An Experimental Comparison of Permanent Magnetic Bearing and Deep Groove Ball Bearing

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Abstract

In today's era, high-speed and high-precision is the main requirement of any rotating machinery. Ball bearings are the main element used to support this rotating machinery. Ball bearings have some limitations like it requires lubrication, more friction, heat generation during operation and less efficient in space applications. Permanent magnetic bearing (PMB) is capable to operate without lubrication, non-contact operation and with less magnetic resistance, no heat generation and less noisy.

This research work presents the experimental comparison of deep groove ball bearing and permanent magnetic bearing. Permanent magnetic bearing is designed and developed to evaluate performance of it. Experimental work is carried out on permanent magnetic bearing as well as deep groove ball bearing with the help of experimental set-up to find static magnetic resistance and resistance torque. The magnetic resistance and torque of permanent magnetic bearing are experimentally evaluated and compare that of with static friction co-efficient and frictional torque of six deep groove ball bearings (SKF, FLT, HCH, MAG, NBC, and NSK)

Experimental results shows that the permanent magnetic bearing having six times less static magnetic resistance than the lowest static friction bearing FLT bearing. Permanent magnetic bearing having 1.9 times less magnetic resistance torque than the lowest frictional torque bearing SKF at a speed of 597 RPM.

Keywords - *Permanent Magnetic Bearing (PMB), Static Friction, Magnetic Resistance, Frictional Torque, Magnetic Resistance Torque*

Nomenclature
M_w=weight of shaft and rotor
m_w =hanging weight
μ=static co-efficient of magnetic resistance
τ_{fm} = magnetic resistance torque of magnetic bearing
I_m=mass moment of inertia of magnetic bearing ($1/2mr^2$)
dω =change in rpm, 2πN/60
dt= change in time
I_{1m}= mass moment of inertia of rotor for magnetic bearing
I_{2m}=mass moment of inertia of shaft and magnetic ring for magnetic bearing
R=radius of rotor
R_s =radius of shaft
m=mass of rotor
m_m =mass of shaft and inner magnetic rings
μ_s=static co-efficient of friction for deep groove ball bearing
τ_{fb} = frictional torque of deep groove ball bearing
I_b= mass moment of inertia for deep groove ball bearing ($1/2$ mr ^{2})
I_{1b}= mass moment of inertia of rotor for deep groove ball bearing
I_{2b}=mass moment of inertia of shaft for deep groove ball bearing
m_b =mass of shaft and bearing inner race for ball bearing

I. INTRODUCTION

Bearing is the main element used to support rotating elements [1]. A bearing is a supporting machine element that control relative motion and reduces friction between moving parts [2]. Main purpose of bearing is to reduce friction between rotating parts for this purpose various research works are carried out on bearing for friction reduction and design improvement. In ancient time people were using wheel for the reducing friction and work. After that day by day revolutions of many civilizations invented various methods for friction reduction. Leonardo da Vinci integrated drawings of ball bearings in his design for a helicopter and carried out various experiment for static friction of sliding parts [3].

In this research work permanent magnetic bearing is designed and developed and compared permanent magnetic bearing with deep groove ball bearing. In present work various companies deep groove ball bearings static friction co-efficient and frictional torque are measured for different speed and compared with static magnetic resistance and resistance torque of permanent magnetic bearing.

Ball Bearing

A ball bearing is a type of rolling-element bearing that uses balls to maintain the partition between the bearing races [4]. The purpose of a ball bearing is to reduce rotational friction and support loads [5].

Magnetic Bearing

Magnetic bearings are contactless suspension devices, which are mainly used for rotating applications. There is no contact between stator and rotor therefore less resistance between the rotating part and its supporting parts.

There are two types of magnetic bearing, [6] Active magnetic bearing and passive magnetic bearing. Main applications of passive magnetic bearings (PMB) are high speed applications such as, in space technology (satellite), energy storage flywheel, High-speed machine tool spindles, Turbo-molecular pumps, Turbo-compressors, Ultra-centrifuges etc. [6] [7]

In permanent magnetic bearings (PMB) the rotor is levitated by the repulsive forces which generated between the magnets placed on both rotor and stator. The magnets on periphery of stator are arranged such that the same poles of magnet face each other and also same poles magnetic ring mounted on shaft. Due to same poles on stator magnet and magnetic ring, repulsive force will generate and magnetic ring will levitate in air. .

II. 3D MODEL AND DEVELOPMENT OF MAGNETIC BEARING TESTING SETUP

A 3D drawing of permanent magnetic bearing is prepared using creo 2.0 parametric modeling. Experimental set up of permanent magnetic bearing is developed for the measurement of static magnetic resistance and resistance torque.

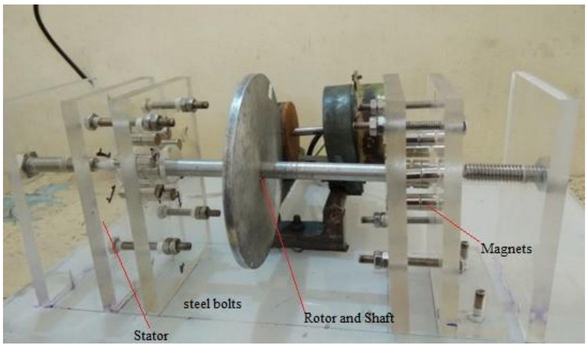

Figure 1: Experimental setup of permanent magnetic bearing

Parts specification of permanent magnetic bearing experimental set up is given in Table 1.

Table 1: Part specification of permanent magnetic bearing experimental set up

Name of Parts	Material	Dimensions
Base	Acrylic	300mm×400mm
Stator	Acrylic	150mm×100mm
Magnet	NdFeB	Φ10mm×10mm
Magnetic ring	NdFeB	Φ20mm×12mm×5mm
Shaft	Aluminum	Φ12mm×270mm
Rotor	Aluminum	Φ140mm×5mm
Steel bolt (1/4")	Steel	Φ6.35mm×63mm
Steel bolt (1/2")	Steel	Φ12.7mm×50.8mm

III. 3D MODEL AND DEVELOPMENT OF DEEP GROOVE BALL BEARING TESTING SETUP

A 3D model of deep groove ball bearing is prepared using creo 2.0 software.

Experimental set up of deep groove ball bearing is developed for the measurement of static friction and frictional torque of various companies deep groove ball bearing. The various companies deep groove ball bearing is tested for various speeds and compare with permanent magnetic bearing.

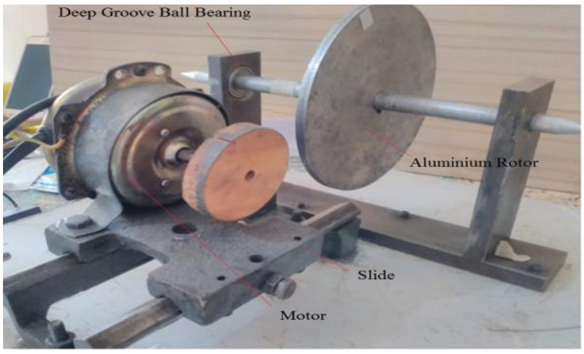

Figure 2: Experimental testing setup of deep groove ball bearing

List of various deep groove ball bearings are given in Table 2 which are used in this research for comparison purpose.

Table 2: List of various deep groove ball bearings

Bearing Company	Designation	Country
SKF	6001-2Z	ITALY
nbc	6001Z	INDIA
MAG	6001ZZ	CHINA
NSK	6001DDU	POLAND
FLT	6001RS	POLAND
HCH	6001-2RS	CHINA

IV. MEASUREMENT OF STATIC MAGNETIC RESISTANCE OF MAGNETIC BEARING

For the measurement of static magnetic resistance, load on shaft is applied by hanging a weight. So the load at which shaft just start to rotate is noted down and by applying equation $F=\mu \times R_N$ static magnetic resistance is calculated.

$F=\mu \times R_N$

$m_w \times g=\mu \times M_w \times g$

$\mu= mw / Mw$................................[8]

$\mu =10/410$

$\mu= 0.0243$ (for both magnetic bearings)

V. METHODOLOGY FOR MEASUREMENT OF MAGNETIC RESISTANCE TORQUE OF MAGNETIC BEARING

For the measurement of magnetic resistance torque, here, measurement is performed on rotor mounted on bearings that is gives an initial specific RPM and allowed to spin until it comes to a stop. By measuring stopping time and applying standard kinematic equations for constant angular acceleration magnetic resistance torque is calculated. Motor is sliding away after giving initial required RPM to the rotor.

Magnetic resistance torque,

$\boldsymbol{\tau_{fm} = -I_m\, d\omega/dt}$ ……………………………......[9]

$I_m = 1/2\ mr^2$

$I_m = I_{1m} + I_{2m}$

For magnetic bearing,

$I_{1m} = 1/2\ mR^2$

$I_{1m} = 0.5 \times 0.264 \times 0.07^2$

$I_{1m} = 6.468 \times 10^{-4}$ Kg.m^2

$I_{2m} = 1/2 m_m \times R_s^2$

$I_{2m} = 0.5 \times (0.08+0.066) \times 0.006^2$

$I_{2m} = 2.628 \times 10^{-6}$ Kg. m^2

$I_m = I_{1m} + I_{2m}$

$\boldsymbol{I_m = 6.494 \times 10^{-4}}$ **Kg.m^2**

Table 3: Magnetic bearing magnetic resistance torque calculations

Speed (RPM)	Stopping Time (Second)	Magnetic Resistance Torque τ_{fm} (N. m)
597	31.00	1.3089×10^{-03}
550	28.04	1.3332×10^{-03}
500	27.01	1.2582×10^{-03}
450	24.02	1.2733×10^{-03}
400	21.07	1.2903×10^{-03}
350	18.70	1.2721×10^{-03}
300	15.50	1.3155×10^{-03}
250	12.80	1.3275×10^{-03}
200	11.20	1.2137×10^{-03}
150	9.1	1.1203×10^{-03}
100	6.6	1.0298×10^{-03}

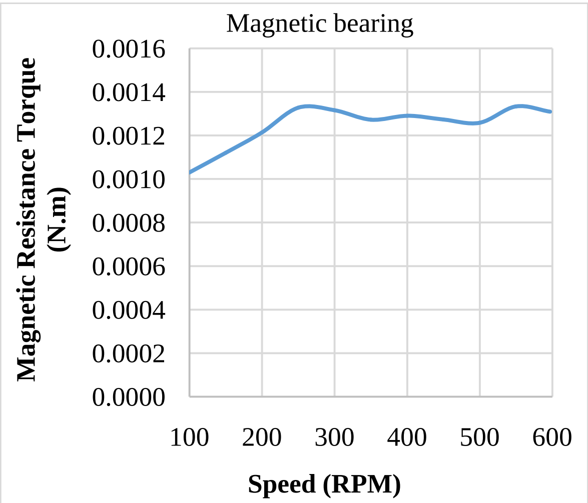

Figure 3: Graph of magnetic resistance torque vs. Speed

VI. EXPERIMENTAL MESURMENT OF STATIC FRICTION

For the measurement of static co-efficient of friction, load on shaft is applied by hanging a weight. So the load at which shaft just start to rotate is noted down and by applying equation $F=\mu_s \times R_N$ static co-efficient of friction is calculated.

$F=\mu_s \times R_N$

$\mu_s = m_w / M_w$ ………………………….………[8]

For deep groove ball bearing,

$\mu_s = m_w / M_w$

For SKF bearing,

$\mu_s = 66/368$

$\mu_s = 0.1793$ (for both SKF bearings)

Table 4: Static friction co-efficient of various deep groove ball bearings

Bearing Compan y	Mass Of Rotor And Shaft (M_w In Gram)	Hanging Weight (m_w In Gram)	Static Co-Efficient of Friction (μ_s)
SKF	368	66	0.0896
nbc	368	94.6	0.1285
MAG	368	80.6	0.1095
NSK	368	86.6	0.1176
FLT	368	50.6	0.0687
HCH	368	102.6	0.1394

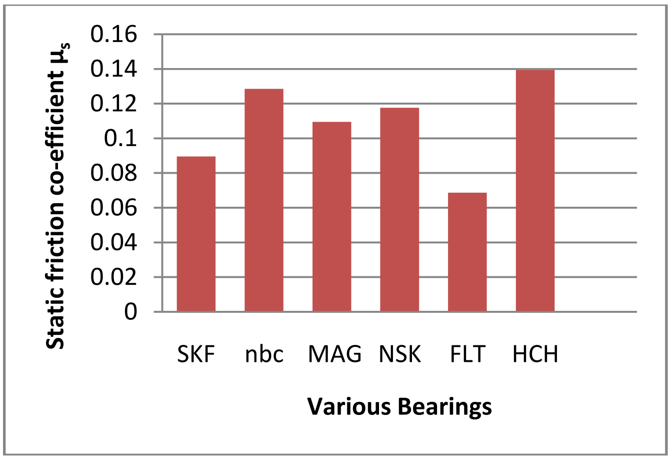

Figure 4: Graph of static friction co-efficient of various Deep groove ball bearings

From figure 4, FLT bearing has the lowest value of static friction co-efficient of 0.0687 compare to all other companies deep groove ball bearing. HCH bearing has the highest value of static friction co-efficient of 0.1394. All other bearing has in between static friction co-efficient.

VII. EXPERIMENTAL MESURMENT OF FRICTIONAL TORQUE OF DEEP GROOVE BALL BEARING

For the measurement of frictional torque, here, measurement is performed on rotor mounted on bearings that is gives an initial specific RPM and allowed to spin until it comes to a stop. By measuring stopping time and applying standard kinematic equations for constant angular acceleration frictional torque is calculated. Motor is sliding away after giving initial required RPM to the rotor. For the measurement of speed digital non-contact laser type tacho-meter is used. Frictional torque,

$\boldsymbol{\tau_{fb} = I_b\, d\omega/dt}$……………………….………..[9]

Moment of inertia of deep groove ball bearing,

$I_{1b}=1/2\ mR^2$

$I_{1b}=0.5\times0.264\times0.07^2$

$I_{1b}=6.468\times10^{-4}$ Kg.m^2

$I_{2b}=1/2m_b \times R_s^2$

$I_{2b}=0.5\times (0.08+0.024) \times0.006^2$

$I_{2b}=1.872\times10^{-6}$ Kg. m^2

$I_b= I_{1b}+I_{2b}$

$\boldsymbol{I_b=6.486\times10^{-4}}$ **Kg.m^2**

VIII. EXPERIMENTAL RESULTS & DISCUSSION

Deep Groove Ball Bearing Frictional Torque Calculations

Table 5: Frictional torque of SKF bearing

Speed (RPM)	Stopping Time (Second)	Frictional Torque τ_{fb} (N. m)
597	16.17	2.5076×10^{-03}
550	15.58	2.3977×10^{-03}
500	14.16	2.3983×10^{-03}
450	12.73	2.4009×10^{-03}
400	11.20	2.4257×10^{-03}
350	10.45	2.2748×10^{-03}
300	9.54	2.1358×10^{-03}
250	8.61	1.9721×10^{-03}
200	7.86	1.7282×10^{-03}
150	6.32	1.6120×10^{-03}
100	4.02	1.6895×10^{-03}

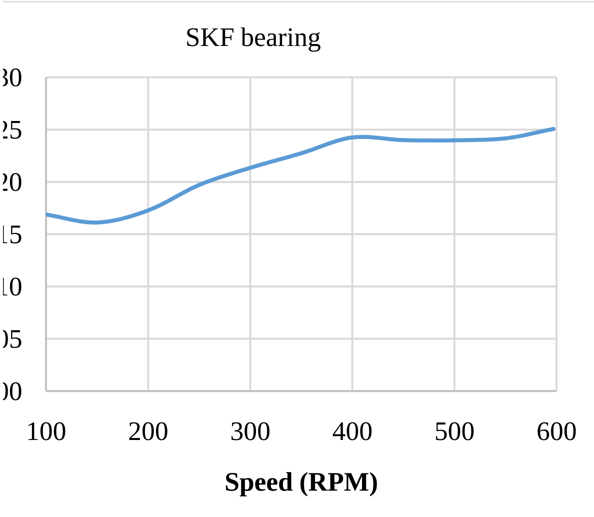

Figure 5: Graph of frictional torque vs. Speed of SKF bearing

Table 6: Frictional torque of nbc bearing

Speed (RPM)	Stopping Time (Second)	Frictional Torque τ_{fb} (N. m)
597	9.00	4.5054×10^{-03}
550	7.75	4.8202×10^{-03}
500	6.87	4.9433×10^{-03}
450	6.30	4.8515×10^{-03}
400	6.00	4.5280×10^{-03}
350	5.40	4.4023×10^{-03}
300	3.98	5.1196×10^{-03}
250	3.40	4.9942×10^{-03}
200	2.69	5.0499×10^{-03}
150	2.20	4.6309×10^{-03}
100	1.60	4.2450×10^{-03}

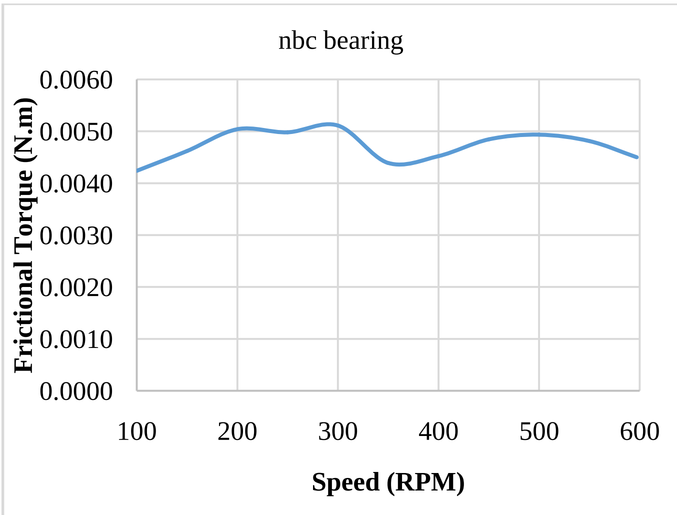

Figure 6: Graph of frictional torque vs. Speed of nbc bearing

Table 7: Frictional torque of MAG bearing

Speed (RPM)	Stopping Time (Second)	Frictional Torque τ_{fb} (N. m)
597	7.30	5.5546×10^{-03}

550	6.51	5.7383×10^{-03}
500	5.60	6.0643×10^{-03}
450	4.68	6.5308×10^{-03}
400	4.20	6.4686×10^{-03}
350	3.50	6.7921×10^{-03}
300	3.20	6.3676×10^{-03}
250	2.78	6.1080×10^{-03}
200	2.60	5.2247×10^{-03}
150	2.10	4.8515×10^{-03}
100	1.85	3.6714×10^{-03}

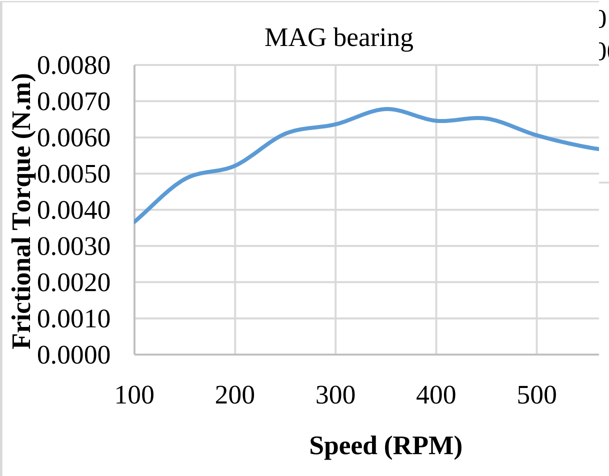

Figure 7: Graph of frictional torque vs. Speed of MAG bearing

Table 8: Frictional torque of NSK bearing

Speed (RPM)	Stopping Time (Second)	Frictional Torque τ_{fb} (N. m)
597	4.48	9.0511×10^{-03}
550	4.10	9.1113×10^{-03}
500	3.88	8.7527×10^{-03}
450	3.60	8.4901×10^{-03}
400	3.40	7.9907×10^{-03}
350	2.80	8.4901×10^{-03}
300	2.65	7.6891×10^{-03}
250	2.45	6.9307×10^{-03}
200	2.08	6.5308×10^{-03}
150	1.74	5.8552×10^{-03}
100	1.02	6.6589×10^{-03}

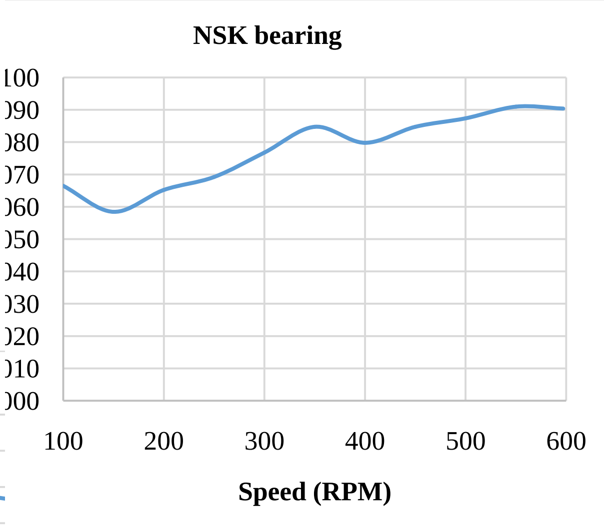

Figure 8: Graph of frictional torque vs. Speed of NSK bearing

Table 9: Frictional torque of FLT bearing

Speed (RPM)	Stopping Time (Second)	Frictional Torque τ_{fb} (N. m)
597	10.91	3.7166×10^{-03}
550	10.65	3.5076×10^{-03}
500	9.79	3.4689×10^{-03}
450	9.45	3.2343×10^{-03}
400	8.60	3.1591×10^{-03}
350	8.3	2.8641×10^{-03}
300	7.83	2.6023×10^{-03}
250	7.03	2.4154×10^{-03}
200	6.85	1.9831×10^{-03}
150	5.07	2.0095×10^{-03}
100	3.81	1.7827×10^{-03}

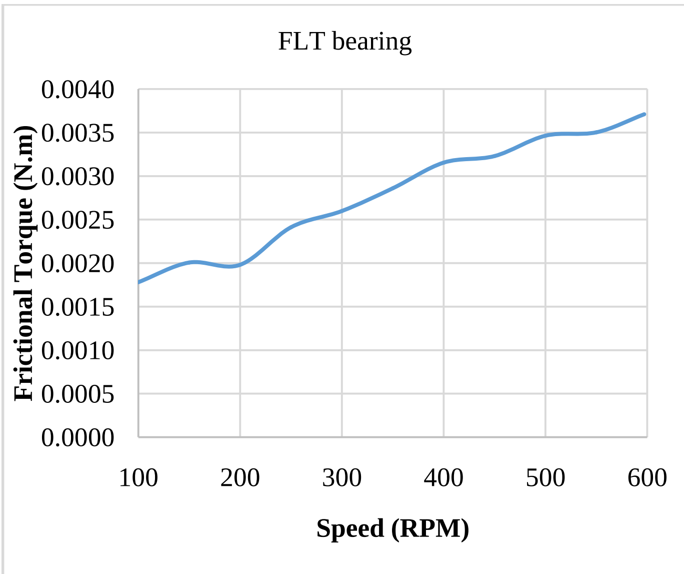

Figure 9: Graph of frictional torque vs. Speed of FLT bearing

Table 10: Frictional Torque of HCH bearing

Speed (RPM)	Stopping Time (Second)	Frictional Torque τ_{fb} (N.m)
597	3.92	1.034×10^{-02}
550	3.67	1.0101×10^{-02}
500	3.35	1.0101×10^{-02}
450	3.16	9.6723×10^{-03}
400	2.98	9.1169×10^{-03}
350	2.71	8.7721×10^{-03}
300	2.33	8.7452×10^{-03}
250	1.89	8.9842×10^{-03}
200	1.48	9.1785×10^{-03}
150	1.32	7.7183×10^{-03}
100	1.14	5.9580×10^{-03}

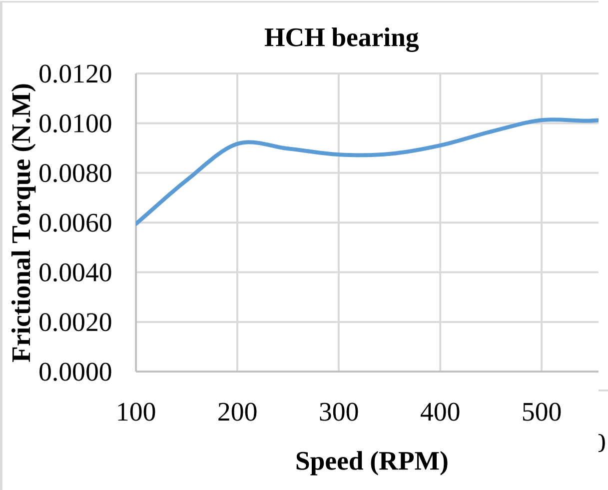

Figure 10: Graph of frictional torque vs. Speed of HCH bearing

IX. STATIC FRICTION /MAGNETIC RESISTANCE CO-EFFICIENT COMPARISON OF VARIOUS BEARINGS

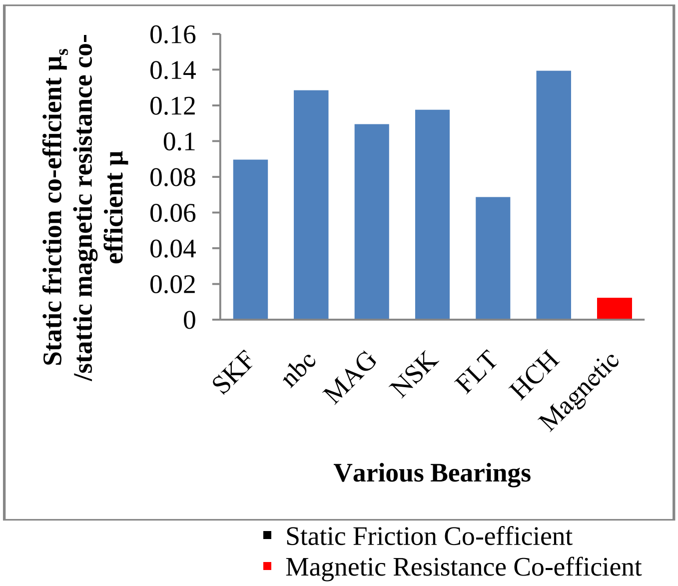

Figure 11: Static friction /magnetic resistance co-efficient comparison of various bearings

From figure 11, Magnetic bearing has the lowest static magnetic resistance co-efficient of 0.0121 compare to all other bearing. Out of various companies deep groove ball bearing FLT bearing has the lowest static friction co-efficient of 0.0687 and HCH bearing has highest static friction co-efficient of 0.1394. All other bearings are coming in between maximum and minimum static friction co-efficient.

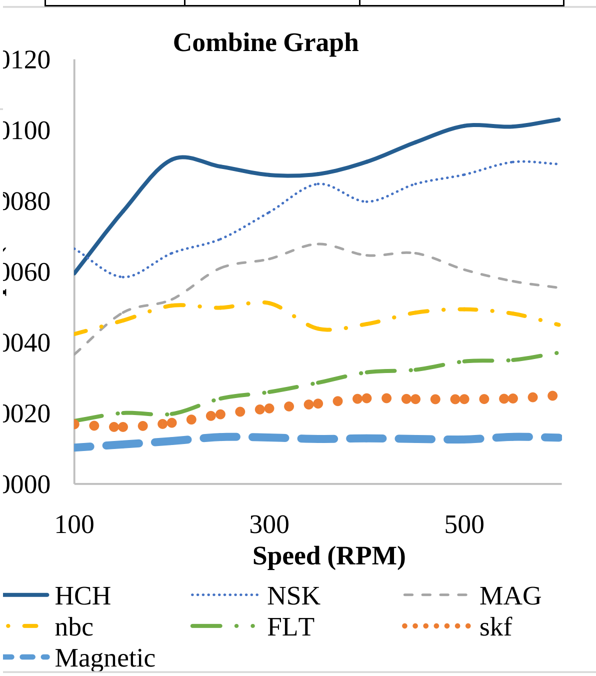

Figure 12: Combine graph of frictional torque/magnetic resistance torque of various bearings

From figure 12, magnetic bearing has the lowest magnetic resistance torque. HCH bearing has the maximum frictional torque out of all this various companies deep groove ball bearing. SKF deep groove ball bearing has the lowest frictional torque compare to all other companies deep groove ball bearing.

X. COMPARISON OF MAXIMUM FRICTIONAL TORQUE/MAGNETIC RESISTANCE TORQUE OF VARIOUS BEARINGS

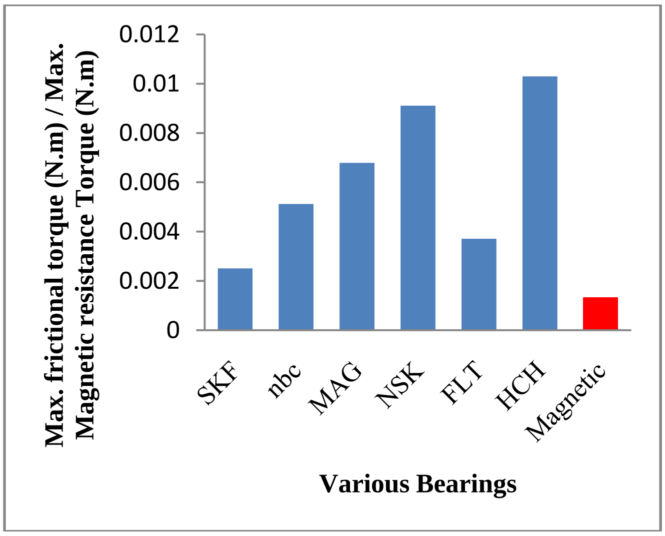

Figure 13: Comparison of maximum frictional torque/magnetic resistance torque of various bearings

In figure 13, magnetic bearing has the lowest magnetic resistance torque (1.33×10^{-3} N.m) compare to all other bearing frictional torque.HCH bearing has the highest value of frictional torque (1.03×10^{-2} N.m) compare to all other bearing. So compare to frictional torque of deep groove ball bearing magnetic bearing has very low magnetic resistance.

XI. CONCLUSION

After performing all the experiments it is concluded that permanent magnetic bearing having less magnetic resistance compare to deep groove ball bearing friction. Hence, permanent magnetic bearing has less power loss.

Following important facts are concluded from experimental results.

- Permanent magnetic bearing has the lowest 0.0121 static co-efficient of magnetic resistance which is lowest of all the bearings.
- Permanent magnetic bearing having six times less static magnetic resistance than the lowest static friction bearing FLT.
- FLT bearing has the lowest 0.0735 static co-efficient of friction among all tested deep groove ball bearings.
- Permanent magnetic bearing having less magnetic resistance means less power loss during running condition compare to all other tested deep groove ball bearing.
- Permanent magnetic bearing has the lowest starting magnetic resistance torque (1.0298×10^{-03} N.m) at a speed of 100 rpm and running magnetic resistance torque (1.3089×10^{-03} N.m) at a speed of 597 RPM compare to other bearings frictional torque.
- Permanent magnetic bearing having 1.9 times less magnetic resistance torque than the lowest frictional torque bearing SKF at a speed of 597 RPM.
- SKF bearing has the lowest starting frictional torque (1.6895×10^{-03} N.m) at a speed of 100 RPM and running frictional torque (2.5076×10^{-03} N.m) at a speed of 597 RPM among all tested deep groove ball bearings.
- Rubber sealing producing more friction and noise.

During selection of bearings, it is necessary to optimize the initial cost and power loss of bearing. This work provides guideline for selection of different bearing with consideration of power loss as well as cost and payback period.

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