron that shows higher Curie temperatures (Mayergoyz & Engdahl, 1999). Both TbFe2 and DyFe2 alloys have extensive magnetocrystalline anisotropies and thus require substantial magnetic fields to drive them to immersion. Be that as it may, by including Tb and Dy in the right extent magnetocrystalline anisotropy can be lessened fundamentally (Abbundi & Clark, 1977). This prompted to the advancement of the alloy known as terfenol-D by scientists at the Naval Ordinance Laboratory, which displays mammoth magnetostriction of ~2000 ppm at room temperature. Terfenol-D has extensively low magnetocrystalline anisotropy than both TbFe2 and DyFe2. One of the drawbacks of terfenol-D is that it is brittle in nature, which constrains its capacity to withstand shock loads or operate in tension (Atulasimha, 2006).

Magnetostriction alludes to any adjustment in measurement of an attractive material brought on by an adjustment in its polarization. Variations in magnetization result from magnetic moment rotations, which can be realized by the utilization of magnetic fields, heat, or stresses. The Joule magnetostriction is ordinarily utilized in actuator and sensor applications. While most magnetic materials display Joule magnetostriction, just few mixes containing rare earth elements give strains in abundance of1000×10^{-6}(Dapino, 2002). These huge strains are an immediate result of a solid magnetoelastic coupling emerging from the reliance of magnetic moment orientation with interatomic dividing.

Likewise, if the magnetostriction is positive, the sample stretches independent of the course of pivot of the attractive minutes, and the distance across is diminished with the end goal that the volume stays consistent (Downey, 2008; Tabib-Azar, 2013). In the event that the magnetostriction is negative, the sample length diminishes, and the diameter increments. A symmetric magnetostriction curve is then gotten as the magnetic field is cycled. If a uniaxial stress is loaded, interatomic displacements prompt to magnetic moment reorientation and an ensuing change in whole polarization. Since magnetostriction is a characteristic property of attractive materials, it doesn't degrade after some time as can be the situation with some piezoelectric substances. Table-1 outlines the important events in the field of Magnetostrictive materials.

Moreover, current magnetostrictive materials give more strains, strengths, vitality densities, and coupling coefficients which contend favourably with more settled transducer advancements (Y. Zhou, Yang, & Huang, 2013). Nevertheless, the required solenoid and related attractive circuit parts, magnetostrictive

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transducers are generally bigger and bulkier than their piezoelectric or electrostrictive counterparts (Bystricky, 2012; Dapino, 2002). One extra thought is that the most innovatively progressed magnetostrictive mixes are expensive to make, as cutting-edge crystalline transducer drivers must be fabricated through precious stone development systems that create directional cementing along the drive hub, in mix with accuracy machining of laminations, final diameters, and parallel finishes of slice to-length pieces.

Table-1. Outline of important events in the field of Magnetostrictive materials.

Year	Event
1842	Magnetostriction discovered in Nickel by Joule
1865	Villari discovers inverse Joule effect
1926	Anisotropy in single crystal iron
1965	Rare Earth metal magnetostriction in Terbium and Dysprosium by Clark
1972	$TbFe_2$ and $DyFe_2$ at 300 ^{0}K by Clark
1975	Terfenol-D by Clark
1994	Polymer Matrix and Terfenol-D particulate Composite
1998	Discovery of Galfenol-a more rugged MS material at NSWC
2002	Oriented Particulate Composite
2003	Potentiality of composite elastic magnets
2010	Morphotropic phase boundary
2015	Nanocrystalline Permanent Magnets Based on Hybrid Metal-Ferrites
2017	Magnetization dynamics of complex magnetic materials by atomistic spin dynamics simulations

2. MAGNETOSTRICTIVE SMART MATERIAL TECHNOLOGY

The strong state attributes of these smart materials enable smaller actuators (Oates, Evans, Smith, & Dapino, 2009). High number of applications utilizes piezoelectric or magnetostrictive materials which separately have electric or attractive field incited relocation and drive. For instance, single gem ferroelectric relaxors have given noteworthy advances in sonar transducer applications because of their productivity and generally high strain conduct (≤ 1%) (S.-E. Park & Shrout, 1997). Moreover ferroelectric lead zirconatetitanate (PZT) has been effectively executed in controlling the position of material (Giessibl, 2003). The power of magnetostrictive terbium-press dysprosium (Terfenol-D) actuators has given reliable actuator designs to a few applications including unequivocally machined out of round cylinder heads by adequately controlling the cutting device position (Nealis & Smith, 2007).

In spite of the fact that ferroic materials have been effectively executed in various applications, restrictions related with nonlinear and hysteretic material conduct have displayed challenges in growing elite activation reaction over a wide recurrence run (Oates, Evans, Smith, & Dapino, 2007; Oates et al., 2009; Zhong, Seelecke, Smith, & Büskens, 2003). The nonlinear and hysteretic material conduct is basically due to the reorientation of nearby electric or attractive variations that adjust to the connected electric or attractive fields. Direct to substantial field levels can instigate 0.1% strain in polycrystalline PZT(Lynch, 1996) and up to 6% strain in single gem ferromagnetic shape memory alloys (SMAs) (O'Handley, Murray, Marioni, Nembach, & Allen, 2000); at these field levels, getting exact control is significantly convoluted by nonlinearities and attractive hysteresis. This has spurred explore in growing new outlines that can viably adjust for nonlinearities and hysteresis actuated by ferroelectric or ferromagnetic exchanging while as yet giving precise strengths or removals over a range of frequencies.

From a device usage outlook, magnetostrictive materials show critical nonlinearities and hysteresis to a degree which other smart materials, for example electrostrictive, normally don't (Fung, 1996; Haines et al., 2016; J.-K. Park, 2012). The deleterious impacts because of these practices can be bypassed through feedback control systems. In any case, the improvement of broadband feedback control solutions that don't degrade in performance over a substantial execution run has been subtle in numerous magnetostrictive frameworks. The adequacy of real time monitoring and feedback control is reduced by noise inherent to hysteresis, thermal crawl, and solid material property varieties. One compelling method for representing and constraining the deleterious impacts of these issues is through the advancement of feed forward circles using constitutive laws portraying material conduct regarding its inalienable physical properties.

Iron–gallium composites created at the Naval Surface Warfare Center by Clark et al (Clark, Wun-Fogle, Restorff, & Lograsso, 2001) have all the earmarks of being promising materials for an assortment of actuator and sensor applications. They show direct magnetostriction (∼350 ppm) under low attractive fields ∼100 Oe (8000 A m−1) and have low hysteresis, while displaying high elasticity (∼500 MPa) and restricted reliance of magneto-mechanical properties on temperatures amongst −20ºC and 80ºC(Kellogg, 2003). The high tensile strength and restricted temperature reliance of magneto mechanical show these combinations can withstand stun loads and brutal working situations (Jayaraman, Srisukhumbowornchai, Guruswamy & Free, 2007). These assets and the capacity to work in tension are probably going to essentially extend the design space for the utilization of magnetostrictive materials in the field of smart structures.

The impact of alloying iron with other third gathering components, aluminium and beryllium, has likewise been explored (Atulasimha and Flatau, 2011; Cullen, Clark, Wun-Fogle, Restorff, and Lograsso, 2001; He *et al*., 2016; Li, Yuan, Qi, Bao, and Gao, 2017; Witte et al., 2008; Wu, Liu, and Jiang, 2015; Yao *et al*., 2015).

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While both FeGa and FeAl combinations show comparative patterns up to 25% of Ga or Al, the magnetostriction (λ100) of FeGa is more than twice that of FeAl. However, the FeBe composites show magnetostriction like FeGa, yet the high lethality of Be makes FeBe compounds hard to prepare (Atulasimha & Flatau, 2011). Moreover, constrained reviews to date have demonstrated that combinations of Fe and Ga with nickel, molybdenum, tin, aluminum and cobalt, best case scenario don't altogether enhance its magnetostrictive properties and have a negative impact at some basic pieces (Lu, Matsubae, Nakajima, Nakamura, & Nagasaka, 2016; Restorff et al., 2002; Shackelford, Han, Kim, & Kwon, 2016). Another exhaustive examination has affirmed that, while some ternary alloying enhances malleability (Summers, Lograsso, & Wun-Fogle, 2007), the main work to date those outcomes in an expansion in magnetostriction is the little expansion of carbon (Huang, Du, McQueeney, & Lograsso, 2010). Carbon limits the development of DO3 stage that adversely impacts magnetostriction in compounds with gallium arrangements of more noteworthy than ~21%.

3. CHARACTERISTICS OF MAGNETOSTRICTIVE MATERIALS

The physical foundation to the re-introduction of magnetic areas is delineated and disentangled schematically in Figure-1 (Olabi & Grunwald, 2008). In the area in the vicinity of 0 and 1, where the loaded magnetic field is little, the magnetic domains indicate no regular orientation pattern. Based on how the material was framed there might be a little measure of a typical orientation pattern, which would show itself as a permanent magnet bias. The subsequent strain depends especially on how homogeneous the base structure of the magnetostrictive material and the material detailing is. In the locale 1-2, there ought to be a practically straight relationship amongst strain and attractive field for perfect case. Since the relationship is a basic one, it is not difficult to estimate the behaviour of the material thus most devices are designed to work in this locale. Past point 2, the relationship gets to be non-straight again therefore of the way that the greater part of the magnetic domains have turned out to be adjusted to the magnetic field direction. At point 3 there is a saturation effect, which avoids additionally strain increment.

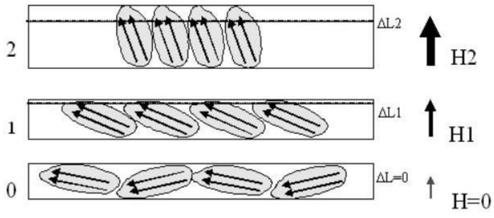

Figure-1. Strain versus magnetic field, schematically (Olabi & Grunwald, 2008).

A highly significant plot is one of dimension change versus intensity of magnetization rather than field as appeared in Figure-2 (Kikuchi, 1968). The most comprehended impact which is identified with magnetostriction is the Joule impact. This is the expansion, positive magnetostriction, or contraction, negative magnetostriction, of a ferromagnetic bar in connection to a longitudinal magnetic field. This impact is predominantly utilized as a part of magnetostrictive actuators. Without the magnetic field, the shape comes back to its actual measurements. The proportion of ΔL/L in Terfenol-D is in the scope of more than 1500 ppm and can be up to 4000 ppm at resonance frequency. The expansion long (longitudinal strain) or the withdrawal of width (sidelong strain) is generally relative to the connected attractive field and this can be utilized for different purposes in an actuator system.

Another generally used impact identified with magnetostriction is the Villari Effect. This impact depends on the way that when a mechanical load is forced on a specimen, there is an adjustment in the attractive flux thickness which courses through the example therefore of the making of an attractive field. The ΔE-Effect is another impact identified with magnetostriction. It is the change of the Young's Modulus subsequently of an attractive field. The ΔE/E in Terfenol-D is in the range of more than 5 and can be utilized in tuneable vibration and broadband sonar frameworks. Because of the change of the Young's Modulus there is an adjustment in the speed of sound inside magnetostrictive materials, and this can be watched. Another impact identified with magnetostriction is the Wiedemann Effect. The physical foundation to this impact is like that of the Joule impact, yet rather than an absolutely tractable or compressive strain framing accordingly of the attractive field, there is a shear strain which brings about a torsional uprooting of the ferromagnetic example.

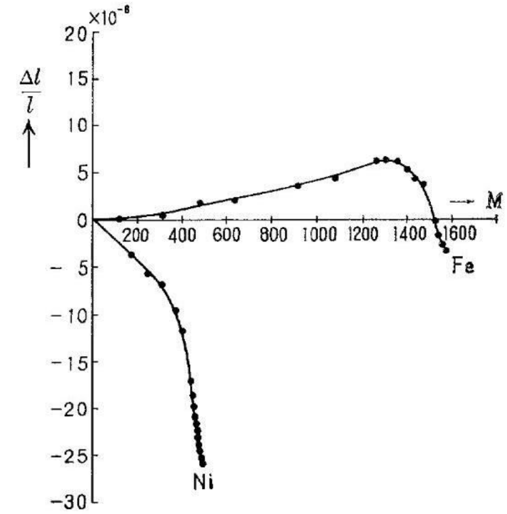

Figure-2. The magnetostriction characteristics represented as function of intensity of magnetization (Kikuchi, 1968).

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4. RECENT TRENDS IN TECHNOLOGY

A micro-displacement actuator is a key unit in the field of aerospace, precision automation, robotics and other modern industries (Zhang, Zhang, & Jiang, 2012). A piezoelectric ceramic actuator has hundreds of kilohertz bandwidth, but only 0.1% elongation and needs hundreds, even thousands, of volts to drive. SMA is considered as an available material in actuators, whereas the large temperature hysteresis limits its application in a low frequency range. The giant magnetostrictive material discovered by researchers, has large elongation and fast response, such as Terfenol-D, with large strain up to 2000 ppm under pre-stress, low driving voltage of tens of volts and fast response of the order of microseconds (Wang et al., 2013), and has been a promising choice for most micro-actuating devices (Angara, Si, & Anjanappa, 2009; Claeyssen, Lhermet, & Maillard, 2003; Tang, Lv, Xiang, & Li, 2004; Xue et al., 2016). A giant magnetostrictive actuator is a device with fast response and high force output, which has been used in electromagnetic-mechanical energy conversion and powerful precision automation (Rajapan, Rajeshwari, & Rajendran, 2005; Shao, Yang, Chen, & Yang, 2009).

The quantity of actuator applications in light of magnetostrictive materials, principally Terfenol-D, is persistently expanding as an outcome of the high energy density, high force, broad frequency bandwidth and quick reaction that these materials (Giurgiutiu, 2001). Despite the fact that the cost of Terfenol-D is high at present, the scope of applications will probably keep on increasing as assembling procedures are consummated and costs decrease. Actuators have been utilized, among others, in the accompanying applications: sonar, chatter control of boring devices, high-accuracy micro positioning, borehole seismic sources, geographical tomography, water driven valves for fuel infusion frameworks, deformable mirrors, pressure driven pumps, bone-conduction hearing aids, exoskeleton telemanipulators, self-detecting actuators, degassing in assembling procedures, for example, elastic vulcanization, and mechanical ultrasonic cleaning (Mayergoyz & Engdahl, 1999).

Since magnetostrictive materials are inductive and piezoelectric components are capacitive, it is worthwhile to join both sorts of materials in a similar device so that a full electric circuit is framed. At the point when driven at resonance, such a device acts like a simply resistive load and just the vitality viably changed over to mechanical movement or lost to internal misfortunes should be provided remotely. This enormously improves amplifier design and aides for accomplishing high efficiencies. A literature survey was conducted using the Web of Science search engine and Scopus search engine with search keywords pertaining to magnetostrictive smart materials and aerospace-related disciplines. Results are presented in Figures 3 and 4.

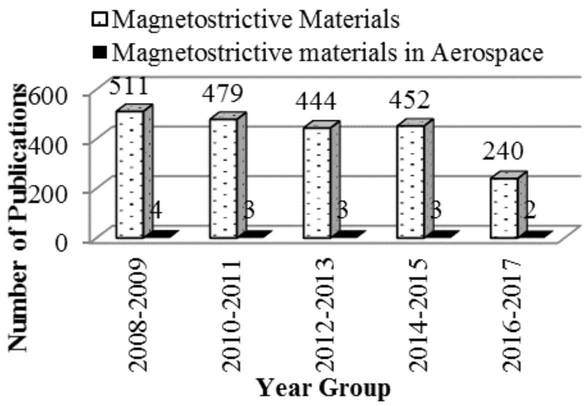

Figure-3. Number of Scopus-indexed smart material articles published in different year groups.

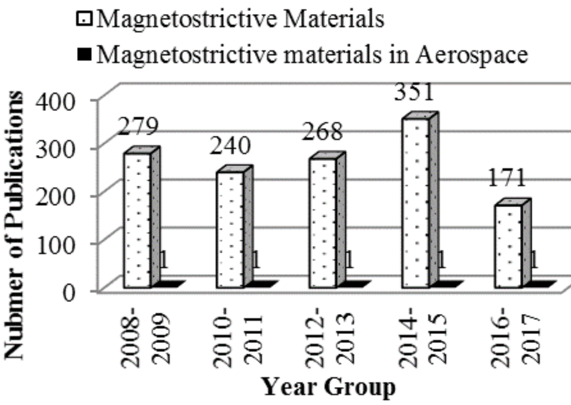

Figure-4. Number of Web of Science-indexed smart material articles published in different year groups.

The growth of magnetostrictive smart materials and actuators in different commercial sectors is also evident. Magnetostrictive “smart materials” have a performance and durability envelope which covers a different range from that of piezoelectric devices, allowing applications that cannot be serviced by ceramics. Potential also exists to replace existing piezo applications with magnetostrictive solutions to extend tool performance parameters. Specific applications, with patents and/or licenses, include de-emulsification, acoustic source, and acoustic stimulation.

5. MAGNETOSTRICTIVE ACTUATORS IN AIRCRAFT MORPHING

Morphing innovations can change an air vehicle’s geometry parameters amid flight (Weisshaar, 2006). The ordinary settled shape air ship can execute best in the set up missions and can't adjust to the changed missions exceptionally well. Researchers and specialists have been keen on the field right on time from the Soviet Union extending wing demonstrator LIG-7 in the 1930s to the variable compass wings showing up in the 1940s and getting to be distinctly pervasive in the following two decades.

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In the Mission Adaptive Wing program (MAW) in the 1980s a smooth variable camber wing is introduced onto the F-111 warrior making the demonstrator have the capacity of changing the parameters of both the wing arrangement shape and wing airfoil (Gilbert, 1980; Qiu, Wang, Huang, Ji, & Xu, 2014). A hinge less transforming driving and trailing edge with indispensable incitation system in light of the shape memory compound was produced in the Smart Wing Project with correlations with the trailing edge impelled by the routine electric engines and piezoelectric engines (Kudva, 2004).

The unmanned transforming flying machine MFX-1 under a program called "Cutting edge Morphing Structures (N-MAS)" is prepared to do expansive geometry changes incorporating 200% in the angle proportion, 70% in the wing region and 40% in the wing range (Bowman *et al*., 2007). Nonetheless, the hiked weight, wrinkled streamlined surface, framework unpredictability and others counterbalance the advantages brought by the transforming conduct.

For the scientists who need to make aircrafts perform all the more productively at various elevations and paces, morphing technology has dependably been an extraordinary goal. Despite the fact that the past projects on aircrafts have made some sort of progress, there still stay numerous issues to be comprehended before the transforming structure innovation turns out to be genuine, among which the deformable savvy skin and the light-weight driving actuators are the two fundamental deterrents.

Therefore, currently piezoelectric, magnetostrictive, and ferroelectric materials, optical fibres, electrorheological and magnetorheological fluids, SMAs, shape memory polymers, electro-active polymers, and multifunctional nano-composites are considered the smart materials that can be employed in aircraft morphing to resolve the mentioned issues (Donadon & Iannucci, 2014). Smart structures include auxetic honeycombs, variable-stiffness tubes, multi-stable structures, and corrugated structures (Sun, Guan, Liu, & Leng, 2016).

Magnetostriction is defined as the change in the shape of materials caused by the influence of an external magnetic field (Morón, Cabrera, Morón, García, & González, 2015; Olabi & Grunwald, 2008). It only occurs when the material is subjected to temperatures below the Curie temperature. Generally, the Curie temperature is below the environment temperature, thus causing the magnetostrictive effect to have little practical value (Olabi & Grunwald, 2008). Some magnetostrictive materials are presented in Table-2, along with their strain capabilities.

Table-2. Magnetostrictive materials and their strain capabilities (Grunwald & Olabi, 2008; Olabi & Grunwald, 2008).

Material	Saturation strain (ppm)	Curie temperature (K)
Ni	−50	630
Fe	−14	1040
Fe_3O_4	60	860
Terfenol-D	2,000	650
Tb0.5Zn0.5	5,500	180
Tb0.5DyxZn	5,000	200

Therefore, the advancement of these magnetostrictive materials is a progressive research area that could promote the development magnetostrictive actuators with escalating power density. This progress in actuation technology is evident in military and commercial systems. Terfenol-D is a distinctive magnetostrictive material that features an enhanced induced strain in a low magnetic field (Ma, Hu, Li, & Nan, 2011; H.-M. Zhou, Li, Li, & Zhang, 2016).

One such magnetostrictive actuator was used as a linear motor to form truss-type ribs in a two-spar wing of a Gulfstream III aircraft (Langnau, 2000). This actuator motor expands and retracts to change the wing geometry. If a shaft is fabricated with magnetostrictive material such as Terfenol-D, the magnetic field along the shaft axle induces axial elongation (Xue *et al*., 2016). In this case, the maximal strain is needed, and the crystallographic direction of the material structure should be perfectly aligned with the rod axis. Such requirements show that a high magnetic field leads to large elongation (Jiang & Spearing, 2012).

Besides, hydraulic actuation technology is primarily used in full-size aircraft because of their large primary loads that require support from the wing pivot (de Marmier & Wereley, 2003). However, hydraulic systems are not functional for UAVs with large wingspan because the hydraulics are made too heavy by required pumps and complicated servo valves (Huber, Fleck, & Ashby, 1997). Therefore, the potential applications of magnetostrictive actuators come into play and offer alternatives for heavy systems. Magnetostrictive actuators are integrated with servo valves by replacing the torque motor (Karunanidhi & Singaperumal, 2010).

At the same time, the hysteresis of the servo valve with the mechanically amplified actuator was observed to be less than that with the magnetically biased actuator. This difference is due to the additional magnetic hysteresis. The valve with the magnetostrictive actuator was proved to be faster than conventional servo valves. According to some studies, the selection of suitable parameters for actuators helps to improve overall response (Huber *et al*., 1997).

A linear step actuator based on Terfenol-D was found to demonstrate excellent performance, as evidenced by a maximum force of 410 N, a maximum speed of 60 mm/min, a range of motion of 45 mm, and power of 95 W (Kim and Sadighi, 2010; Sadighi, 2010). The linear step actuator could generate higher actuation strains compared with conventional piezoelectric actuators and exhibit higher actuation stresses compared with solenoid and moving coil transducers.

Magnetostrictive materials have been used to drive hydraulic pumps (Chaudhuri, Yoo, and Wereley, 2009; John, Chaudhuri, Cadou, and Wereley, 2009). The principle of a hydraulic pump in an UAV directed by a magnetostrictive motor has been demonstrated (Sneed, Smith, Cash, and Anderson, 2007). The pump performance was optimized by adjusting parameters such as preload on the magnetostrictive material, bias magnetic field, drive waveform and frequency, compression chamber height, and valve stiffness. A similar principle observed in piezoelectric pumps with maximum pressure greater than 1700lbf/in^2 and output power of up to 180W(Sneed *et al.*, 2007).

Furthermore, commercial nanopositioning stages for controlling the position of material specimens for probing atomic structures using atomic force microscopy and scanning probe microscopy have successfully used PZT(Oates et al., 2009). Reliable actuator designs for several applications, including precisely machined out-of-round piston heads, which are realized by effectively controlling the cutting tool position, have benefited from the robustness of magnetostrictive terbium-iron-dysprosium Terfenol-D actuators (Deng, Asnani, and Dapino, 2015).

A hybrid hydraulic actuation system was studied as an active pitch link for rotorcraft applications (Bar-Cohen, 2001). In addition to providing primary control for the helicopter, individual blade control techniques for vibration and noise reduction were implemented using an active pitch link (John, 2007). Conventional technologies, such as electric motors and hydraulic actuators, suffer from major drawbacks when applied to applications in a rotating environment (Constantinos, Pfeiffer, and Mosley, 1999).

A centralized hydraulic system requires mechanically complex hydraulic slip rings. In addition, the high-precision mechanical moving parts of electric motors make them ineffective in applications with a high centrifugal load. The high-energy density of smart materials can be helpful when designing hydraulic actuators in a compact package. Magnetorheological fluid can be used in such a hybrid hydraulic actuation system as the working fluid to implement a valving system with no moving parts (Yoo, Sirohi, and Wereley, 2005). Thus, such an actuation system is theoretically suitable for applications in a rotating environment. A fundamental understanding of the hydraulic circuit is essential when developing an actuation system according to an active material stack and magnetorheological fluidic valves.

A theoretical model was developed to clarify this issue and to understand the effect of the pumping chamber geometry on the pressure losses in the pumping chamber (Olsson, Stemme, & Stemme, 1999). Three-dimensional analytical models were proposed for steady and unsteady flows. Results match those obtained from the computational fluid dynamic (CFD) simulation of fluid flow inside the pumping chamber. The modelling process provides a fundamental understanding of the pressure losses in a pumping chamber (Olsson *et al*., 1999). The major cause of the pressure loss in the chamber is the vortices that form in the pumping chamber (during intake) and the discharge tube (during discharge). During dynamic operation, the role of vortices can also be captured with a frequency domain model.

The use of multiple aerodynamic devices (such as flaps and slats) demonstrates the simplification of the morphing concept (P. Skalski, 2014). The development of a one-dimensional morphing structure is hindered by the development of a useful morphing skin. This morphing skin is defined as a continuous layer of material that stretches over the morphing structure and a mechanism to form a smooth aerodynamic skin surface (Paweł Skalski and Parafiniak, 2012). Large geometrical changes are needed for morphing wings, especially in span morphing.

Consequently, metal or resin-matrix-composite skin materials are suitable. One investigation presented the new possibilities in the application of an magnetorheological material (a smart skin), such as morphing structures (P. Skalski, 2014). Smart materials possess properties that can be altered by temperature, moisture, electric or magnetic fields, pH, and stress. The morphing technology on aircraft has received increasing interest over the last decade because it is likely to enhance the performance and efficiency of aircraft under a wide range of flight conditions. The magnetic properties of a smart skin for a morphing structure skin can be controlled (P Skalski, 2014; Paweł Skalski and Parafiniak, 2012). Another new development in morphing aircraft concepts is the use of magnetostrictive skin materials.

6. CONCLUSIONS

Wing structural morphing is a dominant research topic in subsonic aerodynamic applications compared with other methods for enhancing aerodynamic proficiency. Research on airfoil morphing (which includes span, sweep, camber, and thickness distribution changes) has advanced with the use of various smart material technologies. Conventional actuators represent a vastly common actuation method in airfoil morphing, but they are being rapidly replaced by smart actuation technology. Conventional actuation methods include servo-and ultrasonic motors, as well as pneumatic and hydraulic devices. The actuation response of smart actuators is larger than that of conventional motors, but the life cycle and energy consumption of these actuators are not proficient enough for large adaptive mechanisms. In our study, we have presented magnetostrictive smart materials and it is seen that the magnetostrictive materials provides a robust mechanism for bidirectional conversion of energy between the magnetic and elastic states. In addition, newer materials such as Terfenol-D or amorphous metallic ribbons provide a unique combination of high forces, strains, energy densities, operating bandwidths and coupling coefficients which has justified their use in an ever- increasing number of actuators and sensor applications ranging from vibration controllers in aerospace to actuators in morphing structures. Furthermore, the optimization techniques utilized by many researchers have resulted in noteworthy developments, including novel hybrid giant magnetostrictive actuators. However, significant technological challenges need to be addressed to make morphing airplanes a reality. Nonetheless, wing morphing has shown great promise and may eventually allow planes to be designed for all operating manoeuvres with full efficiency.

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