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Smart materials: A Review

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Abstract –*Smart or intelligent materials are materials that have the intrinsic and extrinsic capabilities, first, to respond to stimuli and environmental changes and, second, to activate their functions according to these changes. The stimuli could originate internally or externally. Since its beginnings, materials science has undergone a definite evolution from the employment of inert structural materials to materials designed for a specific operate, to active or adaptive materials, and finally to smart materials with more acute recognition, discrimination and reaction capabilities. To comprehend this last transformation, new materials and alloys have to satisfy a number of fundamental specifications. Smart materials will are available in a spread of sizes, shapes, compounds, and functions. But what all of them share— so what makes them "smart"—is their ability to adapt to dynamical conditions. Smart materials are the ultimate shape shifters. They can additionally alter their physical type, monitor their environment, and even diagnose their own internal conditions. They can additionally do all of this whereas showing intelligence interacting with the objects and other people around them. The parts of the sensible materials revolution are finding their answer of the labs and into industrial applications for the past decade.*

Key Words: Smart material, Polymer, Effect

1. INTRODUCTION

Science and technology have created superb developments within the style of physics and machinery mistreatment customary materials, which do not have particularly special properties (i.e. steel, aluminum, gold). Imagine the vary of potentialities, that exist for special materials that have properties scientists will manipulate. Some such materials have the flexibility to vary form or size just by adding a bit little bit of heat, or to vary from a liquid to a solid virtually instantly once close to a magnet; these materials ar referred to as sensible materials. What are they? They are those materials that posses both intrinsic and extrinsic capabilities to respond to stimuli and environmental changes. They reply to changes in temperature, moisture, pH, magnetic Field, electric field, etc. The term "smart materials" encompasses a wide variety of materials, such as piezoelectric materials, magneto-rheostat materials (MR), electro-rheostat materials (ER), and shape memory alloys etc. [1]

1.1 Basic definition

Basically, there's no customary definition for sensible materials, and also the term sensible Material is usually outlined as a fabric which will modification one or a lot of of its properties in response to an external stimulus. For example, the form of the fabric can modification in response to completely different temperature or application of electrical charge or presenting of force field. In general, it can be catalogued to three main groups, which are thermo-to-mechanical, electrical-to- mechanical and magnetic-to-mechanical. In the other hand, there are some materials which termed as "smart material" does not have the properties stated above, like the material with self-healing property is also termed as "smart material". Therefore, smart material can also be expressed as a material that can perform a special action in response to some specific condition such as very high/low temperature, high stress, very high/low pH value, even material failure, etc. [2]

1.2 Types of Smart Materials

1.2.1 Piezoelectric materials –

These ceramics or polymers archaracterised by a swift, linear shape change in response to an electric field. The electricity makes the fabric expand or contract virtually instantly. The materials have potential uses in actuators that control chatter in precision machine tools, improved robotic parts that move faster and with greater accuracy, smaller microelectronic circuits in machines ranging from computers printers, and health-monitoring fibers for bridges, buildings, and wood utility poles.

1.2.2 Electrostrictive and magnetostrictive materials –

This refers to the material quality of changing size in response to either an electric or magnetic field, and conversely, producing a voltage when stretched. These materials show promise in applications ranging from pumps and valves, to aerospace wind tunnel and shock tube instrumentation and landing gear hydraulics, sports, ergonomics, neurology, cardiology, and rehabilitation.

1.2.3 Rheological materials –

Smart materials comprehend not solely solids however additionally fluids, electro rheological and magneto rheological fluids that can change state instantly through the application of an electric or magnetic charge. These fluids show promise in shock absorbers, dampers for vehicle seats and exercise equipment, and optical finishing. 1.2.4 Thermo responsive materials – Shape memory alloys, the dominant sensible material, deform in response to heat or cold. They are most commonly Nitinol, or nickel and titanium combined. Less popular but still possessing the shape memory effects are gold cadmium, silver cad-mium, copper-aluminum-nickel, copper tin, copper zinc, and copper zinc aluminum. They are useful in couplers, thermostats, automobile, and plane and helicopter parts.

1.2.5 Electro chromic materials –

Electrochromism is defined as the ability of a material to change its optical properties when a voltage is applied across it. These materials are used as antistatic layers, electro chrome layers in LCDs (liquid crystal displays), and cathodes in lithium batteries. [3]

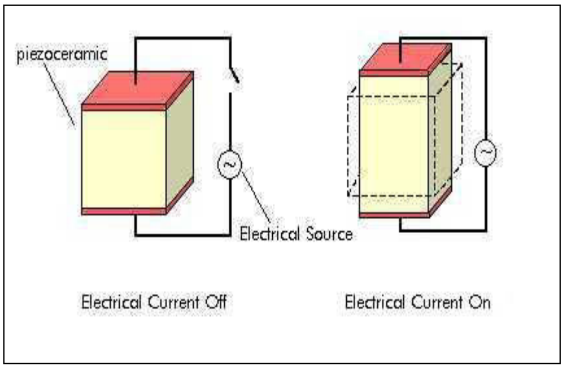

Fig:-1 Piezoelectric effect.

Fig:- 2 :M.R. fluid in working

Fig. 1 & 2:- Types of smart material

2. LITERATURE REVIEW

The first observation of the shape memory effect in materials occurred in the 1930's. A Swedish physicist by the name of Arne Olander discovered an interesting phenomenon when working with an alloy of gold (Au) and cadmium (Cd). The Au- Cd alloy was plastically deformed when cool and upon heating it returned to original or 'memorized' dimensional configuration. This phenomenon was called the Shape Memory Effect (SME) and the alloys that exhibited this behavior were called Shape Memory Alloys (SMA). At this time however, there were few, if any, practical uses of this type of alloys, until 1958, when researchers Chang and Read demonstrated the Shape Memory Effect at the Brussels World's Fair. They showed that the SME could be used to perform mechanical work by cyclically lifting a weight using an Au-Cd SMAFurther research revealed other materials that also demonstrated this phenomenon. In 1962 the shape memory properties of Nickel Titanium alloys were discovered by accident at the US Naval Ordnance Laboratories. Although pure Nickel Titanium has very low ductility in the martensitic phase, the properties can be much modified by the addition of a small amount of a third element. [1]

This group of alloys is now known as Nitinol™ (Nickel-Titanium-Naval-Ordnance-Laboratories). NiTi SMAs proved to be less expensive, easier to work with and less dangerous from a health standpoint than previously discovered alloys. These factors led to a renewed interest in SMAs and their application. Companies recognized the potential of using the SME in engineering applications. As a result, starting in the 1970's commercial products began to appear. The first commercial applications for this new material were static devices, like pipefittings. [3]

These fittings were applied first by the U.S. Air Force and later also the Navy used them for original equipment production and tube system. Also in the early 1970's a group of Brass (CuZnAl) alloys were discovered to exhibit shape memory properties. Although they were cheaper than Nitinol™ and able to perform at wider temperature ranges, they also has some disadvantages like lower work output and unwanted ageing, which made them less interesting for high power applications. Following these static applications, researchers began to propose SMA devices to perform dynamic tasks. The SMA devices began to play the role of sensors and actuators. [4]

Actually, most of smart materials have been discovered around 50 years ago, but they were not applied to aerospace industry yet. As the demand of smart structure aircraft is increasing significantly, engineers started to focus on the application of smart materials on aerospace industry. Accordingly, the attention of smart material has been increasing continuously since the past decade (Monner HP 2005). By now, they have been widely applied in aircrafts to improve their performance. For example, a simply structured smart material actuator can replace the heavy, multi-components structured actuator according to reduce the weight and difficulty of maintenance. Moreover, the fast response in electro-to-mechanical effect of some smart material achieves an excellent result of vibration/noise control. Like many scientific advances, smart fluids were discovered by accident. Researchers' using marble and oil to construct a very high voltage switch in 1940's noticed that as the switch operated, the marble eroded into a dust in the oil, which turns into from a liquid to a paste in the presence of high voltage. After the initial novelty wore off, interest in smart fluids languished through the 1970. [5]

The automotive and aerospace industries were probably the first to identify the potential engineering application of smart fluids and material – Notably for vibration control, variable torque transmission, medical rehabilitation, and Chromogenic application. Nowadays, many additional avenues are been explored, e.g., civil engineering structures, Robotics and manufacturing and distributed structures.Today, the most promising technologies for lifetime efficiency and improve reliability include the use of small material and structures. Understanding and controlling the composition and microstructure of any new material are the ultimate objectives of research in these fields, and is crucial to the production of good smart materials. New and advanced material will definitely enhanced our quality of our life. [6]

3. Smart Materials:

Emerging Markets for Intelligent Gels, Ceramics, Alloys, and Polymers is your guide to the world of smart materials. In one handy volume it will give you a hard-headed assessment of new applications and markets and brief you on important developments related to dozens of materials in a wide range of categories, including:

3.1 Piezoelectric materials

Piezoelectric materials are materials that produce a voltage when stress is applied. Since this effect also applies in the reverse manner, a voltage across the sample will produce stress within the sample. Suitably designed structures made from these materials can therefore be made that bend, expand or contract when a voltage is applied.

3.1.1 Properties

Among different types of smart material, piezoelectric material is widely used because of the fast electromechanical response, wide bandwidth, high generative force and relatively low power requirements. There are two main types of piezoelectric materials are applied as smart material, which are piezoelectric ceramic and polymer. The classic definition of piezoelectricity is the generation of electricity polarization in a material due to the mechanical stress. It is called as direct effect. Also, the piezoelectric material has a converse effect that a mechanical deformation will happen if an electrical charge or signal is applied. Accordingly, it can be a sensor to detect the mechanical stress by direct effect. Alternatively, a significant increase of size due to the electrical charge can be an actuator. [5]

3.1.2 Theorem of Piezoelectric Materials

The basic concept of piezoelectricity is to change the orientation of polarization of the molecules. To illustrate clearly, a polar axis is imaginatively set in a molecule that run through the center of two different charges. For piezoelectric material, the crystal is in form of polycrystalline initially and the crystal is connected with the electrodes. By applying the electric charge to the polycrystal, it almost become the monocrystal, accordingly the sharp will change which is shown as the converse piezoelectric effect.

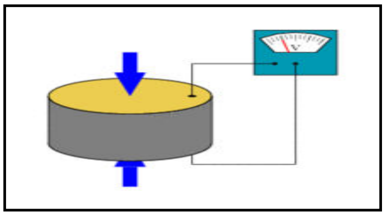

Fig 3:- Converse piezoelectric effect

In order to different direction of applied stress or charge, it will have different outcome which is shown in fig below In (a), it is the initial state of the piezoelectric material. For (b), a compressive force is applied to the material, and then the polarity current will flow in the same direction with polar axis. Conversely, it will have the opposite polarity current if it is in tension. In (c), it shown that the applied opposite polarity current will result in elongation. Also, the same direction of polarity voltage, (d), will result in compression. Finally, (e), a vibration will happen if the AC signal is applied, furthermore, their frequency will be the same.

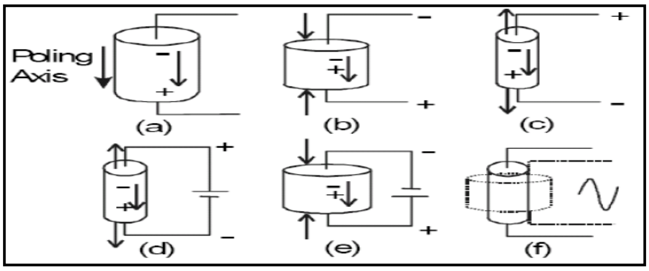

Fig 4:- Effect of different direction of applied stress or charge

Piezoelectric actuators are small-scale, stiff, load-bearing, stackable actuators. They are the most commercialized and understood technology in the smart actuator market. While also used for sensors, the more relevant application is in actuation, for which the most common materials are piezoceramics. The most popular piezoceramic material is lead zicronatetitanate (PZT). [4]

3.2 Magnetostrictive

The magnetostrictive material was first discovered by singaperumalM . Iron, cobalt and nickel have the magnetostrictive effect. However, Co and nickel have little strains in their properties. Application of them is limited and therefore commercialization has begun to discover the giant magnetostriction rare-earth alloys during the 1960s. Magnetostrictors are large-scale, high-force, and high-stiffness actuators. They derive their actuation from the elongation they experience in the direction of a uniform longitudinal magnetic field.

3.2.1 Principle

The dimensional modification of magnetostrictors is explained at the atomic level. Small internal magnetic domains rotate to align with the applied field of force. The distortion of the crystal structure from random to aligned provides "proportional, positive, and repeatable expansions within microseconds." Because the displacement per unit magnetic field increases with dimension, magnetostrictionfavors large-scale, heavy-duty actuators.

3.2.2 Properties of Magnetic Smart Materials

Magnetostrictive material can stand for high force and it has a low density in its properties. The elongation of Magnetostrictive material is caused by a change in its magnetic state. Magnetostriction arises from a reorientation of the atomic magnetic moments (Energen 2007). When the magnetic moments are completely aligned, saturation occurs after increasing the applied magnetic field and thus the magnetostriction will no longer be occurred. The amount of magnetostriction at saturation is that the most quantity of Magnetic sensible material. For applied fields below saturation, the magnetostriction is approximately linear. Magnetic sensible materials may be exactly controlled to repeatedly and faithfully position objects inside terribly shut tolerances (Energen 2007). The advantage of MSM is the ability to provide a large force through a small displacement.

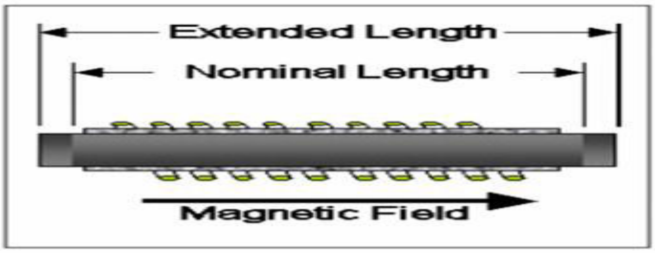

Fig 4:- Theorem of magnetic smart material

3.3 Electrostrictive

Electrostrictive actuators perform equally to magnetostrictors, but have applications more similar to those of piezoceramics. Their prime distinction from piezoceramics is that electrostrictors solely expertise elongations despite the direction of the applied field, while piezoceramics can exhibit bi-directionality.

3.3.1 Principle

The strain in electrostrictors results from deformation because of a field gradient, but not a direct polar strain. Rather, individual polar, micro-domains within the ceramic rotate to align with an electric field, analogous to the rotation of magnetic micro-domains in magnetostrictors. The electrostrictive effect is present in all materials, but only those with a giant effect (>0.7 nm/V) are useful as actuators. [2]

3.4 Thermo responsive materials

Shape memory alloys, the dominant smart material, change shape in response to heat or cold. They are most typically Nitinol, or nickel and titanium combined. Less popular but still possessing the shape memory effects are gold cadmium, silver cad-mium, copper-aluminum-nickel, copper tin, copper zinc, and copper zinc aluminum. They are helpful in couplers, thermostats, automobile, and plane and helicopter parts.

3.4.1 Introduction of Shape Memory Alloys

Shape memory alloys (SMAs) are metallic alloys which undergo solid-to-solid transformations caused by temperature and stress changes and they can recover to their original state (Hartl and Lagoudas, 2007). The section transformations ar distinctive as they're connected to massive retrievable strains. The strains are referred to as transformation strains and standard thermo elastic strains as well (Hartl and Lagoudas, 2007). With the power to recover strain within the presence of stress, SMAs are defined as one kind of smart materials which are highly demanded in aerospace industry. SMAs have higher exploit forces and displacements at low frequencies compared to alternative sensible materials. In region trade, the development of new SMAs technologies is concerned as well as assimilating them into existing systems. With the application of SMAs, the complexity of a system can be reduced compared to the same system utilizing standard technology such as electromechanical or hydraulic actuator (Hartl and Lagoudas, 2007). Aerospace industry always conduct complex systems to operate an aircraft or a rocket, the complexity should be reduced in order to improve efficiency of the systems. For example, a multiple moving parts can be replaced with a single active element which can lead to higher overall reliability. Therefore, SMAs were known as sensible materials as a result of they appear to be a possible answer to terribly advanced engineering issues particularly in region trade. [4]

3.4.2 Principle

When plastically deformed, SMAs can recover their original state when heated above a specific transformation temperature. As this happens, phase-transformations occur in and out of a martensic phase. These transformations occur with either mechanical loads or temperature, providing the opportunity for actuation. For one-way actuation, strains typically range from 4-6%. Materials can also be “trained” to work bi-directionally, but at the cost of reduced strains.

While speed is limited by heating and cooling and size is only limited by manufacturing capabilities, forces and displacements are governed only by a limit on overall power. This limit is typically near 1 in-lb/sec (0.1 Watt) . SMAs can therefore theoretically provide infinitely high displacements (or forces), but at the trade-off of either device size, near-zero force, (or near-zero displacement), depending on the arrangement.

3.4.3 Properties of SMAs (Shape Memory Alloys)

SMAs have a unique behaviour which they show a thermally or stress-driven Thermo elastic martensitic transformation. The martensitic transformation can convert into two phases which are austenite and martensite. Austenite is a cubic crystalline structure exist in high temperature while martensite is a tetragonal crystalline in high temperature. The martensite transformation has three special properties:

1) They are able to switch from high to low damping characteristic when temperature or stress changes.
2) Austenite has a super elastic behaviour in high temperature.
3) The shape memory effect upon heating from a deformed martensitic state.

Therefore, SMAs can be a good temperature sensor due to the electrical conductivity, stiffness, shape change memory and damping characteristics (Michaud, 2004). Most of the alloys have a large transformation range and thus the change in properties is gradual.

3.5 Conducting Polymer

Conducting polymer is a smart material which was found thirty years ago. It is a new type of material which having the attributes of both metals and polymers. As it contains a light weight with high conductivity with electricity, it is widely used in the modern aerospace industry (Pratt 1996). This section is going to introduce the application and benefits of using conducting polymer in aircraft. The first part is going to describe the properties and the working theorem that the conducting polymer is base on. Then the second part will discuss the application of the conducting polymer to aircraft and showing some real case examples. In the end, this section will conclude with summarizing the benefits of using conducting polymers in the aircraft and spaceship design. [7]

4. PERFORMANCE

4.1 Advantages of smart material

1. Piezoelectric

a. Compact and light weight
b. Displacement proportional to applied voltage
c. Operate over large temperature range
d. Fast response to applied voltage (msec)
e. Repeatable sub-nanometer steps at high frequency
f. As there is no moving parts, no wear and tear on the elements.
g. Functions at high frequencies
h. Excellent stability
i. Easily embedded into laminated composites [1]

2. Magnetostrictive

a. Fast response time (μsec)
b. High curie temperature
c. Relatively high strain and force capabilities compaired to piezoelectrics
d. No aging effects
e. Operate over large temperature range
f. Low voltage operation. [5]

3. Shape memory alloys

a. Produced very large recovery stresses
b. Easily machined into different shapes and sizes
c. Manufactured to desired properties (mechanical and transition temperatures)
d. Material is ductile
e. Very effective for low frequency vibrations (<5 Hz)
f. Heating is easily done by resistive heating
g. Easily embedded into laminated composites. [8]

4.2 Limitations of smart materials

1. Piezoelectric

a. Brittle due to crystalline structure
b. Produced small strains compared to SMA and magnetostrictives
c. Cannot withstand high shear and tension
d. Material does age
e. Can become depolarized (High voltage, high temperature, large stresses). [1]

2. Magnetostrictive

a. Low tensile strengths
b. Brittle
c. Costly due to rare earth metals involved
d. Large magnetic field required
e. Equipment intensive in order to produce magnetic field. [5]

3. Shape memory alloys

a. Slow reaction time and ineffective at higher frequency ranges
b. Low energy efficiency conversion
c. May not be able to operate in conditions with large temperature ranges
d. Unweldable and expensive for large scale projects
e. Non-linear thermo mechanical behaviour can limit the accuracy. [8]

4.3 Application of smart materials

The following are some of the specific applications of smart materials in automobiles:

a. SMAs
   1. Open-close mechanisms
   2. Release mechanisms
   3. Active braking systems
   4. Active skin systems. [8]
b. Piezoelectric Materials
   1. Sensors for wiper actuation
   2. Sensors for side impact diagnosis (in smart cars)
   3. Sensors for force/ motion
   4. Sensors for platform stabilization
   5. Ultrasonic motors [1]
c. Magnetostrictive Materials
   1. Active cabinet noise control
   2. Sonar for collision avoidance (in smart cars)
   3. Active sensing and actuation
d. Magneto rheological/ Electro rheological Fluids
   1. Active clutch mechanisms
   2. Position and velocity control
   3. Active suspension [5]

Some of the application areas of Smart Material are discussed below:

4.3.1 Piezoelectric material as Sensors

Piezoelectric materials area unit most generally used as sensors in numerous environments. An example of a electricity material in lifestyle is that the airbag sensing element in your automotive. The material senses the force of a control on the automotive and sends and charge deploying the airbag. Fig. 4.1 - View of different series of standard APAs (XS, S, M, ML, L) Piezoceramic materials will manufacture motion by receiving potential across their polarized surfaces. A piezoelectric crystal vibrates when an alternating voltage is applied to it, and almost all of the energy given to the material is converted into mechanical motion. Piezoceramic materials make very good candidates in a low power consumption design for vibrators oscillating in their fundamental modes. When it's excited at low frequency, a piezoceramic material vibrates; at high frequencies it also produces sound, as a transducer does. The resonant frequency of the ceramic is too high to produce an audible tone by itself, so a metal plate must be attached that vibrates with the contraction and expansion of the piezoceramic. Therefore, both audible and silent alerts can be generated from the same source by exciting it with two different frequencies. [1]

4.3.2 In Aerospace Industry

The material always influences the weight, service life, function and strength of the aircraft. Hence discovery of latest material is sometimes respecting associate degree innovation in region trade. Regarding the application of piezoelectric material, there are two main functions which are shape control and vibration control.

1. Adaptive Smart Wing

Conventionally, the flap, rudder and elevator area unit adjusted by electronic motor or mechanical system like cable or mechanism. By applying piezoelectric actuator, no discrete surfaces are required because the control surface can be change the shape itself in order to change the aerodynamic feature (shown in fig). Therefore, it creates a continuous surface which will not cause early airflow separation hence to reduce the drag, but also the lift is increased due to the delay airflow separation. Accordingly, it increases the efficiency significantly.

Basically, the concept of smart wing is to construct a continuous control surface embedded by a series of piezoelectric actuator. Furthermore, it is required to have a high strength-to-weight ratio; It means the actuator has to be placed strategically for optimizing a light weight design. Finally, it should have an ability to change the shape response to different flight condition, hence the performance of cruise flight can be improved that the conventional aircraft cannot achieve. However, the smart wing system is mainly focus on military aircraft performance and maneuver improvement. Since 1994, this smart wing project has been started by many industries and research centers such as

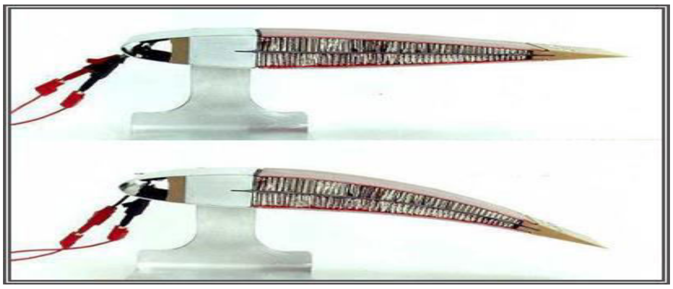

Fig. 5:-Adaptive smart wings

US Air Force, NASA, Northrop Grumman, Lockheed Martin, UCLA and the Georgia Institute of Technology. They constructed a 30% scale Unmanned Combat Air Vehicle (UCAV) at NASA Langley Research Centre. By two wind tunnel testing, it showed that the system had a high rate, large deflection, conformal trailing edge control at realistic flight conditions. [4]

4.3.3 Application of Magnetic Smart Material

In order to minimize the vibration produced by the aircraft, light weight and unique property of the materials will be considered. When the aero-plane is lifting, a lift force is very large to lift up the plane. Therefore, this material must with stand the high force. Moreover, the material needs to keep its stability with different temperature range and pressure. According Energen 2007, actuator technology is applied to active control of vibration. The properties of precise change in length with high force and light weight makes MSMs excellent component for building actuators. A coiled MSN rod is enclosed in a shell that protects it from damage and concentrates the coil's magnetic flux onto the MSM rod. The MSM rod is contacted with a plunger and the plunger is held by a spring. When the coil is energized, the MSM rod elongates and pushes the plunger (Energen 2007). This is the way how the actuator works. It can be installed as a starter in the jet engine.

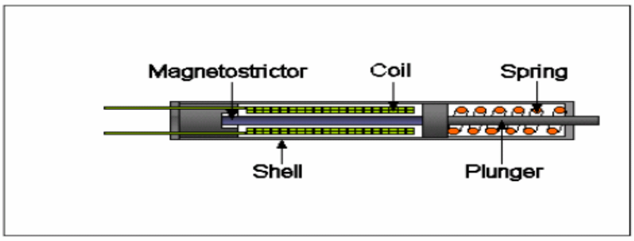

Fig. 6:- MSM's actuator

Linear Actuator Geometry With the accelerometers, control electronics and active vibration control systems are being developed for both cryogenic and room temperature applications. For the vibration control in aircraft, MSM is more efficient than the current piezoelectric material for controlling low frequency high amplitude vibrations. It can be used to build the main frame of the aircraft so as to prove its stability and stiffness in any condition. Thus passengers' lives will be guaranteed. However, this special material is typically applied in building spacecraft since the conditions occurred is far quite earth. The capability of the magnetic smart material is a feasible material to with stand harsh condition. Aircraft has started to apply more on this material recently because it is low in price, light weight and good stability. [9]

4.3.4 Application of Conducting Polymerinfuel cell

Another application of conducting polymer is using it as a component for fuel cell system. Fuel cell could be a new technology that victimization in part trade within the last thirty years as conducting polymers was outlined. It is used for the shuttle on-board power system and support of the space exploration initiative in spaceship industry (Kohout 1989). Moreover, fuel cell system is more efficient than combustion engines because it is not limited by temperature as is the heat engine and it will not produce any green house gases. Therefore since 1990's independent agency is making an attempt to use the cell to the space laboratory, high altitude balloon and high altitude aircraft (Cathey, Loyselle& Maloney 1999). In the cell structure, conducting polymer is taking an important part. The fuel cell structure is containing an electrolyte layer in contact with an anode and cathode electrode on either side of the electrolyte. The metal of the electrolyte layer is carbon. However, carbon has low proton conductive. Therefore, conducting polymers such as polypyrrole and polyaniline is applied as a support material for the layer because conducting polymer could help to increase the interfacial properties between the electrode and electrolyte (Choi, Kim, Lee, Lee,Park& Sung 2003). Figur.7 showed the cell system with conducting polymers.

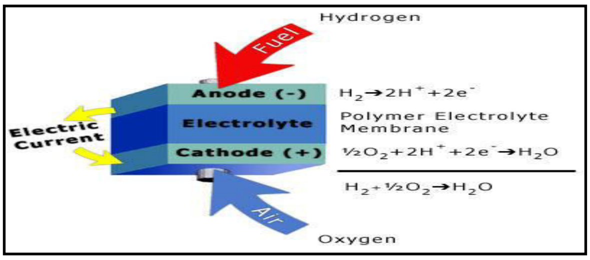

Fig. 7:- Fuel cell system with conducting polymer

5. CONCLUSION

In the studying of smart materials, their properties in response to external condition such as temperature, stress, electrical charge, magnetic field, are understood and these unique properties receive a great attention from the airspace industry. The reason is that properties can be applied to different parts in the aircraft to improve the overall performance. For example, by using the smart material actuator, its performance is much more efficient than the conventional system since the electricity is directly converse to actuation, numbers of parts are greatly reduced and transmitting speed of electricity is much higher. Moreover, AN innovative analysis is experiencing to form the adaptational wing or management surfaces which may greatly increase the manoeuvrability. In addition, smart material is usually light in weight and can be made in the compact size. At constant time, cost can be reduced and maintenance can be minimized by using vibration control smart material. Accordingly, the demand of smart structure constructed by smart materials is increase dramatically because it can improve the overall efficiency, maneuverability, safety, stability, light weighted structure of the aircrafts. Therefore, the sensible materials represent the innovation of part trade and that they square measure believed to be wide employed in the long run.

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