Thermal and Vibration Analysis of 6200 Deep Groove Ball Bearing

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***Abstract* — *Bearings are used to transmit force and moment in the machinery with rotating shafts. For high speed and low power requirement, deep groove ball Bearings are widely used in many applications. In the present work, 6200 deep groove ball Bearing is considered and four different materials are used for analysis. First bearing is made up of complete stainless steel; second and third Bearings are hybrid Bearings in which the inner and outer raceways are made up of stainless steel and the balls are made up of ceramic materials namely aluminum oxide and zirconium oxide respectively, and the fourth Bearing is a ceramic ball Bearing which is completely made up of aluminum oxide. Temperature variation and the heat flux at different rotating speeds are calculated both theoretically and by using steady state thermal analysis in ANSYS. Both the theoretical and ANSYS results are in good agreement. The modal frequencies and the corresponding mode shapes are obtained from modal analysis using ANSYS. The amplitude of vibration variations along the x, y, and z directions are obtained by using harmonic analysis using ANSYS. The results obtained from modal analysis and harmonic analysis depict each other*

Keywords **—***Deep groove ball bearings, Thermal Analysis , Modal Analysis, Harmonic Analysis, ANSYS, CATIA***.**

I. INTRODUCTION

The primary goal of this work is obtain the Static Structural, Thermal, and Vibrational analysis results and then compare the results to find best deep groove ball bearing among the four bearings considered.
Hybrid and Ceramic ball bearings are being recently studied upon due to their high strength bearing capacity and lower wear when compared to steel bearings. Friction in bearings causes an increase of the temperature inside the bearing. If the heat produced cannot be adequately removed from the bearing, the temperature might exceed a certain limit, and as a result the bearing would fail [1]. A full parametric study is conducted that could include a matrix of parameters, which can be varied on the Vibrational analysis of a bearing [2 & 3]. Failure analysis of a ball bearing is performed by using different techniques, such as, oil analysis, wear debris analysis, vibration analysis and acoustic emission analysis [4, 5, 6, & 7]. The harmonic analysis and vibration monitoring of structures is studied [8]. The present paper deals with the Thermal and Vibrational analysis of a deep groove ball bearing both theoretically and by using ANSYS.

II. THERMAL ANALYSIS OF A DEEP GROOVE BALL BEARING

In the present work, the speed of the rotating shaft is varied. Due to this rotation, friction is generated between the rolling elements and the raceways. In order to reduce the friction, lubricant is used. Due to the interaction between the rolling elements and the fluid, an Elasto-hydrodynamic Layer is formed between the contact surfaces. Heat flux is generated due to frictional force, thereby increasing the bearing temperature. These heat fluxes and the corresponding bearing temperatures are calculated both theoretically and by using ANSYS software. The results thus obtained are compared.

II.A THEORETICAL CALCULATION FOR THERMAL ANALYSIS

Friction plays a main role in the operation of a bearing. The frictional moment M of a rolling bearing is the sum total of rolling friction, sliding friction and lubricant friction is the bearing's resistance to motion. Repeat the calculations for various speeds between the range of 1000 rpm to 20000 rpm.

II.A.1 FRICTION MOMENT

The mean diameter of the bearing is given by the following relation:

$$D_m = \frac{D_i + D_o}{2} \text{ mm}$$

Where, D_i is the diameter of the inner ring and D_o is the diameter of the outer ring.
The relation for the load-independent component of the frictional moment is as follows:

$$M_{\text{load ind}} = F_o \times 10^{-7} \times \left(\nu N\right)^{2/3} D_m^3 \text{ N}\cdot\text{mm}$$

Where, F_o is the friction factor.

The relation for the load-dependent component of the frictional Moment is as follows:

$$M_{\text{Load}} = f_i \times P \times D_m \ \text{N} \cdot \text{mm}$$

Where, f_i is the friction factor.

The relation for the friction factor f_i is as follows:

$$f_i = 0.0005 \times \left(\frac{F_r}{C_o} \right)^{0.5}$$

Where, F_r is the radial load applied and C_o is the static loading capacity of the bearing.

The total frictional moment of the bearing is given by the following relation:

$$\begin{aligned} M &= M_{\text{load ind}} + M_{\text{load}} \\ &= F_o \times 10^{-7} \times (\nu N)^{2/3} D_m^3 + (f_i \times P \times D_m) \ \text{N} \cdot \text{mm} \end{aligned}$$

The Heat flow due to this frictional moment is given by the following relation:

$$Q_R = 1.047 \times 10^{-4} \times N \times M \qquad \ldots\ldots (1)$$

Calculate the internal heat generated by the ball elements.

$$\dot{Q}_R = \frac{Q_R}{\cancel{V}}$$

Where, $\cancel{V}$ is the volume of the ball element.

II.A.2 HEAT GENERATED BY THE BEARING

Write the relation for the velocity transmitted by the shaft to the bearing.

$$V = \frac{\pi D N}{60} \ \text{mm/s}$$

Where, N is the speed of the shaft and D is the diameter of the shaft onto which the bearing is mounted.

The lubricant considered is VG R22 grease and consider the ambient temperature to be $30°\text{C}$.

The Reynolds number for the flow in between the balls and the inner ring is given by the following relation:

$$\text{Re} = \frac{V D_b}{\nu}$$

Where, ν is the kinematic viscosity of VG R22 grease.

Write the relation for the Nusselt number.

$$Nu_D = 2 + \left(0.4 \text{Re}_D^{1/2} + 0.06 \text{Re}_D^{2/3}\right) \text{Pr}^{0.4} \left(\mu / \mu_s\right)^{1/4}$$

Where, Pr is the Prandtl number μ and μ_s are the dynamic coefficients of viscosity of VG R22 grease.

The Convective heat transfer coefficient is calculated by using the following relation for Nusselt number.

$$h = \frac{Nu_D \times k}{D_b} \ \text{W/mm}^2 \cdot \text{K}$$

Where, k is the coefficient of thermal conductivity of VG R22 grease.

Calculate the bearing temperature as follows: $Q_R = ZhA(T_b - T_\infty)$ …… (2)

Where, T_b is the operating temperature of the bearing, Z is the number of balls, and T_∞ is the ambient temperature of VG R22 grease.

The relations (1) and (2) and find the temperature of the bearing at the operating conditions.

II.B THERMAL ANALYSIS USING ANSYS

In the present work, the bearing model is imported into Steady state Thermal Analysis module and the geometry of the various parts are defined. Apply the load of 5000 N in the negative Z direction. Specify the values of the coefficient of convection by considering the fluent Figures 1 and 2 shows the temperature variation and heat flux generated by the bearing at 1000 rpm for Stainless steel bearing.

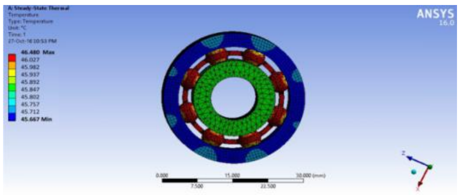


Figure 1 Temperature of the Stainless Steel Bearing at 1000 rpm

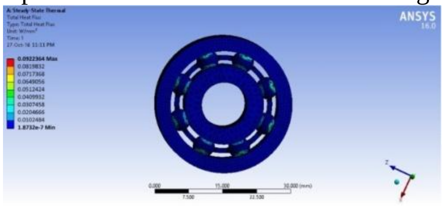


Figure 2 Heat flux of the Stainless Steel Bearing at 1000 rpm

II.C. COMPARISON OF THERMAL ANALYSIS RESULTS

The temperature of the bearing at the rotating speed and the corresponding heat flux generated from the theoretical calculations and Steady State Thermal Analysis are tabulated as shown in the tables 1 and 2 respectively.

Table 1 Comparison of Temperature

Speed (rpm)		Temperature (°C)			
		Steel	Al_2O_3	ZrO_2	Complete Al_2O_3
1000	Theoretical	47.5	46.90	46.85	44.24
	ANSYS	46.48	45.84	45.76	43.002
4000	Theoretical	62.74	62.53	62.28	58.32
	ANSYS	61.65	61.46	61.13	57.26
8000	Theoretical	75.48	75.04	74.48	70.23
	ANSYS	74.39	73.98	73.42	69.97
12000	Theoretical	85.21	84.51	83.63	79.47
	ANSYS	84.32	83.27	82.52	78.32
16000	Theoretical	93.42	92.45	91.24	85.39
	ANSYS	92.18	91.33	90.13	84.28
20000	Theoretical	100.68	99.44	97.89	94.57
	ANSYS	99.34	98.43	96.81	93.43

Table 2 Comparison of Heat Flux

Speed (rpm)		Heat Flux (W/mm^2)			
		Steel	Al_2O_3	ZrO_2	Complete Al_2O_3
1000	Theoretical	0.092536	0.092302	0.092012	0.091838
	ANSYS	0.092236	0.092123	0.091845	0.091634
4000	Theoretical	0.375445	0.373093	0.370163	0.368412
	ANSYS	0.375118	0.372857	0.36853	0.361421
8000	Theoretical	0.761218	0.753751	0.744448	0.738889
	ANSYS	0.760978	0.753312	0.744135	0.738523
12000	Theoretical	1.15482	1.140144	1.121858	1.110933
	ANSYS	1.151240	1.139763	1.121467	1.110586
16000	Theoretical	1.555224	1.531520	1.501983	1.484337
	ANSYS	1.554987	1.528760	1.501568	1.483979
20000	Theoretical	1.961796	1.927413	1.88457	1.858974
	ANSYS	1.961343	1.927035	1.88301	1.858681

III. VIBRATIONAL ANALYSIS OF A DEEP GROOVE BALL BEARING

In, the present work, the modal analysis, Harmonic analysis, and transient dynamic analysis of the bearing are carried out under the application of load of 1000 N. Modal analysis gives the modal frequencies and the modal shapes of the bearing. Harmonic analysis gives the amplitude of vibration of the bearing along the x, y, and z directions. Transient dynamic analysis gives an overall view of the deformation and stress variation for a period of 10 s upon impact loading of 1000 N at the end of 2 s. All three analysis are carried out for the four bearings considered.

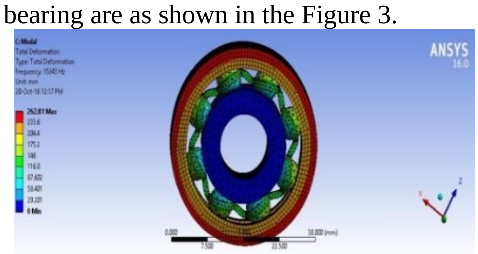
III.A MODAL ANALYSIS USING ANSYS

Modal Analysis of the 6200 deep groove ball with different materials are performed using ANSYS and the values are as tabulated in the Table 3.

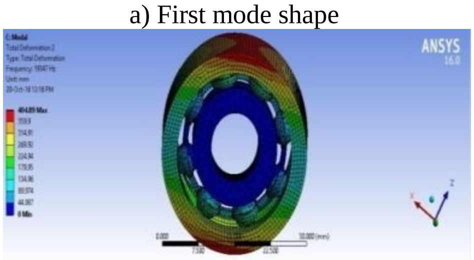
Table 3 Natural Frequencies of the bearing with different materials

Mode	Frequency (Hz)			
	Stainless steel	Al_2O_3	ZrO_2	Complete Al_2O_3
1	15243	17639	16145	32208
2	19347	22344	20468	39636
3	19545	22555	20672	40041
4	22652	25039	23503	46246
5	22697	25073	23546	49075

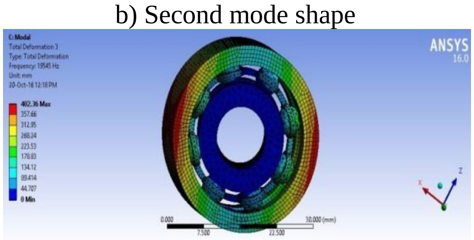
The five mode shapes of a stainless steel deep groove ball bearing are as shown in the Figure 3.



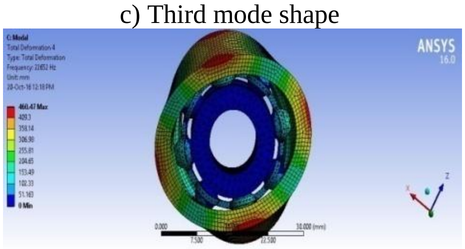
a) First mode shape



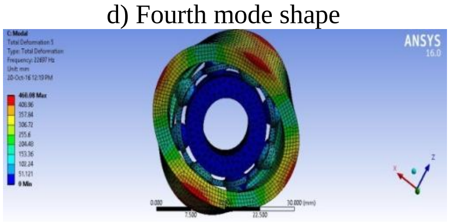
b) Second mode shape



c) Third mode shape



d) Fourth mode shape

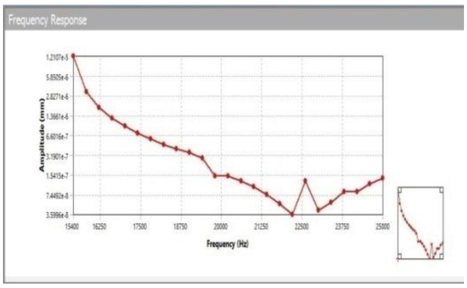


e) Fifth mode shape

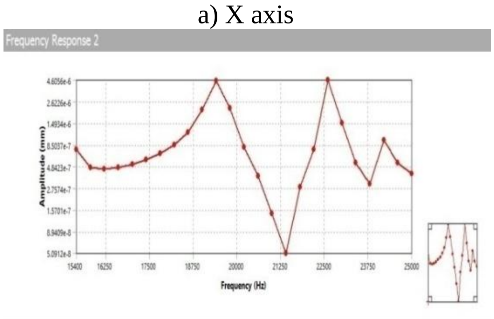
Figure 3 Different mode shapes of Stainless steel bearing

III.B. HARMONIC ANALYSIS USING ANSYS

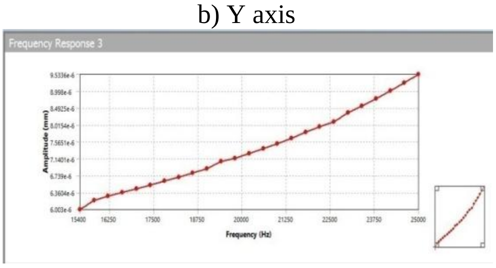
The amplitude versus frequency curves are obtained in the X, Y, and Z directions for the four bearings considered from Harmonic Analysis using ANSYS. Harmonic analysis is performed by applying a load of 1000 N in the Z direction. The frequency range is specified between 15000 Hz to 25000 Hz and the number of steps is given as 25. The frequency responses of the stainless steel bearing in the X, Y, and Z directions are as shown in the Figure4.



a) X axis



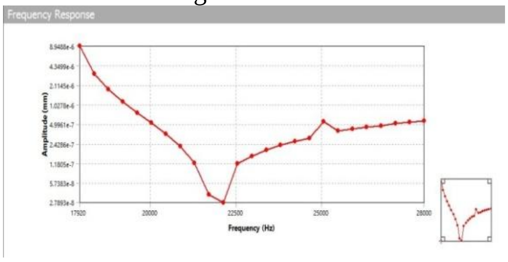
b) Y axis



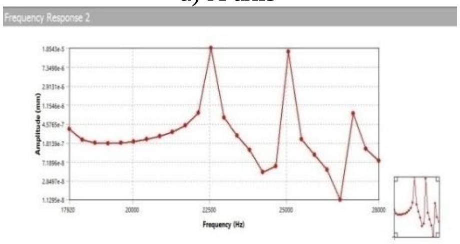
c) Z axis

Figure 4 Frequency response of Stainless steel bearing

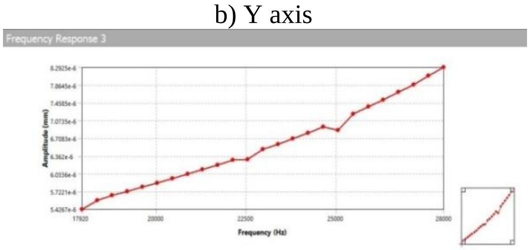
Harmonic analysis is performed by applying a load of 1000 N in the Z direction. The frequency range is specified between 17500 Hz to 28000 Hz and the number of steps is given as 25.The frequency responses of the deep groove ball bearing with Aluminum oxide balls in the X, Y, and Z directions are as shown in the Figure 5.



a) X axis



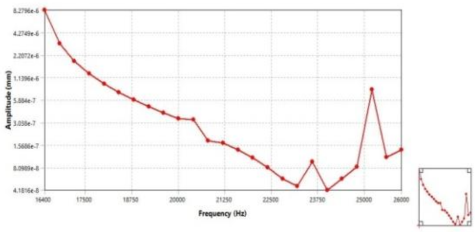
b) Y axis



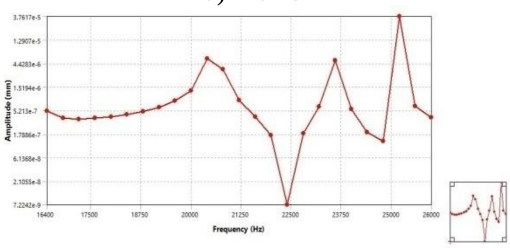
c) Z axis

Figure 5 Frequency response of Al_2O_3 bearing

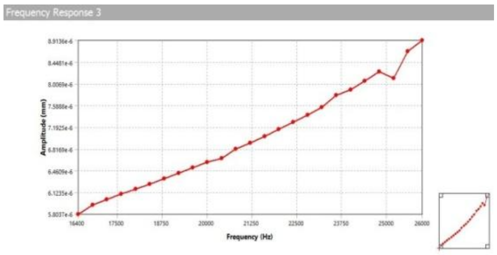
Harmonic analysis is performed by applying a load of 1000 N in the Z direction. The frequency range is specified between 16000 Hz to 26000 Hz and the number of steps is given as 25. The frequency responses of the deep groove ball bearing with Zirconium oxide balls in the X, Y, and Z directions are as shown in the Figure 6.



a) X axis



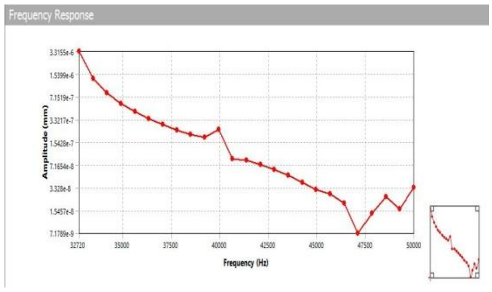
b) Y axis



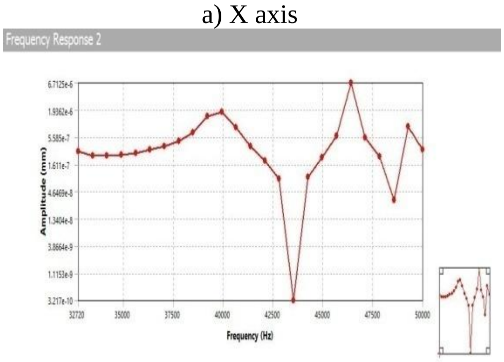
c) Z axis

Figure 6 Frequency response of ZrO_2 bearing

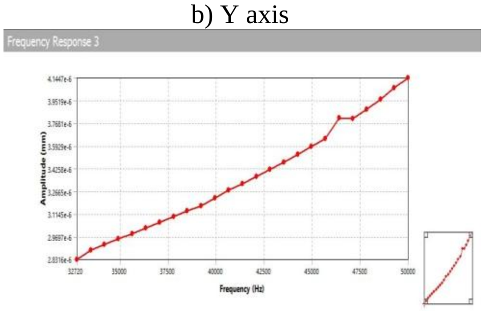
Harmonic analysis is performed by applying a load of 1000 N in the Z direction. The frequency range is specified between 30000 Hz to 50000 Hz and the number of steps is given as 25. The frequency responses of the deep groove ball bearing made up of Aluminum oxide in the X, Y, and Z directions are as shown in the Figures 7.



a) X axis



b) Y axis



c) Z axis

Figure 7 Frequency response of complete Al_2O_3 bearing

IV. RESULTS AND DISCUSSIONS

The results obtained from the thermal analysis, and Vibrational analysis for all the four bearing materials used for 6200 deep groove ball bearing are discussed in this section.

IV.A COMPARISON OF STEADY STATE THERMAL ANALYSIS RESULTS

The Maximum Temperature obtained at the contact and the heat flux generated obtained for varying speeds are compared for the four deep groove ball bearings considered.

IV.A.1 COMPARISON OF TEMPERATURE

The maximum temperature created due to friction between the rubbing surfaces for different operating speeds for the four types of bearing are as shown in the Figure 8. From the graph, it is clear that deep groove ball bearing completely made up of Aluminum oxide have relatively lower temperature when compared to the other three at higher speeds.

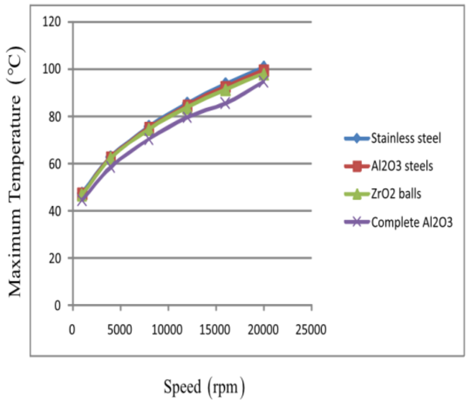


Figure 8 Maximum Temperature at operating speed versus Speed

IV.A.2 COMPARISON OF HEAT FKUX GENERATED

The heat flux generated due to friction between the rubbing surfaces for different operating speeds for the four types of bearing are as shown in the Figure 9. From the graph, it is clear that at lower operating speeds, there is no much difference in the heat flux generated by the bearings. As the speed increases, the ceramic bearing has relatively lower heat flux when compared to steel and hybrid bearings.

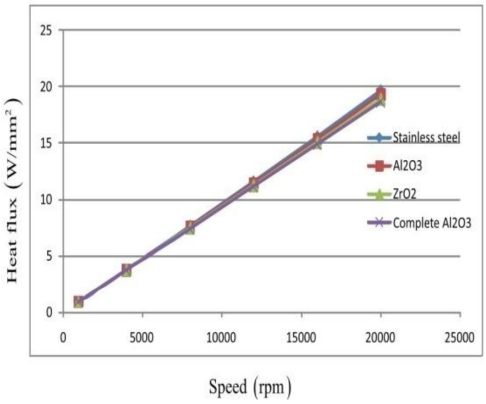


Figure 9 Heat flux generated versus Speed

V. CONCLUSIONS

Thus, from the results obtained, the ceramic deep groove ball bearings have higher resistance to moment friction thereby generating lower heat fluxes and relatively lesser temperatures when compared to hybrid and steel deep groove ball bearings. Also, the modal frequencies of the ceramic bearings are far higher than that of the steel deep groove ball bearings, which indicates that these bearings can operate successfully at higher speeds.

The following conclusions are drawn from the project work:

- The theoretical and ANSYS (steady state thermal analysis) results obtained for temperature of the bearing surface at the operating speed and the heat flux generated from are in agreement with each other.
- The modal and harmonic analysis are in good agreement with each other.

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