

ANALYSIS AND OPTIMIZATION OF BALL BEARINGS FOR ROBOTS TO INCREASES EFFICIENCY, ALSO REDUCE STRESS

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ABSTRACT

Bearing have important role in every rotating machinery system. One of the commonly used bearing types is a ball bearing. The aim of this research focuses mainly on analysis and optimization of ball bearing for fatigue analysis & stress reduction by different optimization parameter. The optimization is done by analytical method and it is validated by using ANSYS. The result of this research work is that by varying optimization parameter like contact angle, material & variation in number of ball increases in fatigue life of bearing & reduction in contact stresses. The material optimization is done by changing material of all bearing , generally steel material are used for inner race ,outer race , ball & retainer. By replacing the material ball by ceramic, inner race, outer race & retainer by PEEK material. The life of bearing increased by increasing no of balls and by material optimization.

1.INTRODUCTION

The ball bearing used wide range of engineering application. It is used for relative motion and to reduce friction between them. It sustain axial as well as radial load. It consist of four main parts 1) Outer race 2) Inner race 3) Rolling element 4) Cage / Separator.

The main aim of this research work is the increases the Fatigue life of bearing. For this purpose identify influencing factor like Material, load, contact angle, no of balls, lubrication, etc.

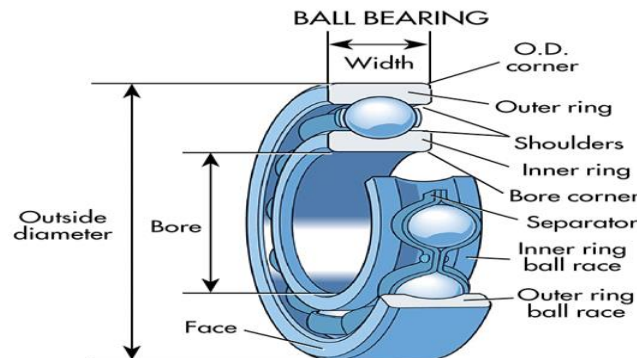


Fig.1.1 Bearing Terminology

2.LITERATURE REVIEW

The ball bearing used in various application, in this paper research work focused on unicompartamental Arthroplasty & understand effect of polyethylene cross linking and bearing design on wear of unicompartamental Arthroplasty.[01] Hydrodynamic bearing used widely due to simplicity & low cost construction. In this research work focus on rotary part wear, understanding effect of critical factor with respect to stability & failure analysis of the bearing.[02] The research work focused on power losses in Gear box . to investigate power loss influencing factor roller bearing & seals, operating condition ,used lubrication & Lubrication method.[05] The research work focus on failure of bearing used in electric motor. For optimization of bearing uses contact stress analysis & material optimization.[09] In this paper focus on large diameter ball bearing in which bearing load condition changes , majority of failures occurs due to spalling. Contact stress distribution is analysis by using Hertzain elliptical contact theory.[10]

3. OPTIMIZATION OF BEARING

3.1 Optimization Methods

Application-foundry robot- picks up & drop robot. Pay load-IRB 6640-235 kg / 2.5 m and IRB 7600- 340 kg/2.8m.

Bearing specification:

Name of Bearing Manufacturers: SKF

Bearing No.: **6210-2Z**

Table No. 3.1: Bearing specification

d	D	B	Z	C	C _o	P _u	N _R	N	K _r	F _o	Mass
50	90	20	10	37.1	23.2	0.98	15000	8000	0.025	14.4	0.47

3.2 Optimization Parameters

- 1) **Ball diameter:** Ball diameter parameter affects the no of balls in bearing, contact stress and life bearing.
- 2) **Number of ball:** Number of ball increases then reduction in contact stresses.
- 3) **Contact Angle:** as contact angle alpha changes loading conditions also changes.
- 4) **Material used:** the life of bearing is depending upon the material used for ball bearing.
- 5) **Contact stresses:** contact stress are depends upon the loading condition and material used in ball bearing.
- 6) **Life of bearing:** for increasing the life of bearing we change the material of ball bearing like steel ball will replaced by ceramic material ball. Steel cage will be replaced by brass, PEEK which is recent innovated material. Inner race & outer race material with special steel. Optimised loading condition.

3.3 Mathematical Modelling for Life of Bearing:

Case – I: Considering Contact Angle $\alpha = 28.5^\circ$ and Number of Balls 10

Input Data:

Material	-	440 C Stainless Steel
Ball Diameter	D_w	14 mm
Axial Load	F_a	9514.67 N
Radial Load	F_r	28544 N
Revolutions	N	15000 rpm
Number of Ball	Z	10
Ball Pitch Diameter	d_{pw}	72.7 mm
Number of Ball Row	i	01

1) Determination of factors f_c and f_o by Geometry of Bearing Components:

$$\frac{D_w \cos \alpha}{d_{pw}} = \frac{14 \cos 28.5}{72.7} = 0.1692$$

Now, equivalent values of factor are,

$$f_o = 14.9, f_c = 59.6$$

2) Determination of Dynamic Load Rating, C_r :

$$C_r = f_c \times (i \cos \alpha)^{0.7} \times Z^{2/3} \times D_w^{1.8}$$

$$\therefore C_r = 29219.47 \text{ N}$$

3) Determination of Dynamic Equivalent Radial Load, P_r :

$$P_r = XF_r + YF_a$$

Hence, radial load factor (X) and static thrust loading factor (Y), $X = 1$ and $Y = 0$

$$\therefore P_r = (1 \times 28544) + (0 \times 9514)$$

$$\therefore P_r = 28544 \text{ N}$$

4) Determination of Static Equivalent Load, P_{or} :

$$P_{or} = X_o F_r + Y_o F_a$$

The radial load factor (X_o) and axial load factor (Y_o) can be determined by contact angle $\alpha = 28.5^\circ$

Hence, $X_o = 0.5$ and $Y_o = 0.33$

$$\therefore P_{or} = (0.5 \times 28544) + (0.33 \times 9514)$$

$$\therefore P_{or} = 17411.83 \text{ N}$$

5) Determination of Basic Life of Bearing in Revolutions, L:

$$L = \left(\frac{C_r}{P_r} \right)^k \times 10^6$$

Considering the value of factor $k = 3$ for ball bearing,

$$\therefore L = 1.072 \times 10^6$$

6) Determination of Life in Working Hours, L_H :

$$L_H = \frac{L}{60 \times N}$$

$$\therefore L_H = 1.18 \text{ Hrs}$$

3.4 Mathematical Modelling for Contact Stresses:

The maximum contact stresses between balls and inner-outer races can be calculated by Hertz contact stress. The stresses can be vary by varying the material of bearing, hence for optimization of maximum contact stresses Stainless Steel 440C and Polyetherether Ketone (PEEK) materials have consider.

The stresses can be calculated by,

$$\sigma_{c(max)} = 0.388 \sqrt[3]{\frac{4F_r (d_1 + d_2)^2 E^2}{d_1^2 \times d_2^2}}$$

1) Stresses in Stainless Steel (440C) are

$$\therefore \sigma_{c(max)} = 102.20 \text{ MPa}$$

2) Stresses in Polyetherether Ketone (PEEK)are

$$\therefore \sigma_{c(max)} = 26.35 \text{ MPa}$$

3.5 Results by Analytical Method:

The analytical results are obtained as below,

3.5.1 Results for Life of Bearing:

Table No. 3.2: Results for Life of Bearing

Sr. No.	Contact Angle (α)	Number of Balls (Z)	Life in Revolutions (L)	Life in Hours (L_H)
1	28.5°	10	1.072 × 10 ⁶	1.18 Hrs
2	15.77°		1.32 × 10 ⁶	1.47 Hrs
3	28.5°	12	1.55 × 10 ⁶	1.72 Hrs
4	15.77°		1.89 × 10 ⁶	2.11 Hrs

It is to be observed that life in revolution as well as life in hours is increases as increasing number of balls and decreasing the contact angle. From above table it can be say that the optimum life of bearing by analytical method is obtained at contact angle 15.77° and 12 numbers of balls.

3.5.2 Results Maximum Contact Stresses of Bearing:

Table No. 3.3: Results for Maximum Contact Stresses

Sr. No.	Material of Bearing	Maximum Contact Stresses
1	Stainless Steel (440C)	102.20 MPa
2	Polyetherether Ketone (PEEK)	26.35 MPa

It is to be observed that by changing material from Stainless Steel to Polyetherether Ketone the stresses between inner-outer races and balls get reduced, hence material is also affects the contact stresses in the bearing.

4.1 Introduction to Finite Element Analysis

Many problems in engineering & applied science are governed by differential or integral equations. The solution to these equations would provide an exact, closed-form solution to these equations to the particular problem being studied. However, complexities in geometry & in boundary conditions that are seen in most real world problems usually means that an exact solution cannot be obtained or obtained in real amount of time.

4.2 FEA of Bearing:

4.2.1 Finite Element Analysis of Ball Bearing

Finite element analysis is done for finding critical stress location in component at loading condition. The 3-D model of deep groove ball bearing is modelled in 3 D Modelling software as shown in the figure 5.2.

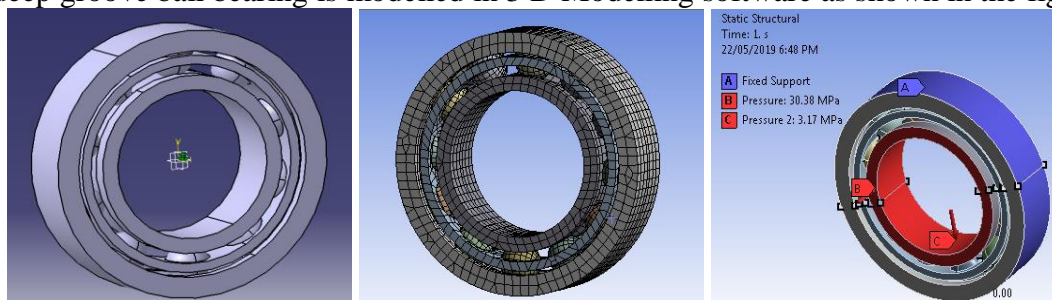


Fig. No. 4.1: 3-D Model, Meshing and Boundary Condition of Ball Bearing

Material properties applied for block as shown in the table

Table No. 4.1: Material Properties

Component	Material	Modulus of Elasticity (N/mm ²)	Density (tonne/mm ³)	Poisson's ratio
Complete bearing	Steel	2.10 X 10 ⁵	7.89 X 10 ⁻⁹	0.3
Ball	Ceramic	3.10 X 10 ⁵	3.29 X 10 ⁻⁹	0.27
Cage	Peek	3.6 x10 ⁵	1.320 X 10 ⁻⁹	0.4

4.2.2 Case Results:

Analysis shows in figure 5.5, the figure shows the stresses at critical locations.

1) Ball Bearing Static Stress Location:

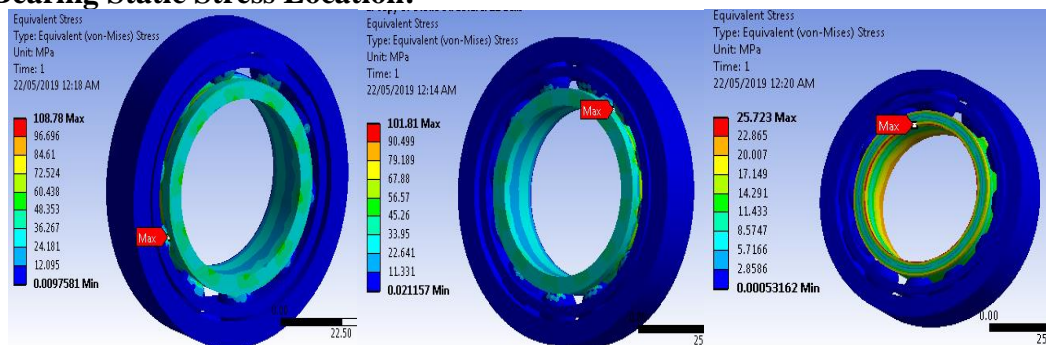


Fig. (a): 10 Balls Steel Fig. (b): 12 Balls Steel Fig. (c): 12 Balls Ceramic
Fig. No. 4.2: Static Stresses in Ball Bearing

2) Ball Bearing Static Deflection Location:

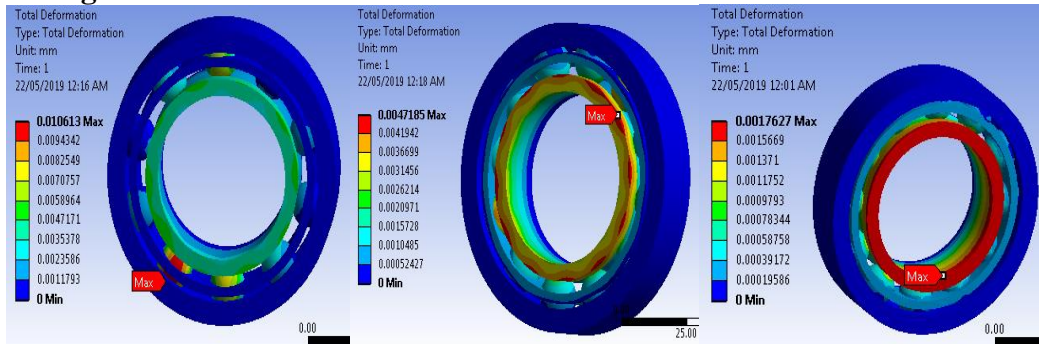


Fig. (a): 10 Balls Steel Fig. (b): 12 Balls Steel Fig. (c): 12 Balls Ceramic
Fig. No. 4.3: Static Deflection in Ball Bearing

3) Fatigue Life of Ball Bearing:

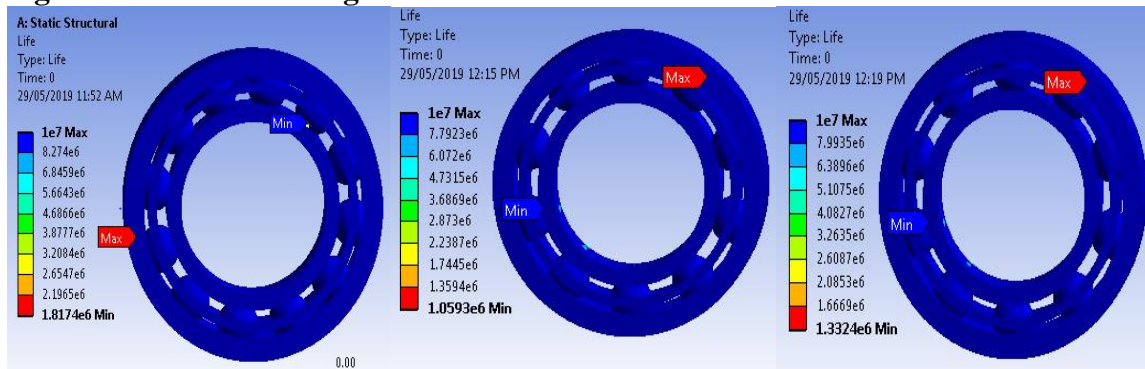


Fig. (a): $\alpha=15.77^\circ$, $Z=12$ Fig. (b): $\alpha=28.5^\circ$, $Z=10$ Fig. (c): $\alpha=15.77^\circ$, $Z=10$
Fig. No. 4.4: Fatigue Life of Ball Bearing

5.RESULT & DISCUSSION

5.1 Stress and Deformation Table:

Table No. 5.1: Comparison of Contact Stresses

	Stress (MPA) Analytical method	Stress (MPA) FEA method	Deflection (mm)
10 balls/ Steel material 440C	102.20	108.78	0.0106
12 balls/ steel material 440C	102.20	101.81	0.0047
12 balls/ ceramic material	26.35	25.72	0.003269

5.2 Life of Bearing:

Table No. 5.2: Comparison of Life of Bearing

Sr. No	Condition	Life (Cycle) (Analytical Method)	Life (Cycle) (FEA Method)	Error In %
1	10 balls $\alpha=15.77$	1.32×10^6	1.332×10^6	0.90
2	10 balls $\alpha=28.5$	1.072×10^6	1.059×10^6	1.2
3	12 balls $\alpha=15.77$	1.89×10^6	1.81×10^6	4.23

In analytical design, by increasing numbers of ball, decreasing ball diameter, and changing the contact angle, the life in working hours can be increased. From the results of analytical design and analysis it can be seen that life of bearing is nearly same in both cases. Due to higher stresses, the life in working hours is limited to hours. It can be further increased by changing the parameters, material and lubrication of the Bearing.

5.3GRAPH

Table No. 5.3: Time Vs deformation table

Time	12 ball steel	12 balls ceramic	10 balls steel
0.1	4.47E-03	4.47E-03	4.50E-03
0.2	8.94E-03	8.94E-03	9.00E-03
0.3	1.34E-02	1.34E-02	1.35E-02
0.4	1.79E-02	1.79E-02	1.80E-02
0.5	2.24E-02	2.24E-02	2.25E-02
0.6	2.68E-02	2.68E-02	2.70E-02
0.7	3.13E-02	3.13E-02	3.15E-02
0.8	3.58E-02	3.58E-02	3.60E-02
0.9	4.02E-02	4.02E-02	4.05E-02

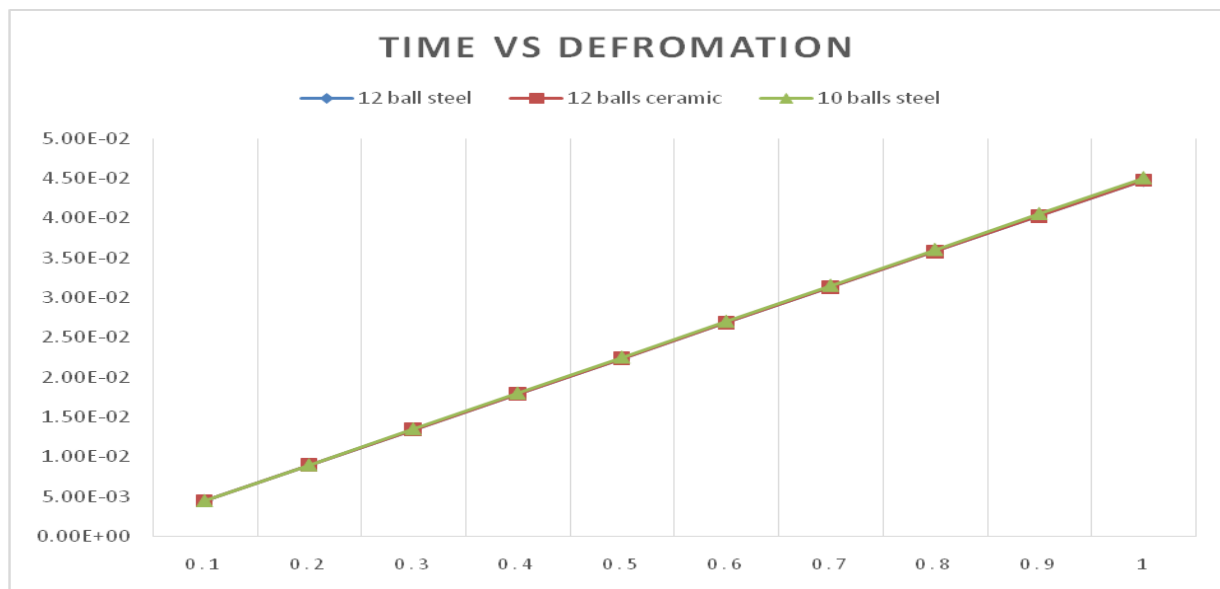


Fig. No. 5.1 Time Vs deformation table

Table No. 5.4: Time Vs stress

Time	12 ball steel	12 balls ceramic	10 balls steel
0.1	9.9635	2.514	13.404
0.2	19.94	5.0316	26.828
0.3	29.929	7.553	40.272
0.4	39.93	10.078	53.735
0.5	49.943	12.607	67.216
0.6	59.967	15.139	80.715
0.7	70.002	17.675	94.233
0.8	80.049	20.215	107.77
0.9	90.106	22.758	121.32

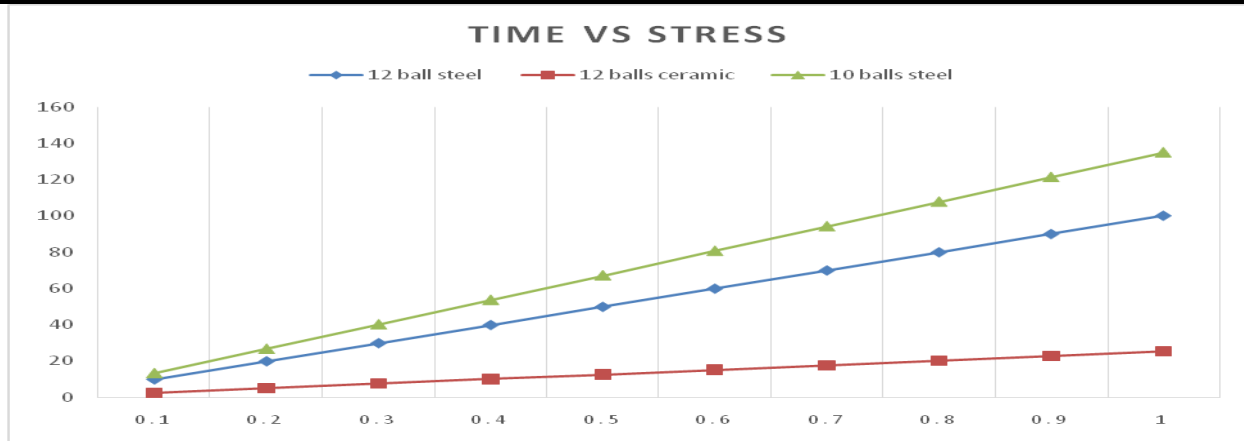


Fig. No. 5.2.: Time Vs stress

6.1 CONCLUSION:

For increasing the life of bearing flowing parameter get optimised

- 1) by changing the material of inner race & outer race & ball material contact stress reduced from 108.78 Map to 25.72 Map.
- 2) Deflection is reduced from 0.106 mm to 0.003269 mm.
- 3) Harmonic deformation changes from 8.12 mm to 4.85 mm.
- 4) Life of bearing increased from 1.332×10^6 to 1.81×10^6 .

6.2 FEATURE SCOPE :

1. In feature we can replace this single row deep ball bearing 6201-2z with another double row deep ball bearing with higher load carrying capacity. For a given bearing dynamic analysis gives better result

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