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# Fatigue Life and Vibration Analysis of 6200 Hybrid-Deep Groove Ball Bearing

Cheekurumelli Siddhartha[1], Putti Srinivasa Rao[2]

[1]*Post Graduate student, Department of Mechanical Engineering [Machine design], Andhra University Visakhapatnam, Andhra Pradesh*

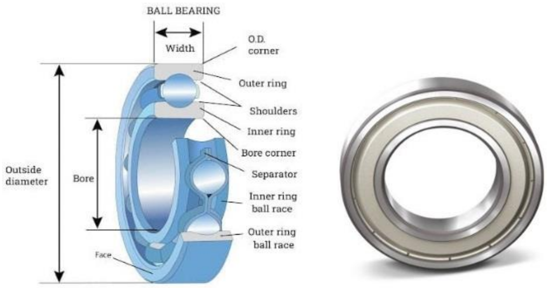
[2]*Professor, Department of Mechanical Engineering [Machine design], Andhra University Visakhapatnam, Andhra Pradesh*

***Abstract—In machinery, deep groove ball bearings are essential for supporting rotating shafts by reducing friction and noise during force and moment transmission. Known for their suitability in high-speed and low-power applications, these bearings are widely used in equipment such as DC motors, fans, and air conditioners. Bearing selection depends on shaft size, application, and applied loads, typically radial, axial, or combined. Leading manufacturers, like SKF, TIMKEN, and NTN, offer catalogues that specify bearing types, dimensions, load ratings, and factors like geometry and basic load capacity. In this study, a standard 6200 deep groove ball bearing is examined under radial loading using three material types: high-chromium steel (GCr15SiMn), full ceramic (silicon nitride), and a hybrid configuration where the rings and cage are 440C stainless steel, and the balls are silicon nitride (Si3N4). A 3D model of the bearing was designed in CATIA based on standard catalogue dimensions. The analysis includes fatigue life evaluation in ANSYS, cross-validated analytically in MATLAB, along with modal and harmonic response assessments. The natural frequencies and frequency responses were calculated to assess the bearing's vibration characteristics under various operating conditions. By examining amplitude against frequency, the vibration response was determined, providing valuable insights into the bearing's behaviour. This comprehensive approach allows for detailed understanding of performance in terms of durability, load-handling capacity, and vibrational stability.***

***Index Terms— 6200Deepgroove ball bearing, Fatigue and Natural frequencies, harmonics of bearings***

## I. INTRODUCTION

The 6200 deep groove ball bearing is a versatile, widely used component ideal for applications needing reliable rotational support and low friction. It is compact and suited for moderate speeds and loads, making it perfect for electric motors, appliances, and industrial machinery. With a straightforward design—an inner ring, outer ring, cage, and balls—its deep grooves support both radial and limited axial loads. Known for high precision, low noise, and minimal maintenance, the 6200 series is available in various materials, such as high-chromium steel, stainless steel, and ceramics, from brands like SKF, TIMKEN, and NTN. These options enable use in high-speed, high-temperature, and corrosive environments, providing engineers with a reliable, cost-effective choice for rotary motion control.




Deep groove ball bearings have a simple structure and are widely used, but they primarily fail due to contact fatigue spalling of rolling elements. Contact finite element analysis (FEA) provides key insights into contact stress, strain, penetration, and sliding distance—factors crucial for optimizing bearing design. Contact problems are complex and nonlinear, involving unknown contact areas that change unpredictably with load, material, and boundary conditions, along with frictional effects that further complicate analysis [1]. Hybrid and ceramic bearings are of particular interest due to their higher strength and lower wear compared to steel bearings. Frictional heat in bearings can lead to failure if not managed properly.

This work conducts a full parametric study, analyzing vibration with varied parameters. Failure analysis techniques such as oil, wear debris, vibration, and acoustic emission analyses are utilized. The study combines theoretical and ANSYS-based thermal and vibrational analyses to evaluate the bearings' performance [2].

## II. PROCEDURE

### *A. Design of Deep groove ball bearing*

Modelling of 6200 deep groove ball bearing with reference to SKF manufacturer's catalogue for the dimensions is considered. The part drawing of each element of bearing which are inner and outer race, cage and balls are modelled individually and assembled in assembly design by CATIA. The dimensions of deep groove ball bearing are as follows:

Table1 Dimensions Deep groove ball bearing

| Part name | Dimension (in mm) |
|---|---|
| Bore diameter (d) | 10 |
| Outer diameter (D) | 30 |
| Ball diameter ($D_b$) | 5.2 |
| No.of balls (Z) | 8 |
| Pitch diameter ($D_m$) | 20 |
| Width (W) | 9 |

For the given dimensions the ball bearing is modelled in CATIA as shown below

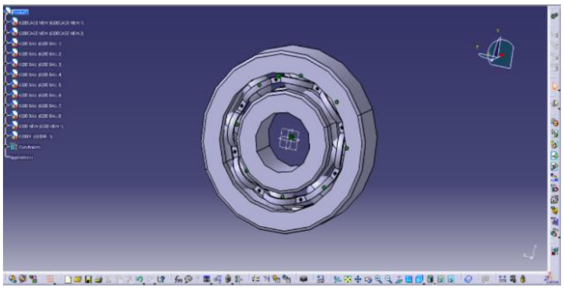


Figure 1: 6200 Deep groove ball bearing

### *B. Material Consideration*

Materials considered are High- Carbon steel (GCr15SiMn), complete silicon nitride for all the elements of bearing and Hybrid material which involves AISI 440C Steel for cage, inner and outer ring, silicon nitride for balls of bearing. GCr15SiMn is a type of cast iron alloy that typically contains silicon and manganese. It is known for its good mechanical properties, making it suitable for various applications, including components that require good wear resistance and strength. Stainless steel 440C is a high-carbon martensitic stainless steel known for its exceptional hardness and high strength, as well as its moderate corrosion resistance. It is widely used in applications requiring both wear resistance and corrosion resistance. Silicon nitride ($Si_3N_4$) is a ceramic material known for its excellent mechanical properties and thermal stability. It is widely used in applications such as cutting tools, bearings, and components in high-temperature environments.

Table 2 Material Properties

| PROPERTY | GCr15SiMn | $Si_3N_4$ | AISI 440C steel |
|---|---|---|---|
| Density (kg/m^3) | 7820 | 3190 | 7800 |
| Young's modulus (Mpa) | 2.16E+5 | 3.03E+05 | 2E+5 |
| Poisons ratio | 0.29 | 0.28 | 0.3 |
| Ultimate Tensile Strength (Mpa) | 748.5 | 800 | 586 |

For fatigue life valuation we consider S-N Curve for finding the bearing's fatigue life.

a. Load consideration

When the bearing is in operational condition and fixed at outer ring and shaft rotating by inner ring of bearing. The loads applied on the inner are considered to be radial loads only viz. 800N and 1000N. Rotating speeds considered to be 2000 RPM and 3000RPM. At this conditions fatigue life of bearing is calculated numerically and analytically.

b. Formulae for fatigue

- $D_m = (D+d)/2$
- $D_b = \frac{\pi\ (D-d)}{Z}$
- $C = \frac{f_c\ .\ (i.cos\alpha)\ .\ D_b\ .\ Z^{2/3}.\ 8\ .\ E}{(1-\vartheta^2)^{1.5}}$
- $C_{hybrid} = f_{material}\ .\ Z^{2/3}.D_m^{1.8}.\ D_b^2$
- $f_{material} = (\frac{E_{ceramic}}{E_{steel}})^{2/3} * (\frac{(1-\vartheta_c^2)}{(1-\vartheta_s^2)})^{1/3}$
- Equivalent load $P = X\ F_r + Y\ F_a$
- Bearing fatigue life $L_{10} = (\frac{C}{P})^p$

Above formulae describes the pitch diameter ($D_m$), Diameter of the ball ($D_b$), Dynamic load capacity with material property factors (C) for hybrid materials ($C_{hybrid}$). 10% of the bearings are expected to fail due to fatigue by the end of the $L_{10}$ life.

c. Formulae for Natural frequencies

- Angular velocity$(\omega) = \frac{2\pi N}{60}$

- Mass per ball ($M_b$) = $\frac{\rho 4\pi}{3} * (\frac{D_b}{2})^3$

  Total mass = $M_b * Z$
- Stiffness per ball ($K_b$) = $E.\pi.(\frac{(\frac{D_b}{2})^2}{2.W})$

  Total stiffness = $K_b * Z$
- Natural frequencies ($f_n$)

  $= (\frac{1}{2\pi} * \sqrt{\frac{mode\ number * Total\ stiffness}{Total\ mass}})$

## III. RESULTS AND DISCUSSION

### a. Fatigue life

In this study, a 6200 deep groove ball bearing is modeled using CATIA V15 to investigate its fatigue life, natural frequencies, and harmonic response. Key analyses include determining the number of cycles the bearing can withstand before fatigue failure, identifying its natural frequencies under static loading, under an applied load. The analysis is performed for the same bearing using three different materials, including both steels and ceramics, to compare performance differences.

Table 3 Fatigue life of GCr15SiMn material bearing

| MATERIAL | LOAD (N) | RPM | FATIGUE LIFE ( x$10^6$ cycles) | |
|---|---|---|---|---|
| | | | THEORITICAL | ANALYTICAL |
| GCr15SiMn | 800 | 2k | 2.8786 | 2.6320 |
| | | 3k | 2.8791 | |
| | 1000 | 2k | 2.8134 | 2.3477 |
| | | 3k | 2.8108 | |

Table 4 Fatigue life of silicon nitride material bearing

| MATERIAL | LOAD (N) | RPM | FATIGUE LIFE ( x$10^6$ cycles) | |
|---|---|---|---|---|
| | | | THEORITICAL | ANALYTICAL |
| $Si_3N_4$ | 800 | 2k | 7.1961 | 7.3415 |
| | | 3k | 7.1946 | |
| | 1000 | 2k | 3.7441 | 3.7588 |
| | | 3k | 3.7871 | |

Table 5 Fatigue life of Hybrid bearing

| MATERIAL | LOAD (N) | RPM | FATIGUE LIFE ( x$10^6$ cycles) | |
|---|---|---|---|---|
| | | | THEORITICAL | ANALYTICAL |
| $Si_3N_4$ + 440C SS | 800 | 2k | 7.6654 | 7.4897 |
| | | 3k | 7.6642 | |
| | 1000 | 2k | 7.6651 | 7.5847 |
| | | 3k | 7.6642 | |

### b. Modal analysis

The modal analysis yields a set of natural frequencies for each material configuration. Higher natural frequencies typically indicate better performance in avoiding resonance with operating frequencies. The mode shapes provide insights into which parts of the bearing (e.g., inner ring, balls, cage) are most susceptible to vibration at each frequency.

By examining these results, we can predict how different material choices impact the bearing's vibrational characteristics.

Table 6 Natural frequencies for GCr15SiMn

| MATERIAL | MODE NUMBER | NATURAL FREQUENCY (Hz) | |
|---|---|---|---|
| | | NUMERICAL | ANALYTICAL |
| GCr15SiMn | 1 | 47216 | 47355 |
| | 2 | 57466 | 57997 |
| | 3 | 62104 | 66970 |
| | 4 | 81777 | 74874 |
| | 5 | 82538 | 82021 |
| | 6 | 83630 | 88593 |

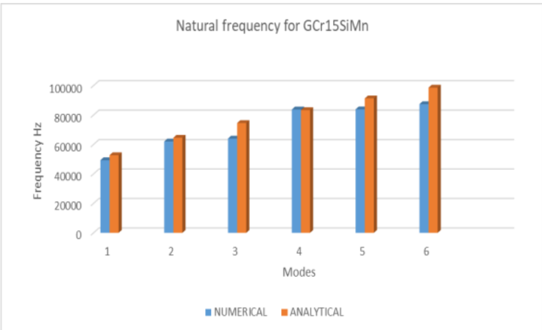



Figure 2 Numerical and Analytical comparision.

Natural frequencies of GCr15SiMn material bearing is validated through MATLAB with ANSYS. Figure2 shows the comparision of frequencies.

Table 7 Natural frequencies for silicon nitride

| MATERIAL | MODE NUMBER | NATURAL FREQUENCY Hz | |
|---|---|---|---|
| | | NUMERICAL | ANALYTICAL |
| $Si_3N_4$ | 1 | 87533 | 87815 |
| | 2 | 106470 | 107551 |
| | 3 | 111100 | 124189 |
| | 4 | 114920 | 138847 |
| | 5 | 152870 | 152100 |
| | 6 | 154880 | 164280 |

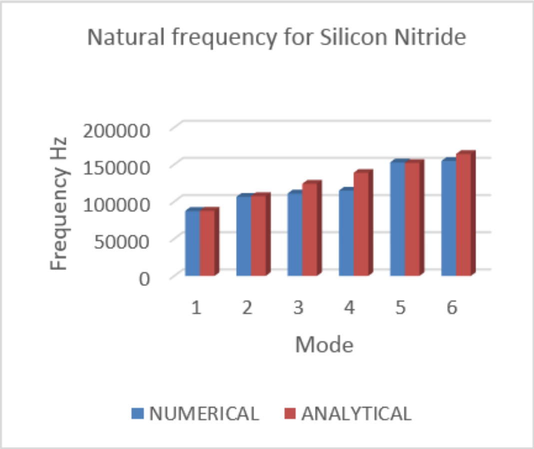


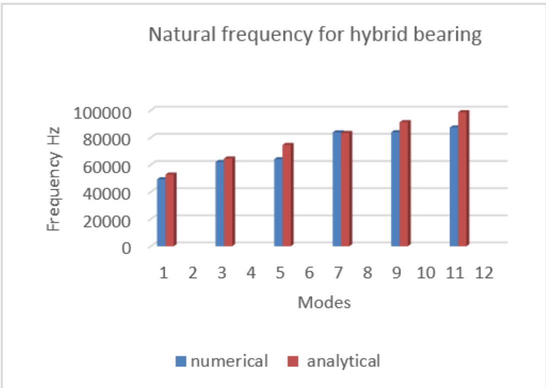

Figure 3 Numerical and analytical comparision

Natural frequencies of $Si_3N_4$ material bearing is validated through MATLAB with ANSYS. Figure 3 shows the comparision of frequencies.

Table 8 Natural frequencies for Hybrid material

| MATERIAL | MODE NUMBER | NATURAL FREQUENCY Hz | |
|---|---|---|---|
| | | NUMERICAL | ANALYTICAL |
| Hybrid bearing | 1 | 49316 | 52717 |
| | 2 | 62031 | 64565 |
| | 3 | 64029 | 74553 |
| | 4 | 83779 | 83353 |
| | 5 | 83892 | 91309 |
| | 6 | 87395 | 98625 |

Figure 4 Numerical and analytical comparison




Natural frequencies of $Si_3N_4$ material bearing is validated through MATLAB with ANSYS. Figure 4 shows the comparison of frequencies.

c. Harmonic analysis

Harmonic response analysis in ANSYS provides insights into how bearings behave under dynamic loading conditions, which is crucial for understanding their vibrational characteristics. Amplitude of Vibrations The analysis provides data on vibration amplitudes at various frequencies. High amplitudes at particular frequencies indicate potential operational issues. For bearings, controlling amplitude is vital to ensure longevity and minimize wear.

Modal analysis provides the "baseline" vibrational characteristics (natural frequencies and mode shapes), and harmonic analysis builds on this by showing how the structure will actually behave under cyclic loading conditions. Together, they help engineers design systems to avoid resonance, ensure stability, and minimize vibration issues.

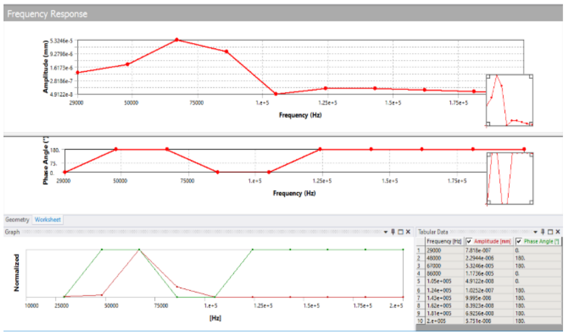



Figure 5 Harmonics of hybrid bearing in X-Direction

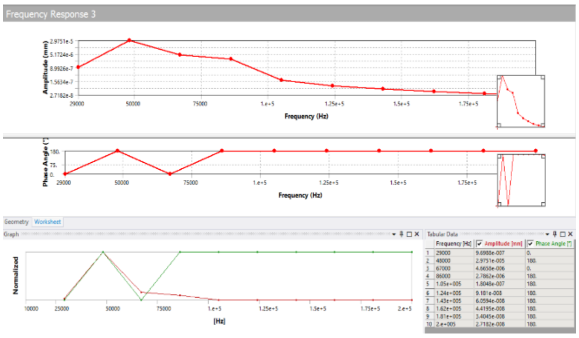



Figure 6 Hamonics of hybrid bearing in Y-Direction

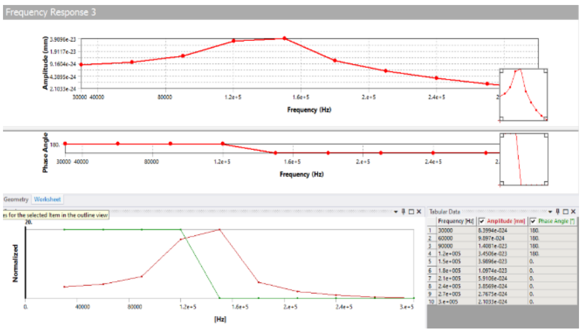



Figure 7 Hamonics of hybrid bearing in Z-Direction

IV. CONCLUSION

This work investigates the fatigue life, natural frequencies, and harmonic response characteristics of a 6200 deep groove ball bearing under varying loads and rotational speeds, with three material configurations: high-carbon chromium steel (GCr15SiMn), full silicon nitride, and hybrid ceramic (silicon nitride balls with 440C steel races and cage). The load cases of 800 N and 1000 N, and speeds of 2000 RPM and 3000 RPM, reflect real-world operating conditions. Fatigue life was analyzed in ANSYS and validated analytically, while modal analysis (natural frequencies) was performed in MATLAB, and harmonic response was assessed for frequency-amplitude characteristics.

Overall, this study highlights the advantages of hybrid ceramic bearings in extending fatigue life and minimizing vibrational issues, supporting their use in critical, precision-driven applications.

## V. FUTURE SCOPE

For future work on the fatigue life and vibrational analysis of 6200 deep groove ball bearings, consider expanding in these directions:

1. Thermal Analysis: Incorporate a coupled thermal-mechanical analysis to study the effects of heat generation on bearing fatigue life and vibrational behavior, especially at high speeds. Heat affects material properties, lubrication, and load distribution, which in turn influences fatigue and harmonic response.
2. Variable Load and Speed Conditions: Analyze the bearing's behaviour under varying load and speed profiles to simulate more realistic operating conditions, such as acceleration and deceleration, which are common in real-world applications. This could provide deeper insights into fatigue life under dynamic conditions.
3. Lubrication Effects: Study the impact of different lubrication types and regimes on the fatigue life and harmonic response of the bearing. Lubrication affects wear, friction, damping, and heat generation, all of which influence the bearing’s performance and lifespan.
4. Experimental Validation: Conduct experimental testing to validate the numerical results from ANSYS and MATLAB, providing a practical benchmark for fatigue life and harmonic response under different material and loading conditions.

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