PERFORMANCE EVALUATION AND SIMULATION OF POLYMER BALL BEARING IN ELECTRIC MOTOR & CIRCULATING PUMP APPLICATION

Pritesh J.Thoriya[1], Prof.B.N.Gelot[2]

[1]Mechanical Engg. Department, Government Engg. College, Dahod, priteshthoriya@gmail.com
[2]Mechanical Engg. Department, Government Engg. College, Dahod, bngelot@yahoo.co.in

Abstract— The use of polymer bearing can improve performance as polymer material is self lubricating material. Nowadays the use of polymer bearing is increasing in place of metal ball bearing. The usage of polymers in bearings has been increasing in recent years due to certain valuable tribological properties, including their ability to self-lubricate and their resistance to corrosion. These advantages encourage manufacturers to use polymer bearings in corrosive and lubricant-free work environments as well as applications in which weight reduction is desirable. Ball bearing used to mount the shaft of circulating pump used in agriculture application has to work in corrosive environment and having continuous contact with water, due to which lubrication loss occur which will cause bearing failure. Ball bearing used to support shaft of industrial DC motor, according to application has to work in corrosive environments and sometimes lubrication is not possible which will cause bearing failure. Into this dissertation an analysis has been done to improve the performance of ball bearing used in electric motor and circulating pump application by using polymer ball bearing. This will provide corrosion free, less noisy and lubrication free performance. To compare the performance, analytical calculation and dynamic analysis of metal ball bearing and polymer ball bearing will be done and results in form of lifecycle and stresses formed on each element on bearing are compared for both materials.

Keywords-polymer, ball bearing, dynamic analysis, self-lubrication

I. INTRODUCTION

Bearings are made of different materials like metals, polymers, ceramics and composite and bearings are available in different sizes varies from 1mm to 400mm.[1] Field data analyses made by Tian indicates that lubrication loss and lubrication degradation are the main causes for failures in miniature bearings. [2] So the use of polymer bearing can improve performance as polymer material is self lubricating material. The usage of polymers in bearings has been increasing in recent years due to certain valuable tribological properties, including their ability to self-lubricate and their resistance to corrosion. These advantages encourage manufacturers to use polymer bearings in corrosive and lubricant-free work environments as well as applications in which weight reduction is desirable. Polymer ball bearing consists of Polymer Rings,Balls made of stainless steel, glass, polymer or other materials and a Polymer Cage. Polymer ball bearings can be made from a variety of materials and materials combination. The materials selected depend on the application. Polymers have significantly different properties than steel. One of the most unique properties is that they are corrosion and chemical resistant. The polymers used to make polymer ball bearings have a low coefficient of friction and are highly resistant to wear and fatigue. These self-lubricating bearings can run dry and require no lubricant. The high specific strength (strength to weight ratio) is a valuable properties where weight is an important design consideration. High dimensional stability throughout the lifespan is achieved by the low creep tendency of the polymer used. Prabhat Singh et al.[2] ,presented a research paper on " Fatigue Life Analysis Of Thrust Ball Bearing Using ANSYS", In

Journal International Journal Of Engineering Sciences & Research Technology In 2014 in which they compares the total deformation of thrust ball bearing & contact stress b/w ball & raceways & its effect on fatigue life of thrust ball bearing. They made dynamic analysis in ANSYS and compare the result with experimental data and found that result given by ANSYS is good and effective. They use Bearing Life cycle theory to calculate bearing life and in dynamic analysis they used von-mises stresses. C.Morillo,E.C.Santos et al.[3] , includes comparison of the performance of polymer with metal in rolling contact. This is carried out by monitoring the acoustic emission, vibration and operating speed of metal and polymer bearings during their operation and found one of the most common failure mechanisms in these kinds of bearings is lubricant degradation, which represents 36% of premature bearing failures. Polymer self-lubricated materials are considered as candidate materials for these applications where lubrication is critical. Pranav B. Bhatt et al.[4] , includes design of four points angular contact ball bearing is done used in propeller shaft of an air craft. Into this research work they have calculated bearing life cycle by using IS standard and compare it with dynamic analysis result getting from ANSYS. Here they use tetra method of meshing for dynamic analysis and found that ANSYS gives good effective result. The main objective of increasing life cycle is also achieved by changing inner groove radius, contact angle, number of balls and diameter of balls. After this they obtained that Life in working hours by design is 55.638 hours and by analysis it is 70 hours. Hitonobu Koike et al.[5], includes investigation of wear performance of hybrid ball bearing (PEEK-PTFE & Alumina Ball). They found that due to self lubrication properties of PEEK , the wear loss of hybrid ball bearing cycle was less. They have made experiment on 52mm ID PEEK material deep groove ball bearing and observe that the wear loss after $1.0 * 10^7$ cycles at 2000 rpm was 20mg only. They also found that Durability of PEEK material is higher than PTFE. They have generate following Graph of wear loss verses No. of Cycles and conclude that Roughness of PEEK decreased with increase in no of cycles. R.K. Upadhyay et al.[6] ,includes failure occurs in AISI 52100 Alloy Steel ball bearing which is having high compressive strength, low cost and good wear resistance. They found that cyclic load may be divide into two parts 1) Surface initiated and 2) sub-surface initiated. Both of this plays important role in fatigue failure of bearing. They recommend that Lubrication degradation is main reason of bearing failure so avoid it and use hard material to decrease contact stresses. J. Sukumaran et al.[7], includes a comparative study on water lubrication has been done to understand the fundamental aspects of tribology. Into this research work commonly used polymer such as PA6, POM, PEEK & PTFE studied for tribological behavior and found that under wet condition PTFE works better. They also found that on using water as a lubrication, it decreases co-efficient of friction to a specific value. K.Kida et al.[8] includes investigation of radial PEEK bearings rolling contact fatigue behavior under dry condition. Due to PEEK's self-lubrication ability, the radial PEEK-Alumina ball bearing lifetime was longer when testing at medium loads (between 85.6 N and 93.1 N) and at 600 rpm. TANG Zhaoping et al.[9], describes how contact analysis changes in stress, strain, penetration among the elements of ball bearing was showed by using ANSYS. After that simulation result was compared to theoretical values. Into this research work 6200 series ball bearing 3-D model is generated in APDL and then by using 8 nodes and 6 faces and free meshing of size 1.5 mm dynamic analysis has been carried out. They found that Max. contact stress from simulation was 8599MPa and from Hertzian theory it was 8572 MPa. They conclude that ANSYS have good consistency and this method of Simulation is useful for dynamic analysis of ball bearing.

II. ANALYTICAL DESIGN AND CALCULATIONS

2.1 Analytical Design of Ball Bearing[13] :

2.1.1 Input Data (For application of 1×1" circulating pump & 1/2 HP 1200 RPM 115 VAC MOTOR DC Motor) :

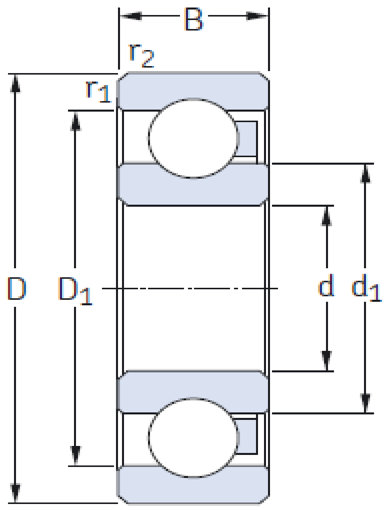

Figure 2.1 Bearing Design

ID (d)	15mm
OD (D)	35mm
d_1	21.5mm
D_1	29mm
Speed	1200 rpm
Ball Diameter	5.75mm
r_1, r_2	0.9mm×45°
Radial Load Fr (In Circulating pump Application)	110N (Higher Load is Selected from Both Application)

Table 2.1 Ball Bearing Input Data

2.1.2 Life Rating for AISI 52100 Metal Ball Bearing[13] :

According to CMTI Standard, Basic Life is expressed by equation, Basic Life Rating , $L_{10} = (Cr/Pr)^k$
Where,
Cr = Basic dynamic load rating = 5886N[12]
Pr = Dynamic Equivalent Radial Load
Pr = X Fr + y Fa Where, X = radial load factor = 1 Y = Thrust load factor = 0
Fr = Radial load, Fa = Axial load, Pr= 1× 110 + 0 × 0 = 110 N, K = 3 for ball bearings
So, $L_{10} = (5886/110)^3 = 153208$

Life in Revolutions :
$L = L_{10} \times 10^6 = 153208 \times 10^6$ Revolutions

3.1.3 Life Rating for PEEK Polymer Ball Bearing[13] :

According to CMTI Standard, Basic Life is expressed by equation, Basic Life Rating , $L_{10} = (Cr/Pr)^k$
Where,
Cr = Basic dynamic load rating = 250 N[13]
Pr = Dynamic Equivalent Radial Load,
Pr = X Fr + y Fa, Where, X = radial load factor = 1, Y = Thrust load factor = 0
Fr = Radial load, Fa = Axial load, Pr= 1× 110 + 0 × 0 = 110 N, K = 3 for ball bearings
So, $L_{10} = (250/110)^3 = 11.74$

Life in Revolutions :
$L = L_{10} \times 10^6 = 11.74 \times 10^6$ Revolutions

2.2 Deformation of Rolling Element

Load acting on the shaft when bearing is stationary is called static load. Due to this load if P_1 is the maximum load experienced by the rolling element then[14],

$$C_0 = P_1 M$$

Where C_0 = Static load acting on bearing in N, P_1= Maximum load experienced by rolling element in N, M is the constant depending on number of balls (Z)[14],

Z	8	10	12	15

M	1.84	2.28	2.75	3.47

Table 2.2 Selection of Constant M

According to above relation, C_0 = 100 N, Z=8 and so M= 1.94,
So Maximum load experienced by rolling element, P_1= 54.3478 N
Now Palmgren formula for deformation for deep groove ball bearing is[15],

$$\delta = \frac{4.3 \times 10^{-8}}{\cos\alpha} \times \left(\frac{P^2}{d}\right)^{\frac{1}{3}}$$

Where δ= deformation of rolling element,
P = Load on most heavily rolling element in N
d = diameter of rolling element in m
α = 0 for single row ball bearing
Here P = P_1= 54.3478 N, α = 0, d = 5.75 mm
So deformation δ = 0.003443 mm

2.3 Conclusion

From above calculation we are getting maximum deformation δ = 0.003443 mm and our rolling element diameter is 5.75 mm. So here deformation is of 0.0005 than rolling element. A total permanent deformation of 0.001 of the ball diameter occurring at most heavily stressed ball can be easily tolerated without any disturbance like noise or vibrations, which means there is no need of dynamic analysis. Here deformation is of 0.0005 of the ball diameter < 0.001, Which means in this case, static analysis is preferable, there is no need of dynamic analysis.

III. MODELING AND ANALYSIS IN ANSYS

3.1 Modeling of Bearing Using Creo-Elements 1.0[16] :

3.1.1 Model and Geometry of Bearing Elements :

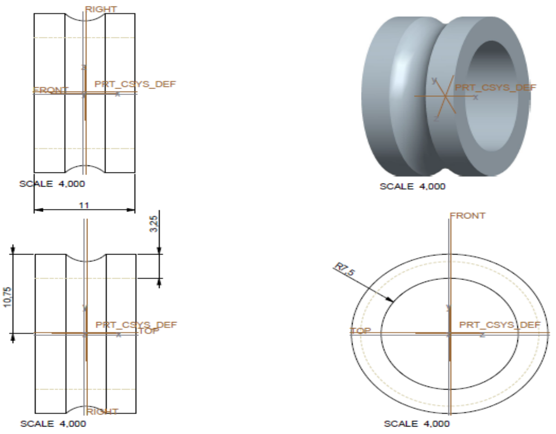

Figure 3.1 Model of Outer Ring

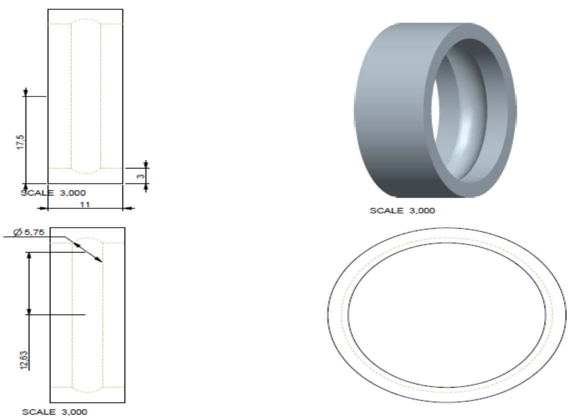

Figure 3.2 Model of Inner Ring

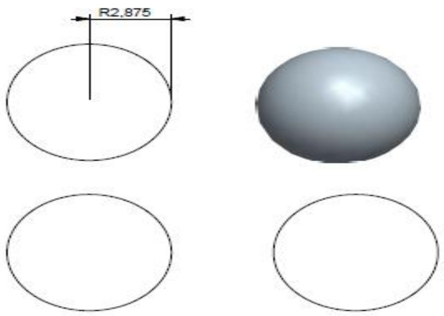

Figure 3.3 Model of Ball

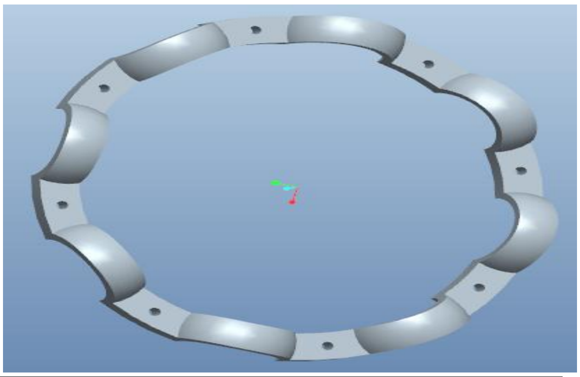

Figure 3.4 Model of Cage

3.1.2 Assembly of Bearing :

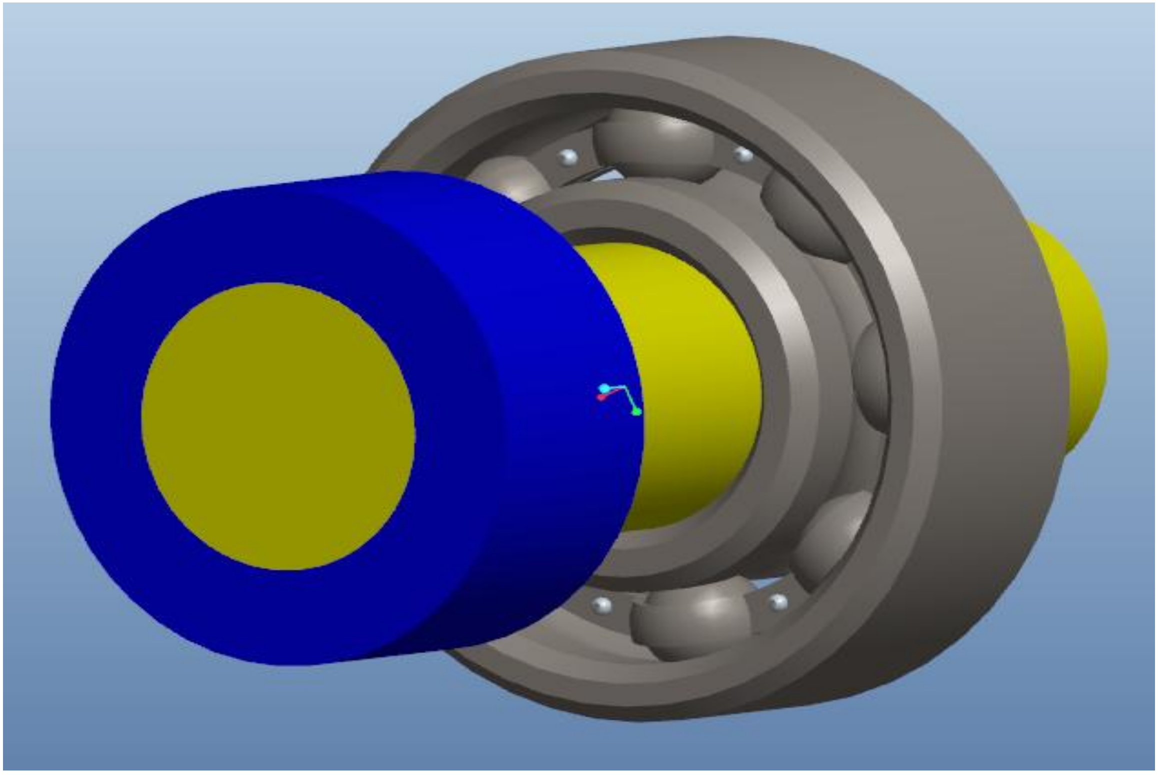

Figure 3.5 Assembly of Bearing

3.2 Selection of Polymer Material:

Following are the some polymer materials and their properties :

Mechanical Properties	PEEK[17]	PTFE[17]	NYLON 6[17]
Density (g/cm^3)	1.263	2	1.14
Melting Temperature (^{0}C)	340	335	220
Thermal Conductivity (W/m-K)	0.25	0.25	0.28
Tensile Yield Strength (MPa)	105	100	76
Young's Modulus (MPa)	3560	2500	3250

Rockwell Hardness	126	50	85

Table 3.1 Polymer Material Properties

PEEK material is self lubricating material[8] and also having higher mechanical properties. From commonly used polymer such as NYLON6, POM, PEEK & PTFE, PEEK works better under wet condition.[7] Though we want an alternative material than we can use PTFE and NYLON 6 as an alternative.

3.3 Materials and Properties of Ball Bearing:

Materials and Properties of AISI 52100 and PEEK are given in below table.

Bearing Part Name	Metal Bearing	Polymer Bearing
Inner Ring	AISI 52100	PEEK
Outer Ring	AISI 52100	PEEK
Rolling Element	AISI 52100	Alumina
Cage	PEEK	PEEK

Table 3.2 Material of Bearing Parts

Mechanical Properties	AISI 52100[18]	PEEK[17]	Alumina[18]
Density (g/cm^3)	7.83	1.263	3.96
Young's Modulus(GPa)	210	3.56	373
Bulk Modulus (Mpa)	159000	2697	723.39
Shear Modulus (Mpa)	82031	1390	373
Tensile Yield Strength (MPa)	3105	105	2930
Tensile Ultimate Strength (MPa)	3445	108	3700
Hardness	60 (HRC)	126(Rockwell)	-
Thermal Conductivity (W/m-K)	46.6	0.25	-

Table 3.3 Properties of Materials

3.4 ANALYSIS RESULTS IN ANSYS[19]:

3.3.1 Pre-Processing for Analysis :

For the analysis of ball bearing boundary condition and load are required parameter. Then after meshing is done. In our analysis free meshing is used, fixed support is given at outer race and then load is applied. Rotational velocity of inner ring is 125.67 rad/s.

Meshing is done by keeping relevance center fine, smoothing is high, Transition is slow, total 142765 nodes and 54543 elements are given.

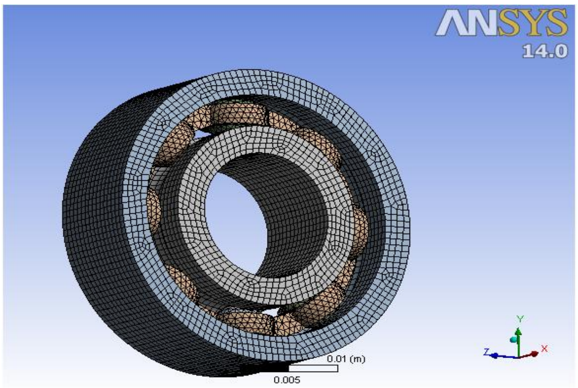

Figure 3.6 Meshing

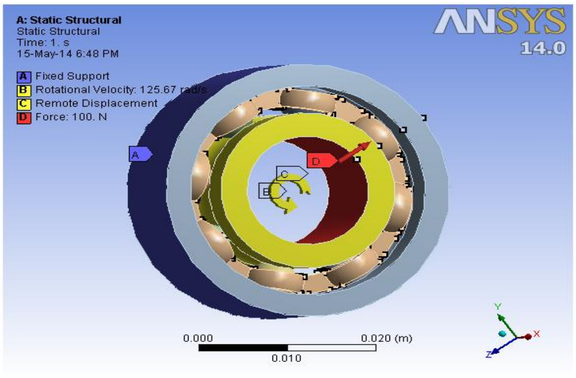

Figure 3.7 Input Parameters

3.3.2 Total Deformation of Metal and Polymer Bearing:

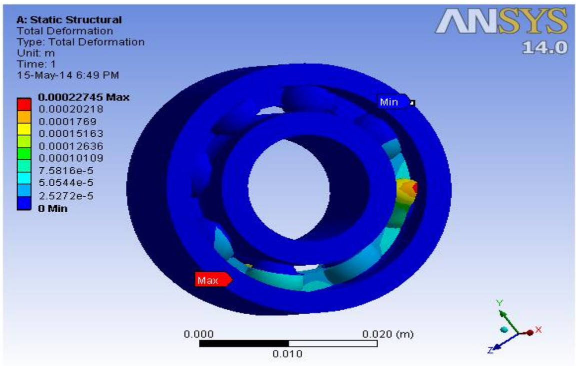

Figure 3.8 Total Deformation of Metal Bearing

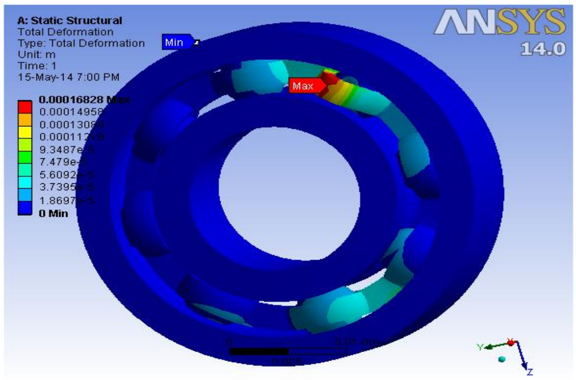

Figure 3.9 Total Deformation of Polymer Bearing

3.3.3 Life Cycle Analysis and Stress Analysis of Metal Ball Bearing in ANSYS 14:

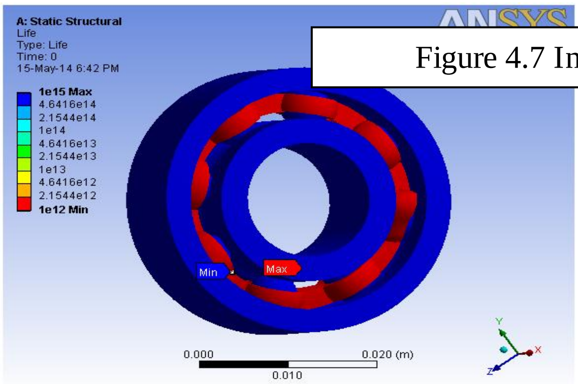

Figure 4.7 Input Parameters

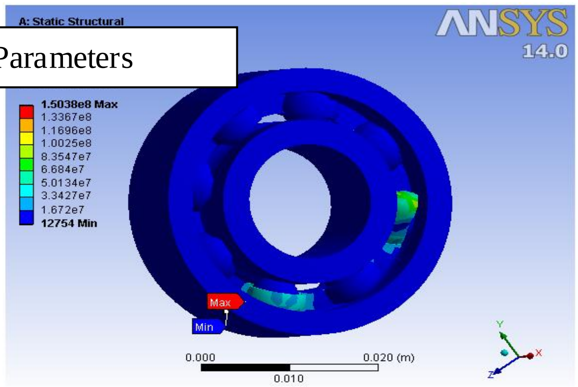

Figure 3.10 Life of Metal Ball Bearing

Figure 3.11 Equivalent Stress on Metal Ball Bearing

3.3.4 Life Cycle Analysis and Stress Analysis of Polymer Ball Bearing in ANSYS 14:

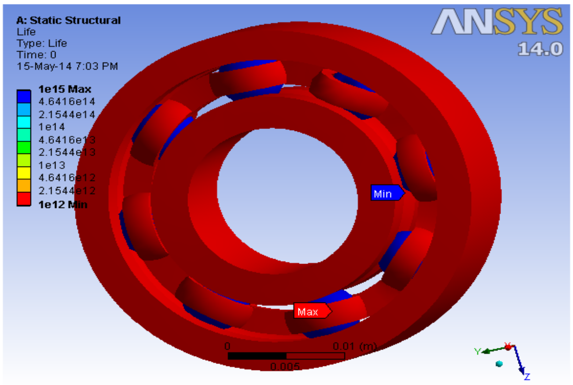

Figure 3.12 Life of Polymer Ball Bearing

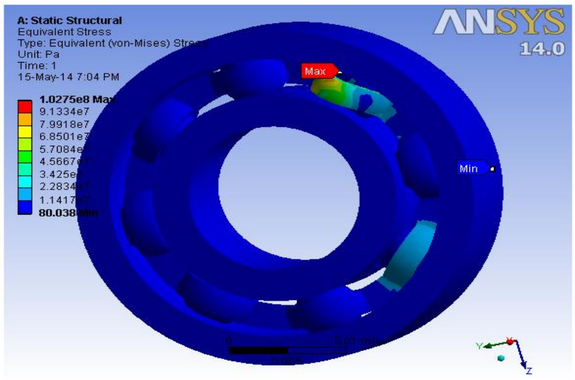

Figure 3.13 Equivalent Stress on Polymer Ball Bearing

IV. CONCLUSION AND FUTURE SCOPE

4.1 Conclusion

Comparison of Deformation for Polymer and Metal Ball Bearing using results of ansys:

Bearing Element	Deformation in Metal Bearing		Deformation in Polymer Bearing	
	Min. (m)	Max (m)	Min. (m)	Max.(m)
Inner Ring	6.5448e-006	9.7308e-006	1.7123e-007	1.0725e-005
Outer Ring	0	1.493e-007	0	7.0886e-007
Ball	1.0676e-007	1.0917e-005	1.9284e-006	7.7254e-005
Cage	4.1901e-006	2.2745e-004	1.419e-006	1.6828e-004

Table 4.1 Comparison of Deformation

Comparison of Life of Polymer and Metal Ball Bearing using results of ansys:

Bearing	Metal Bearing	Polymer Bearing
Life	1.e+012 cycles	1.e+012 cycles

Table 4.2 Comparison of Life

Comparison of Equivalent (von-mises) stress of Polymer and Metal Ball Bearing using results of ansys:

Bearing Element	Stresses in Metal Bearing		Stresses in Polymer Bearing	
	Min. (Pa)	Max (Pa)	Min. (Pa)	Max.(Pa)
Inner Ring	79256	1.9441e+007	22285	2.5234e+006
Outer Ring	12754	1.2623e+007	80.038	9.8117e+005

Ball	95437	1.3123e+008	22652	3.5458e+007
Cage	2.3203e+005	1.5038e+008	72163	1.0275e+008

Table 4.3 Comparison of Stress

For metal bearing maximum deformation is 0.00022745 m and for polymer bearing maximum deformation is 0.00016828 m, which is 73.98% of metal bearing deformation. According to Palmgren formula[15], maximum deformation of rolling element δ is 0.000003443 m and it is found 0.0000011 m from ansys, which is 0.000002 m lesser than analytical result. Hence we can say that ansys performs better and can give accurate result for rolling contact element and our input parameter and concept is right.

Life of metal bearing is 1.e+012 cycles and for polymer bearing, it is 1.e+012 cycles, both are same. Here life is same because in both the cases we are getting minimum life in cage which is of same PEEK material in both bearings. Here both the bearing easily complete 1 million cycles so our design is safe and acceptable for selected application.

Farshid Sadeghi Et al.[20] plot graph of stress verses life (millions of cycle) By using Lundberg-Palmgren theory and found that for life of 1.e+012 cycles Max. stress is 0.1523 Gpa. Maximum stress generated in metal bearing is 150 Mpa, which is approximate value (only 0.002 less) if we compare with Lundberg-Palmgren theory. In case of polymer bearing it is 102 Mpa, comparing with properties we can say that it is below permissible limit, hence tolerated. From above all conclusions we can say that polymer ball bearing of PEEK material can be effectively use in our circulating pump application as it is having same life of metal bearing with advantages like self-lubrication, corrosion resistance, less stress is generated and also less deformation occurs in polymer bearing.

4.2 Future Scope

One can implement this bearing in real life application. If new innovation will be done and new polymer material will introduced than it can be alternative of PEEK. We can also develop such a polymer material which can sustain high load and can work in high speed applications like automobile, gas turbine, gear mechanism etc. We can also evaluate the performance of bearing in many other low speed & low load application by replacing metal bearing with polymer bearing.

Table 5.2 Comparison of Life

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