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Modeling and Analysis of Active Magnetic Bearing-Flywheel System for Vehicular Application

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Abstract—*Active magnetic bearings are the bearings used to support rotating element by keeping it in the magnetic field with the help of magnetic force and electronic controller. It transfers motion by levitating rotor (flywheel), using forces in radial as well as in axial direction, for this a flywheel is used to store the kinetic energy. It uses active magnetic bearing to suspend its rotor at the desired position which provides continuous transfer of motion hence can be used in various industrial applications. This system of active magnetic bearing and flywheel is environmental friendly and no wear and tear takes place during its entire working. Since, lots of research has been done in this field and is still going on the aim of this paper is to review different methods of modelling and analysis of various active magnetic bearing-flywheel systems used by the researchers.*

Keywords*: Active magnetic bearing, flywheel, FEMM.*

1. INTRODUCTION

A bearing is a mechanical component which supports a moving component. It provides linear or rotary motion between the two components. Due to this a surface contact takes place between bearing surface and machine element which leads to friction, heat generation and wear of component. To avoid such problems lubricants such as petroleum, grease etc. are used. At present widely used bearings are plain bearing, roller bearing, and ball bearings which are all surface contact bearings hence there is a need for study of active magnetic bearing.

Magnetic Levitation is a mechanism in which an object is suspended by means of magnetic repulsion and attraction. The effects of the gravitational force are counteracted using magnetic force. The main application of magnetic levitation is in ground transportation. Servomechanisms are used in Trans-rapid system, it pulls the train up from underneath track and maintains desired gap even at high speed.

2. REVIEW OF AVAILABLE LITERATURE

Rosen motors developed a hybrid automotive power train using a 55,000 rpm flywheel [13]. A magnetic bearing is a device that suspends a rotating component using magnetic levitation. It is able to levitate a rotating element and permit relative motion with very low friction and no mechanical wear, this happens due its non- contact nature. It can be used at very high temperatures. In comparison to mechanical bearings magnetic bearings are friction less, contact less, prone to less wear and tear, are more ecofriendly and their overall maintenance is also less. Types of Magnetic Bearings [15] Based on control action, they can be classified as Passively controlled bearing , Actively controlled bearing, Superconductor controlled bearing, Hybrid magnetic bearing (which combines PMB either with SMB or AMB), On the basis of force action Repulsive force, Attractive force, On the basis of sensor action Self sensing, Sensor sensing, On the basis of load supported, Axial, Radial, Conical. Active magnetic bearing uses electromagnet assembly, displacement sensors which monitor the position of rotor placed in stator. It is made up of ferromagnetic material and works on Earnshaw Theorem. It levitates rotor using forces in radial as well as in axial direction. The rotor remains levitated in stable equilibrium even in the presence of external forces. It uses PID controller to maintain desired speed and avoid fluctuation. The maintenance is less and no lubrication is required in AMB. Precise position control can be achieved using AMBs. Load carrying capacity of AMB is very high. It can produce very high rotational speed at very high temperatures. The components of AMB are iron core, windings, rotor, and position sensors [3]. 2.414 times higher load carrying capacity than four-pole AMB for same inputs like current provided, turn number, area of pole, and air gap present [1]. Result of this load carrying capacity lead to the reduction of diameter of outer stator by 24% [1]. Eight-pole bearing are used in many industrial applications as it can easily control the force generated by bearing [2]. Passive magnetic bearing uses Permanent magnets. It is relatively cheap and less complicated than the other two magnetic bearings. It is self-stable. Its main problem is that it cannot maintain rotating element at the desired position for a longer duration, this happens due to the reason stated in Earnshaw Theorem. It has smaller number of degree of freedom as compared to AMB.

Superconductor Magnetic Bearing is a self-stable bearing. It uses diamagnetic material and normal repulsive forces. It is normally used to maintain very high speed. Its application is limited as it is not used at very high temperature. Its overall cost is also very high.

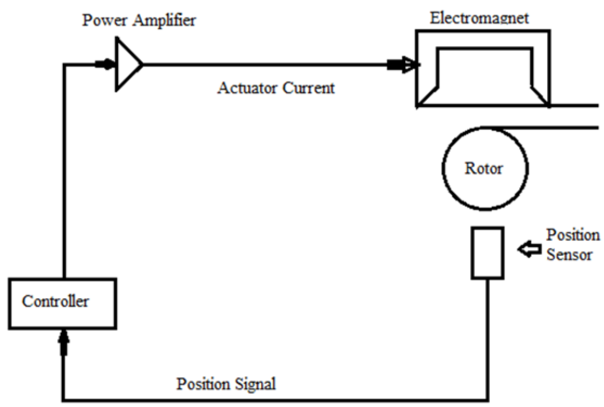


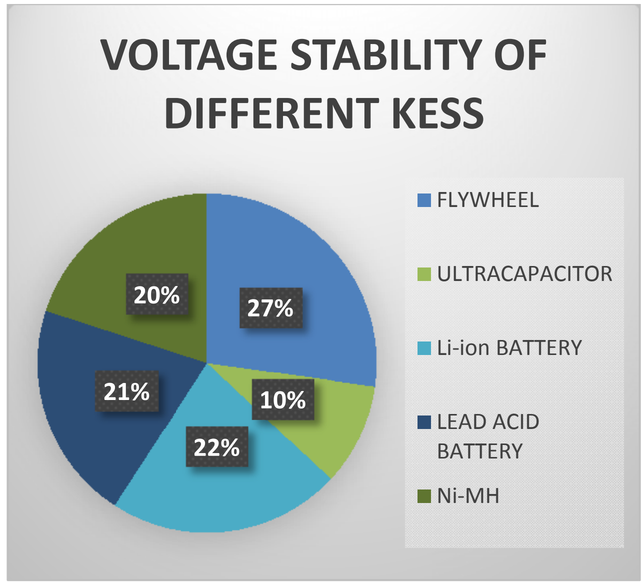
Fig. 1: Block diagram of active magnetic bearing

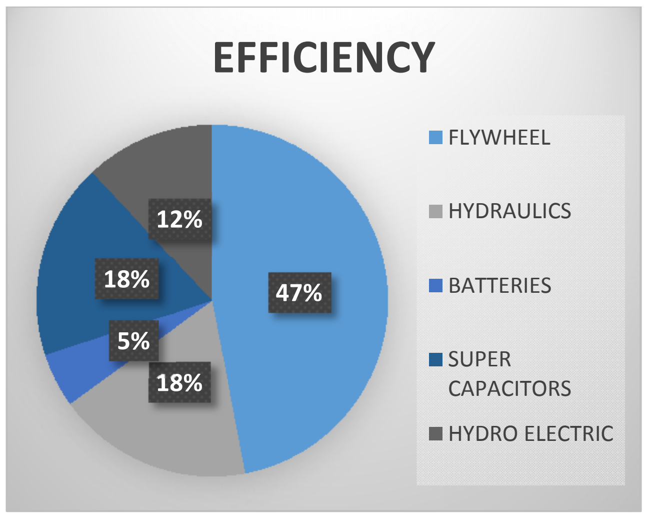
Flywheel is a mechanical device that temporarily store kinetic energy. It uses an AMB to support its rotor. Flywheel uses its inertia called the moment of inertia to resist changes in rotational speed. The composite materials such as epoxy and carbon-fibre are used to make Flywheel due to their high strength. The efficiency of flywheel increases with the introduction of frictionless AMB. Flywheels constructed from high- strength composite materials have lower density than steel flywheels but are ideal for storing a large amount of energy since they can cope with high rotational speeds [4].

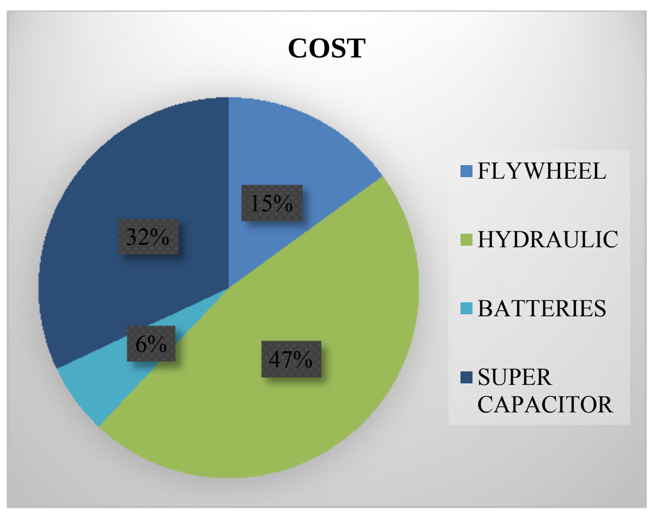
Table 1: Comparison of different energy storage units

Different form of energy storage units	Specific power (W/kg)
EV battery (Li-ion)	90
HEV battery (Li-ion)	256
Ultracapacitor	513
Flywheel (steel)	280
Flywheel(composite)approximate	>1000

In Table 1 comparison of most common property i.e power is provided. The batteries are provided by [20], ultracapacitor by [21] and steel flywheel by [22] [4]. Comparison of voltage stability, efficiency and cost of different kinetic energy storage system [KESS] is given below [23]. Fig. 2 shows comparison of volatage stability of different KESS, Fig. 3 shows comparison of efficiency of different KESS, Fig. 4 shows comparison of cost of different KESS. Different present and future materials which are used and can be used for making flywheel are: Aluminum 7075, Stainlesssteel, Glass fibre composite, Titanium, Vapor grown carbon nanofibers, carbon nanotube, Single wall carbon nanotube, Multi-walled carbon nanotubes (low end), Multi-walled carbon nanotube [17].







Various design consideration for flywheel are: reliability, safety, controlled environment, availability [19]. The flywheel stores kinetic energy which is a type of mechanical energy, this energy is converted into electrical energy by an electrical machine. This machine works on the principle of motor while transferring energy to the flywheel and it works on the principle of generator while restoring the energy into the flywheel. This electrical machine is generally known as motor-generator unit (MGU). Using this MGU energy stored in flywheel can be used to run a vehicle. For charging and discharging of flywheel electrical machines (MGUs) are used [16].

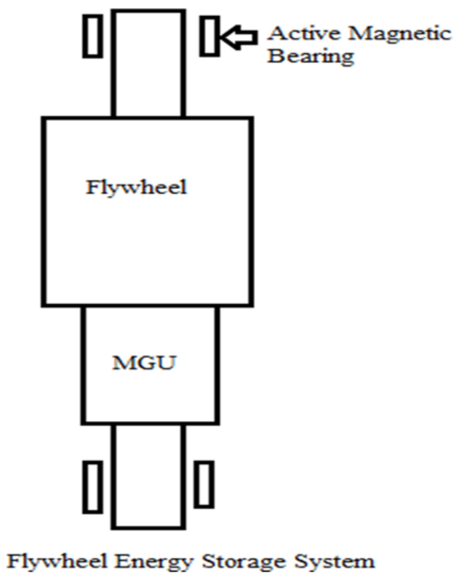


Fig. 5 Showing Flywheel Energy Storage System

Common types of machines which are used in FESS are: the induction machine (IM), the switched reluctance machine (SR) and the permanent magnet synchronous machine (PMSM) [16]. This whole system of flywheel storage is known as flywheel energy storage system which usually consists of five main components- (1) Flywheel, (2) Bearings, (3) Electrical machine i.e MGU, (4) Electronic unit (consisting of sensors, controllers etc.), (5) Housing [16]. AMB-Flywheel system has application in vehicular applications as it can provide continuous energy to the system so that it can to drive. FESS can be the solution for multiple problems in automobile sector like buses, trains, trams and cars by providing efficient, consistent and clean form of energy. This system requires less maintenance than any solar energy system. It does not produce any waste material like any other non- renewable source of energy.

Different research has been done on this system some of them are discussed here. Abbasy et. al [5] explain a design of an active magnetic bearing using MATLAB/SIMULINK. They proposed a system having 60kg flywheel which was able to run 15 thousand rpm, the maximum force generated in radial direction was 9 thousand rpm [5]. They have used different parameters to design such as stator pole arc angle, air gap length, rotor diameter, stack length, bias current, total number of turn per magnet, slot area, coil inductance, winding resistance and copper loss. The PID controller is used to control the fluctuation of rotor. PI and PID controllers used values designed by method of pole placement. ZHANG et. al [6] designed a flywheel energy storage prototype to have large energy density and less bearing losses. Composite flywheel (its stress field) was analysed using the finite element method. The highest speed attained in this research was 700r/s, up to this speed material failure did not occur [6]. Different analyses were performed like flywheel structural analysis, modal vibration analysis, non-synchronous vibrations analysis, passing through the flexible critical speed analysis [6]. Nascimento and Arantes et.al [7] provided parameters for the design of active magnetic bearing. These parameters are permeability of free space steady electric current (bias), nominal air gap, geometric correction factor, number of coils, area face of each coil, transfer function of position sensor, total, derivative, proportional and integral gains of PID controllers and gain of power amplifier [7]. LUDVID et. al [8] provides a design procedure for designing an AMB which is simulated in FEMM [8]. The data which was used to design the shape of AMB was outer diameter of the AMB, its inner diameter, outer diameter of the shaft, its inner diameter, leg thickness, leg crown thickness, air gap between the leg crowns, air gap between the legs and the shaft [8]. The current value used was 12 A (DC). The simulated AMB provided 800N as the maximum force. Different types of shafts (bar and pipe) were used in calculations, different air gaps (1mm-5mm) thickness were also used [8]. Calculations were done in COMSOL and Finite element method is performed for the analysis of the system. Biswas and Banerjee et. al [9] uses ANSYS simulation on different types of AMB that have four and three coil structure located 120 and 90 degrees apart from each other respectively [9]. Four and three coil magnet give a static force which is unstable, it decreases with increase distance, and increases at close spaced (stator) and rotor [9]. Maxwell's stress tensor method is used for calculating forces and is analyzed using Finite element method [9]. This paper concluded that the simulated result of three coils AMB is superior to that of four coil AMB. Pilat et. al [10] The generated flywheel rotor had a speed of 15000rpm [10]. They used radial AMB to stabilize the rotating flywheel. The geometry of AMB was designed using Bezier curves [10]. AMB was also generated using COMSOL/MATLAB. PILAT et.al [11] presented a method for analyzing magnetic field of AMB using FEMLAB software [11]. The parameters used for construction of AMB were number of pole pairs, nominal radial air gap, rotor outer radius, coil turns, nominal current and area of pole [11]. This paper concluded that force range of AMB is very important factor as bearing stiffness is strongly affected by it [11].

3. CONCLUSION

Finite element method is a major tool in designing AMB-Flywheel system. By analyzing various researches we can conclude that eight pole AMB is the most appropriate type of bearing for flywheel system as it can generate more rpm and force. The benefit is long life cycle and higher power density, which allows fast re fueling [4]. It also provides high torque for driving. The practical use of this system is less because of losses and its initial cost. Although the life-long cost of this system is less. Losses may be reduced by using composite instead of metals, by reducing the bias current in the magnetic bearings. Cost of this system is reduced by making the size of AMB very compact, this is done: Creating AMB with less parts hence more robust,by providing bottom of the pole with a crown [4], by providing winding pattern which is trapezoidal in shape as it gives 7% smaller stator outside diameter as compared to parallel winding pattern [4].

Flywheel energy storage system is more efficient and stable compared to other conventional energy storage systems [23]. The future of this system is very bright as this system has a potential to replace solar energy. Its issue such as size, losses and complexity need to be taken care of, once these issues are solved or reduced to minimum there can be no looking back for this alternate source of energy.

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