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High Speed Flywheel Energy Storage system For Efficient Solar Energy Storage

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Abstract - *For efficient utilization of available renewable energy in the form of solar, wind, geo-thermal, etc. it is imperative that a reliable energy storage system is incorporated, so that fluctuations in supply and demand can be smoothed out. Flywheel energy storage (FES), which is the storage system proposed in this report, is a viable alternative to battery storage. Flywheel Energy Storage system is an alternative form of energy storage which can directly replace battery storage from various power applications like unaltered power supply (UPS) etc. These applications mostly require high power to energy ratio, i.e. energy is stored and delivered at a very fast rate. For long duration storage it is imperative that there is least amount of power dissipation because of friction. Advance flywheels address this issue by using magnetic bearings. The flywheel in this case is suspended in air/vacuum with the help of an active electromagnet which exactly balance the gravitational force. The flywheel rotor position feedback goes to the controller, which then manipulates the electromagnet current required to balance the rotor mass. On these bearings there is no contact friction between the rotor and the stationary enclosure. To further reduce skin friction drag between the rotor and the ambient air, the enclosure is kept under partial vacuum. In this way, once the flywheel attains its maximum speed while charging, it can store this kinetic energy for very long durations with a loss of a few revolutions per minutes per day.*

***Key Words*: Renewable energy, Flywheel Energy Storage, Acive Electromagnet, Conroller, Parial Vacuum**

1. INTRODUCTION

Flywheel energy storage (FES), which is the storage system proposed in this report, is a viable alternative to battery storage. Flywheel Energy Storage system is an alternative form of energy storage which can directly replace battery storage from various power applications like unaltered power supply (UPS) etc. The concept of kinetic energy storage via flywheel is not new and can be found in various applications like automobile etc. for smooth power delivery. These applications mostly require high power to energy ratio, i.e. energy is stored and delivered at a very fast rate. For long duration storage it is imperative that there is least amount of power dissipation because of friction. Most mechanical bearings have high losses due to friction and windage. Advance flywheels address this issue by using magnetic bearings. The flywheel in this case is suspended in air/vacuum with the help of an active electromagnet which exactly balance the gravitational force. The flywheel rotor position feedback goes to the controller, which then manipulates the electromagnet current required to balance the rotor mass. On these bearings there is no contact friction between the rotor and the stationary enclosure. To further reduce skin friction drag between the rotor and the ambient air, the enclosure is kept under partial vacuum. In this way, once the flywheel attains its maximum speed while charging, it can store this kinetic energy for very long durations with a loss of a few revolutions per minutes per day. A review of flywheel energy storage was made, with a special focus on the progress in automotive and UPS applications. After an extensive literature survey and patent search in this field, it was found that there are at least 26 university research groups and 27 companies contributing to flywheel technology development. Flywheels are seen to excel in high-power applications, placing them closer in functionality to supercapacitors than batteries. Examples of flywheels optimized for vehicular applications were found with a h 500 flywheel power buffer systems being deployed for London buses (resulting in fuel savings of over 20%), 400 flywheels in operation for grid frequency regulation and many hundreds more installed for uninterruptable power supply (UPS) application. For regular cars, this system has been shown to save 35% fuel in the U.S. Federal Test Procedure (FTP) drive cycle.

1.1 Aims and Objetives

The objective ofthis work is to design an ultra-low friction bearing sysetm for HFES appliction.

The design process shall explore the following

- Modeling of gas film based on theoretical analysis.
- Simulation of gas bearings in a 2-d geometry using Fluent Software.
- Validtion of developed model through pragramtically designed experiments.

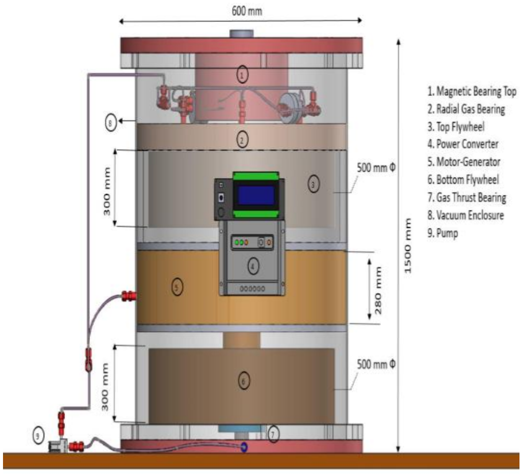

Fig - 1: Schematic drawing of a High Speed Flywheel Energy Storage System [Gyrodrive Machineries (P) Ltd.]

1.2 Theoretical Design

In a gas bearing two parameters are of primary interest to the designer. One being the fluid-film force and the other is the bearing flow. The fluid–film force depends on the pressure field developed in the bearing area whereas the flow depends on the viscosity of fluid. In steady flow pressure field and flow rate are viscosity and density. In case of dynamic conditions, the bulk modulus of lubricant elasticity becomes important. For taking care of compressibility issues, application gas laws are required.

2.THEORETICAL MODELING OF FLYWHEEL ENERGY STORAGE SYSTEM:

The mathematical modelling of a flywheel energy storage system and the experimental techniques to ascertain the modal parameters. The complete system schematic is described in Figure 2. Energy is stored as rotational kinetic energy in the flywheel. When energy is surplus, the flywheel speed increases by virtue of the motor, till it reaches it's design speed. In idol mode, this energy can be stored for long durations as there is minimal loss incurred due to the use of low friction gas magnetic bearings. When energy is needed, the stored kinetic energy is retrieved by using the generation mode of the motor. Overall process of charging, idling and discharging is depicted in Figure 2,

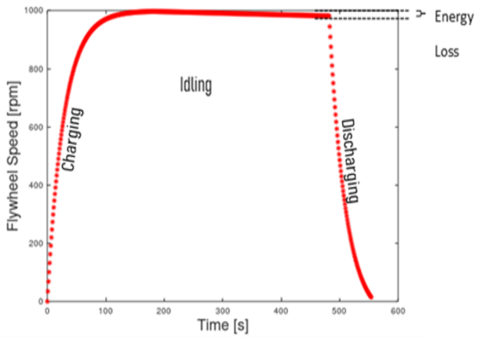

Fig - 2: Process of Charging, idling and discharging in Flywheel Energy Storage System

2.1 Modeling of Switch Reluctance Motor

If we consider a phase winding excited by a voltage source:

$v = Ri + d\Psi/dt$ (1)

Now,

$\Psi = Li$ (2)

$v = Ri + d(Li)/dt$ (3)

$v = Ri + L\,di/dt + i\,dL/dt$ (4)

Now L = f(t,θ)

$v = Ri + L\,di/dt + i\,dL/d\theta \; d\theta/dt$ (5)

$v = Ri + L\,di/dt + \underbrace{\omega i\,dL/d\theta}_{\text{Back EMF}}$ (6)

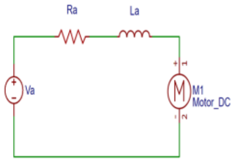

Fig-3:-FESS Motor Modelling

v = Voltage
Ψ = Flux Linkage
t = Time
i = current
R = winding Resistance
ω = rotor speed rad/s

The instantaneous electric power input to the machine is given by

$i(v = Ri + L\,di/dt + \omega i\,dL/d\theta)$

Now we know in this case that $L = (\mu_0 N^2 x L_{Fe})/g$

Also from the geometry of this problem,

$dx = r d\theta$ (15)

$dL = ((\mu_0 N^2 L_{Fe})/g)dx$ (16)

$dL = ((\mu_0 N^2 L_{Fe})/g)\, r d\theta$ (17)

$dL/d\theta = (\mu_0 N^2 L_{Fe}\, r)/g$ (18)

Torque, $T = ½\, i^2 (\mu_0 N^2 L_{Fe}\, r)/g$ (19)

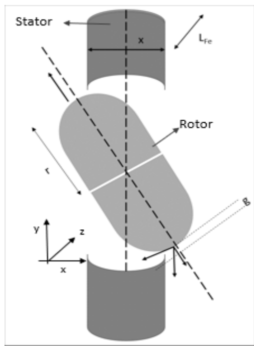

Fig - 4: Flywheel Energy Storage System Switch Reluctance Motor Modeling

2.1 Flywheel Parameter Estimation

Flywheel Mass= 1.524 kg
Flywheel Radius, R = 50 mm
$I = 1/2\, MR^2 = .001926\ kgm^2$
N = 1000 rpm
$\omega = 2\pi N/60 = 104.72$ rad/sec
$E_{Total} = ½ I \omega^2 = 10.564$ Joule

2.2 Apparent Flywheel Mass

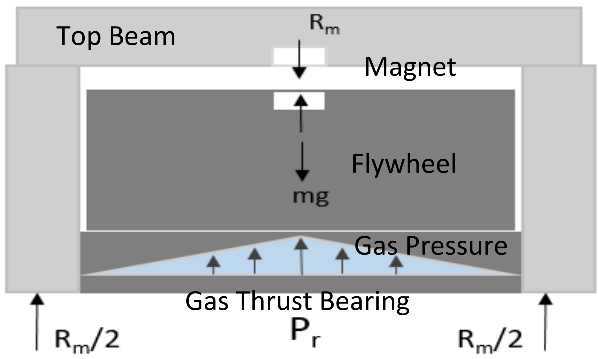

Fig - 5: Gas Thrust Bearing Flow Profile

Flywheel Mass, M= 1.524 kg
Magnetic Pull Force, R_m= 1.26 *kg*
Flywheel Apparent Mass = M – R_m= 0.264 *kg*

3. GAS THRUST BEARING DESIGN

In designing a bearing system for an application we need to keep the following parameters in mind:

- Lifting load
- Bearing Stiffness
- Critical journal speed
- Friction losses
- Bearing system power consumption
- Bearing life

An externally pressurized gas bearing has three functional components, namely the bearing restrictor, bearing land area and pressure control mechanism

3.1 Design of Capilary Restrictor

The gas bearing pad has a capillary restrictor entry which allows the use of higher supply pressure. The presence of higher supply pressure allows the recess pressure to either increase or decrease with respect to the applied load.

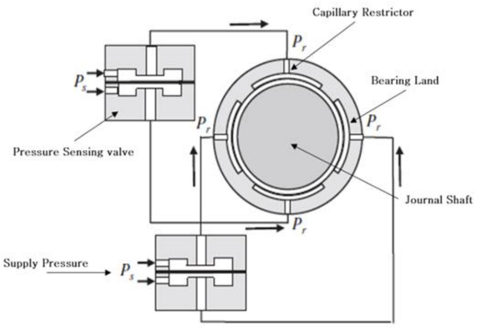

Fig - 6: Externally Pressurized Radial Gas Bearing System

4. EXPERIMENT RESULTS

4.1Estimation of Bearing Disc Friction Factor

Loss of energy in case of an FES is primarily due to bearing viscous losses and pumping power loss. The FES prototype used for this analysis stored 10.5 W of energy at 1000 r.p.m and a cost down analysis showed a good coherence with theoretic values.

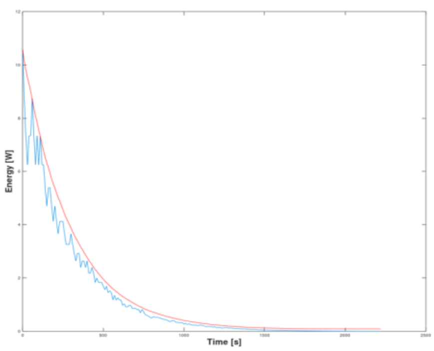

Fig - 7: Experimental validation of bearing friction factor

4.2 Estimation of Bearing Clearance/Film Thickness

For calculating the air film clearance between the Flywheel and the gas bearing, two different methods have been used. Since the flywheel disk is not in contact with the bearing, as it is levitating on the gas film, this system acts like a circular plate capacitor due to the dielectric nature of air. The clearance can then be indirectly measured by measuring the capacitance. The second method is to use a dial gauge.

$$C = \frac{0.00885\,\varepsilon_r \pi r^2}{d} + 0.00885\varepsilon_r r\left[\ln\left(\frac{16\pi r}{d}\right) - 1\right] = 0.933\ \text{nF}$$

H =46 μm

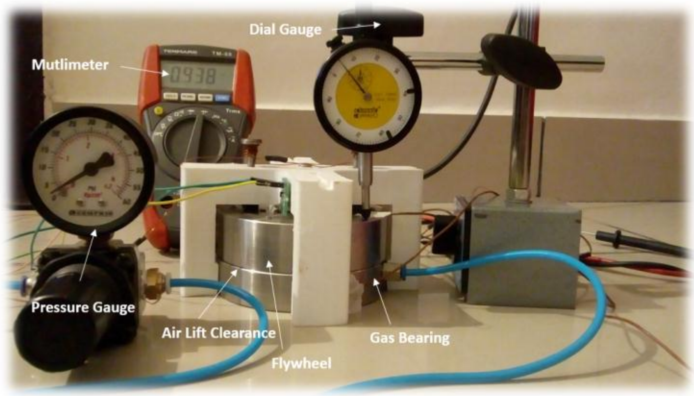

Fig - 8: Experimental set-up for gas bearing lift clearance measurement using system capacitance

4.2 Etimation of Bearing Presure Profile

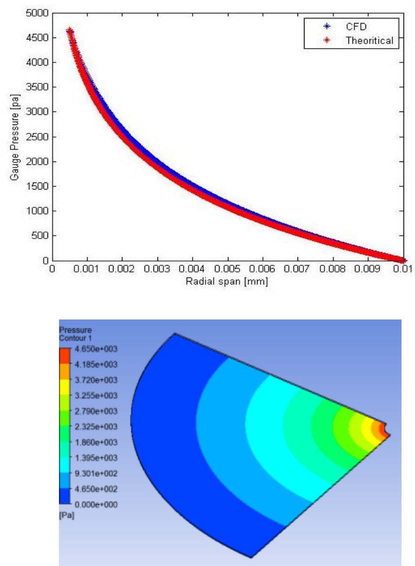

Fig - 9: Computational Fluid Dynamics Vallidation of Gas Bearing Pressure Profile

4.3 Estimation of Bearing Critical Speed

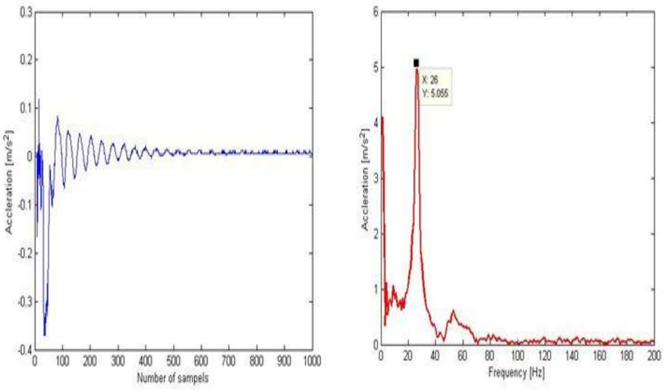

Fig - 10: Experimental Modal Analysis for the FES Gas Bearing System for First Critical Speed

5. CONCLUSIONS

The derived equations for pressure assisted flow in a capillary restrictor and a circular pad bearing are used to design a bearing system for a particular load application. A thrust bearing system was designed using these equations and experimental analyses was performed, where the following observations were made:

(1) The theoretical bearing disc friction coefficient was within 1% of the experimental results.
(2) The experimentally obtained bearing clearance is within 2% of the theoretically derived value.
(3) The theoretically obtained pressure and velocity profiles match with the CFD analysis.
(4) The experimentally obtained bearing stiffness matches with the theoretical values.

The designed gas bearing has a bearing friction coefficient which is 2 orders less than the conventional hydraulic bearings and three orders lower than the conventional ball bearings. The system compressed air requirement is very low (<1% of the system power) and hence it is advantageous for high efficiency applications. Since there is no contact between the bearing surfaces, this system has a very low wear and a very high life (> 15 years).

REFERENCES

[1] S. H. K. S. V. Mohite, “Analytical solutions for the stiffness and damping coefficients of squeeze films in MEMS devices with perforated back plates,” Micromech Microeng, no. 15, pp. 2083-2092, 2005.

[2] S.Jacob,J, "Air-Hammer Instability of Externally Pressurized Compressible Fluid," Nevada: Bently Rotor Dynamics Corporation, 1997.

[3] S. S. K. P. Dhar E, “ Feasibility of a Direct Coupled Turbine-Compressor Power Block for S-CO2 Brayton Cycles. ASME. Turbo Expo: Power for Land, Sea, and Air,,” vol. 9: Oil and Gas Applications; Supercritical CO2 Power Cycles; Wind Energy .

[4] K. D. Abderafi Charki, “ Numerical simulation and experimental study of thrust air bearings with multiple orifices.,” International Journal of Mechanical Sciences, pp. 28-38, 2013.

[5] K. D. Abderafi Charki, “Numerical simulation and experimental study of thrust air bearings with multiple orifices,” International Journal of Mechanical Sciences, pp. 28-38, 2013.

[6] D. G. e. al., “High-Speed Electrical Machines: Technologies, Trends, and Developments,” IEEE Trans. Ind. Electron, vol. 61(6), pp. 2946-2959, June 2014.

[7] A. T. e. al, “Electrical Machines for High-Speed Applications: Design Considerations and Tradeoffs,” IEEE Trans. Ind. Electron, vol. 61(6), pp. 3022-3029, 2014.

[8] E. S. e. al, “A practical review of rotating machinery critical speeds and modes,” Sound and Vibration, vol. 39, pp. 10-17, May 2005.

[9] D. J. Ewins, Modal Testing: Theory and Practice, vol. 359, 1984.

[10] J. C. Y. L. J. T. Wei Ma, “Improving the pneumatic hammer stability of aerostatic thrust bearing with recess using damping orifices,” In Tribology International ISSN 0301-679X, pp. 281-288, 2016.

[11] E. Dhar, “Electromagnetic design of a 5-kW, 10,000-rpm switched reluctance machine,” in 7th India International Conference on Power Electronics (IICPE), 2016.

[12] E. Dhar, "Rotodynamic Study of a High Speed Switched Reluctance Generator," academia.edu, p. 8, 2010.