CONTACT STRESSES ANALYSIS & MATERIAL OPTIMIZATION OF BALL BEARING USING HERTZ CONTACT THEORY

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Abstract - *Rolling element bearings are mostly used in rotating machineries and consider as a most critical component. Proper functioning of bearings is most important in nuclear power stations, chemical plants, aviation industries and also process industries. In many rotating machinery Ball bearings are generally used, such as electric motors, material handling systems, turbines, generators, fan, pumps and compressors, etc. is essential equipment in engineering plants. A large survey on faults in the electric motor was carried out by Electric Power Research Institute (EPRI) in 1985and found that 41% of faults related to worn motor bearings. Well performance and reliability of rolling element bearings is essential for proper functioning of machines and to prevent failure of the machinery. Bearing health and performance can be easily identified by using health monitoring techniques. Condition monitoring as part of the preventive maintenance and widely use to enhance safety, efficiency, and reliability in manufacturing processes. Signature Analysis has been given significant information to diagnose the faults in rotating machinery parts.*

Key Words: turbines, nuclear power station, Generators, Ball handling system.

1. INTRODUCTION

Material selection is a most important in ball bearing design, since it affects a wide range of bearing characteristics. This paper has illustrated the major differences that occur in bearing analysis when two different materials are used for the rolling elements. Ball bearing rings are generally manufactured from steels. This paper will be focusing on steel as a baseline to compare with Ceramics. The function of bearings in an application is to allow relative motion and to carry loads. The loads can be generated internally or externally to the bearing. For high speed applications significant centrifugal loading may be generated on the outer raceway. Assuming that all external loading conditions are equivalent, the centrifugal loading will be lessened by using lighter ball materials. One material of interest is ceramic, which has a density of about 40% of that of steel. As with all material selections in, this paper will discuss the differences between a ball bearing with tool steel balls and Ceramic balls.

1.1 PROBLEM DEFINITION

We see that in maximum electric devices Ex. Electric motor a steel ball bearing is mostly use as per requirement of applications. The steel ball bearing has following drawbacks as given below;

1) Electric arc damage.
2) Contact fatigue.
3) Surface depression & fracture.
4) Mechanical wear & contact stresses.
5) Corrosion problem.
6) Discoloring & overheating.

So to reduce this problem we are going to replacement of steel ball bearing ball material to optimize & reduce the drawbacks in it.

A proper material selection is a most important in ball bearing design, for its wide range of reliable performance. So we select material of silicon nitride (ceramic), which has a less density, high wear resistance, Lower coefficient of expansion as that of steel material for bearing design and analysis. As with material selections in, this paper will discuss the performance differences between a ball bearing with tool steel balls and Ceramic balls analysis.

1.2 BEARING & ITS TYPES

A bearing is a small machine element which constrain relative motion to only desire motion and reduces friction between moving parts.

1.2.1 Types of Bearings:-

I. Plain bearing –

(Journal bearing, sleeve bearing, rifle bearing, composite bearing) A plain bearing (in railroading sometimes called a solid bearing or friction bearing) is the simplest type of bearing, comprising just a bearing surface and no rolling elements. Therefore, the journal (i.e., the part of the shaft in contact with the bearing) slides over the bearing surface.

II. Rolling Element Bearing

A rolling bearing, is a bearing which carries a load by placing rolling elements between two bearing rings called races. The relative motion of the races causes the rolling elements to roll with very little rolling resistance and with little sliding.

III. Jewel bearing

A jewel bearing is a plain bearing in which a metal spindle turns in a jewel-lined pivot hole. The hole is typically shaped like a torus and is slightly larger than the shaft diameter. The jewel material is usually synthetic sapphire or ruby (corundum). Jewel bearings are used in precision instruments where low friction, long life, and dimensional accuracy are important. Their largest use is in mechanical watches.

1.3 OBJECTIVES

The objective for this project is proper material selection and performance evaluations for ball bearing balls for the following purpose;

1) To reduce weight of the bearing.
2) To reduce Electric arc damage of the bearing.
3) To reduce Mechanical wear & contact stresses.
4) To reduce overheating problem & Discoloring.
5) To increases the service life of the bearing.

1.4 SCOPE

The scope for thesis to select a different material for bearing balls which will give a significant optimum performance, reliability and enhance the effectiveness for ball bearing which will be working in different operating conditions.

2. PROJECT OVERVIEW

In this project we can design, analyze and compare all parameters which give significant effect on bearing performance to fulfill the objective of this project. This will be achieved by analytical investigation of Hertz contact stress, variation in point contact fatigue and validation with analytical result by using FEM simulation & Experimentation. Therefore, an analytical model will be prepared so that we analysis these two materials performance by using FEM simulation & Experimentation technique in order to quantify the effectiveness of the different bearing ball materials.

The propose steps is used for this project work is given below;

2.1 FIELD OBSERVATION & PROBLEM DEFINITION.

In field observation we see that in maximum electric devices Ex. Electric motor a steel ball bearing is mostly use but steel ball bearing has following drawbacks as given below;

1) Electric arc damage.
2) Contact fatigue.
3) Surface depression & fracture.
4) Mechanical wear & contact stresses.
5) Corrosion problem.
6) Discoloring & overheating.

So to reduce this problem we are going to replacement of steel ball bearing ball material to optimize & reduce the drawbacks in it. A proper material selection is a most important in ball bearing design, for its wide range of reliable performance. So we select material of silicon nitride (ceramic), which has a less density, high wear resistance, Lower coefficient of expansion as that of steel material for bearing design and analysis. As with material selections in, this paper will discuss the performance differences between a ball bearing with tool steel balls and Ceramic balls analysis.

In this project we select deep groove ball bearing which is having specifications as given in table below,

Table No.2.1. Ball bearing specifications.

BALL BEARING	SPECIFICATIONS
Model No.	SKF 6202B
Bore diameter (di)	30mm
Outer race diameter (do)	35mm
Mean diameter (dm)	27.5mm
Ball diameter (d)	6.123mm
Width (B)	11mm

Table No.2.2. Ball bearing specifications

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BALL BEARING	SPECIFICATIONS
Model No.	SKF 6303B
Bore diameter (di)	34mm
Outer race diameter (do)	47mm
Mean diameter (dm)	27.5mm
Ball diameter (d)	6.912mm
Width (B)	14mm

3. MATERIAL SELECTION

In this project we select materials for bearing ball which is having mechanical properties as given in table below,

Table No.3.1.Mechanical properties use for bearing.

Mechanical properties	Stainless steel	Ceramics Si_3N_4	Ceramics ZrO_2	Ceramics Al_2O_3
Young's modulus (Gpa)	200	320	210	380
Poisson's ratio	0.3	0.26	0.3	0.22
Density (kg/m^3)	7900	3300	6000	3950

3.1 STAINLESS STEEL:

Stainless steels are notable for their corrosion resistance, which increases with increasing chromium content. Molybdenum additions increase corrosion resistance in reducing acids and against pitting attack in chloride solutions. Thus, there are numerous grades of stainless steel with varying chromium and molybdenum contents to suit the environment the alloy must endure.

Stainless steel differs from carbon steel due to the presence of chromium. Unprotected carbon steel rusts readily when exposed to the combination of air and moisture. The resulting iron oxide surface layer (the rust) is porous and fragile. Since iron oxide occupies a larger volume than the original steel this layer expands and tends to flake and fall away exposing the underlying steel to further attack. In comparison, stainless steels contain sufficient chromium to undergo passivation, spontaneously forming a microscopically thin inert surface film of chromium oxide by reaction with the oxygen in air and even the small amount of dissolved oxygen in water. This passive film prevents further corrosion by blocking oxygen diffusion to the steel surface and thus prevents corrosion from spreading into the bulk of the metal.[3] This film is self-repairing if it is scratched or temporarily disturbed by an upset condition in the environment that exceeds the inherent corrosion resistance of that grade. Thus. stainless steels are used where both the strength of steel and corrosion resistance are required.

Properties of Stainless Steel-

In addition to corrosion resistance, the advantageous physical properties of stainless steel include:

- High and low temperature resistance
- Ease of fabrication
- High Strength
- Aesthetic appeal
- Hygiene and ease of cleaning
- Long life cycle
- Recyclable
- Low magnetic permeability

3.2 CERAMICS (Si3N4):

Silicon nitride is a chemical compound of the elements silicon and nitrogen. Si3N4 is the most thermodynamically stable of the silicon nitrides. Hence, Si3N4 is the most commercially important of the silicon nitrides[4] and is generally understood as what is being referred to where the term "silicon nitride" is used. It is a white, high-melting-point solid that is relatively chemically inert, being attacked by dilute HF and hot H2SO4. It is very hard.

Applications exploit the following properties of silicon nitride:

- low density.
- high temperature strength.
- superior thermal shock resistance.
- excellent wear resistance.
- good fracture toughness.
- mechanical fatigue and creep resistance.
- good oxidation resistance.

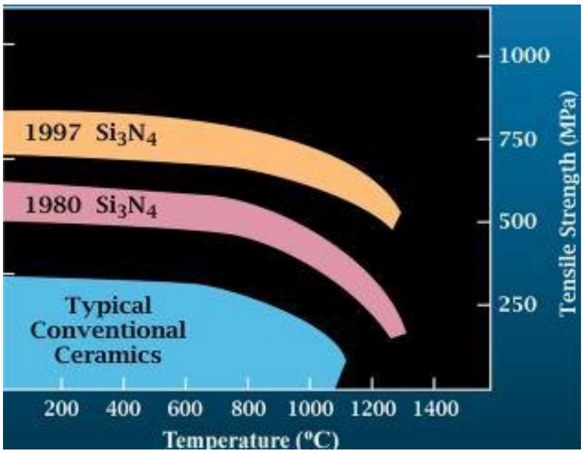


Chart No. 1 Strength of Si3N4

3.3 ZINCRONIUM OXIDE

Zirconium dioxide (ZrO2), sometimes known as zirconia (not to be confused with zircon), is a white crystalline oxide of zirconium. Its most naturally occurring form, with a monoclinic crystalline structure, is the mineral baddeleyite. A dopant stabilized cubic structured zirconia, cubic zirconia, is synthesized in various colours for use as a gemstone and a diamond simulant.

Properties:-

1. It having very high resistance to crack propagation
2. It having very high thermal expansion capacity
3. It having higher strength
4. It contains oxygen ions

Zirconia is often more useful in its phase 'stabilized' state. Upon heating, zirconia undergoes disruptive phase changes. By adding small percentages of yttria, these phase changes are eliminated, and the resulting material has superior thermal, mechanical, and electrical properties. In some cases, the tetragonal phase can be metastable. If sufficient quantities of the metastable tetragonal phase is present, then an applied stress, magnified by the stress concentration at a crack tip, can cause the tetragonal phase to convert to monoclinic, with the associated volume expansion. This phase transformation can then put the crack into compression, retarding its growth, and enhancing the fracture toughness. This mechanism is known as transformation toughening, and significantly extends the reliability and lifetime of products made with stabilized zirconia.

Applications:-

1. Formanufacturing of ball of bearing
2. In medical field for manufacturing of artificial Tooth
3. In Construction Industry

The main use of zirconia is in the production of hard ceramics, such as in dentistry with other uses including as a protective coating on particles of titanium dioxide pigments,as a refractory material, in insulation, abrasives and enamels. Stabilized zirconia is used in oxygen sensors and fuel cell membranes because it has the ability to allow oxygen ions to move freely through the crystal structure at high temperatures. This high ionic conductivity (and a low electronic conductivity) makes it one of the most useful electroceramics. Zirconium dioxide is also used as the solid electrolyte in electrochromic devices.

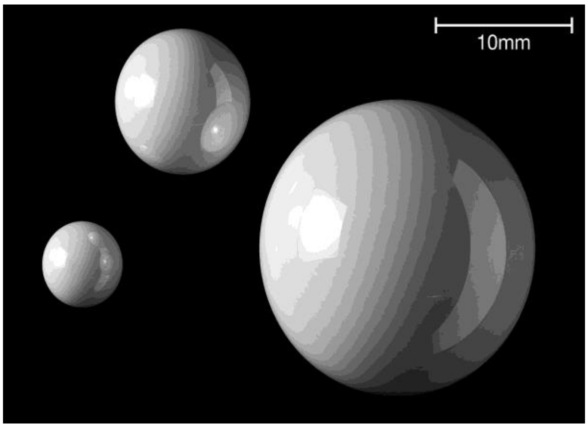


Diagram No.1. Zincronium Oxide Balls

Table No. 3.2

Properties	
Chemical formula	ZrO2
Molar mass	123.218 g/mol
Appearance	white powder
Density	5.68 g/cm^3
Melting point	2,715 °C (4,919 °F; 2,988 K)
Boiling point	4,300 °C (7,770 °F; 4,570 K)
Solubility in water	Negligible
Solubility	soluble in HF, and hot H_2SO_4
Refractive index (n_D)	2.13

Single crystals of the cubic phase of zirconia are commonly used as diamond simulant in jewellery. Like diamond, cubic zirconia has a cubic crystal structure and a high index of refraction. Visually discerning a good quality cubic zirconia gem from a diamond is difficult, and most jewellers will have a thermal conductivity tester to identify cubic zirconia by its low thermal conductivity (diamond is a very good thermal conductor). This state of zirconia is commonly called cubic zirconia, CZ, or zircon by jewellers, but the last name is not chemically accurate. Zircon is actually the mineral name for naturally occurring zirconium silicate (ZrSiO4)

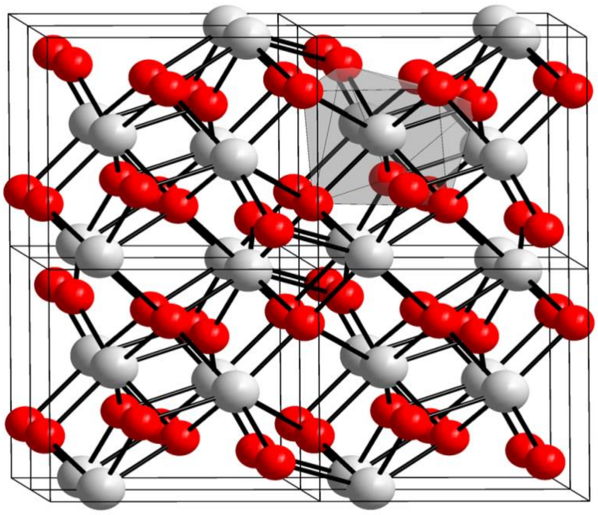


Diagram No. 2 Crystal Structure Of Zincronium Oxide

3.4 Al203

Aluminium oxide (British English) or aluminum oxide (American English) is a chemical compound of aluminium and oxygen with the chemical formula Al_2O_3. It is the most commonly occurring of several aluminium oxides, and specifically identified as aluminium(III) oxide. It is commonly called alumina, and may also be called aloxide, aloxite, or alundum depending on particular forms or applications. It occurs naturally in its crystalline polymorphic phase α-Al_2O_3 as the mineral corundum, varieties of which form the precious gemstones ruby and sapphire. Al_2O_3 is significant in its use to produce aluminium metal, as an abrasive owing to its hardness, and as a refractory material owing to its high melting point.[6]
Properties of Alumina/Aluminum Oxide (Al2O3)

- Very good electrical insulation (1x1014 to 1x1015 Ωcm)
- Moderate to extremely high mechanical strength (300 to 630 MPa)
- Very high compressive strength (2,000 to 4,000 MPa)
- High hardness (15 to 19 GPa)
- Moderate thermal conductivity (20 to 30 W/mK)
- High corrosion and wear resistance
- Good gliding properties
- Low density (3.75 to 3.95 g/cm3)
- Operating temperature without mechanical load 1,000 to 1,500°C.
- Bioinert and food compatible

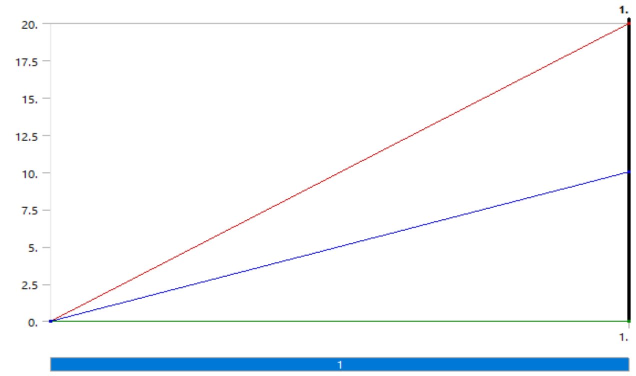


Chart -1: Displacement chart

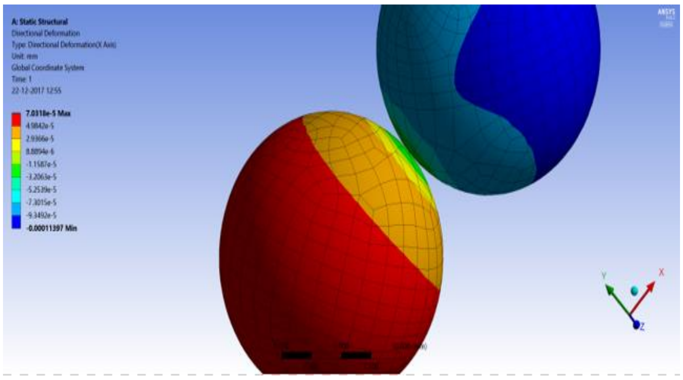


Diagram No. 3 Devlopment Of Contact Stresses

3.5 MATERIAL DATA

3.5.1 Steel

Density	7.85e-006kg mm^-3
Isotropic Secant Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat Constant Pressure	4.34e+005 mJ kg^-1 C^-1
Isotropic Thermal Conductivity	6.05e-002 W mm^-1 C^-1
Isotropic Resistivity	1.7e-004 ohm mm

3.5.2 Zincronious oxide

Density	9.15e-006 kg mm^-3
Isotropic Secant Coefficient of Thermal Expansion	2.3e-005 C^-1
Specific Heat Constant Pressure	4.34e+005 mJ kg^-1 C^-1
Isotropic Thermal Conductivity	9.05e-002 W mm^-1 C^-1
Isotropic Resistivity	3.5e-004 ohm mm

4.MATEMATICAL MODELING & CALCULATION

Here we have,

Given Data(According to Bearing Catalogue)

1. Bearing Name- SKF 6202
   - Inner Diameter = 15mm
   - Outer Diameter = 35mm
   - Width = 11mm
2. Bearing Name- SKF 6303
   - Inner Diameter = 17mm
   - Outer Diameter = 47mm
   - Width = 23.5mm

(1)

BEARING SURFACE AREA (A)= 2πr
= 2x3.14x17.5
= 109.9 = 110mm^2

LOAD ACTING ON ELEMENTAL RING (W) = Pressure x ring area
(W) = 13.7 x 110
(W) = 1507 N

here we have,
MAX. PRESSURE ACTING ON BEARING = 13.7 N

FRICTIONAL RESISTANCE IS (Fr)
Fr = μW
= 0.025 X 1507
= 37.67

FRICTIONAL TORQUE (Tr) = Fr X r
= 37.67 X 14.5
= 546.28 N

(2)

BEARING SURFACE AREA (A)= 2πr
= 2 X 3.14 X 23.5
= 147.58 mm^2

LOAD ACTING ON ELEMENTAL RING (W) = Pressure x ring area
(W) = 19.2 x 147.58
(W) = 2833.53 N

here we have,
MAX. PRESSURE ACTING ON BEARING = 19.2 N/mm

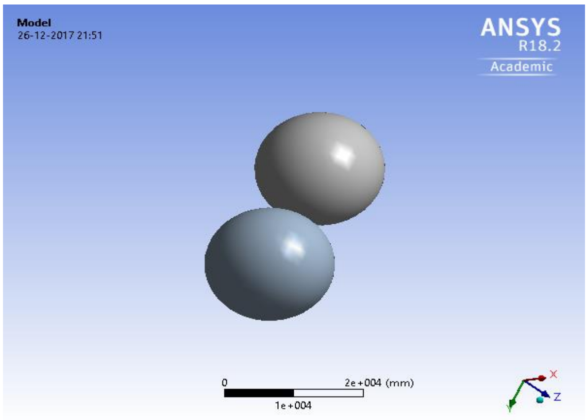
FRICTIONAL RESISTANCE IS (Fr)
Fr = μW
= 0.025 X 2833.53
= 70.83 N

FRICTIONAL TORQUE (Tr) = Fr X r
= 70.83 X 23.5
= 1664.69 N

4.1OBSERVATIONS

Circular contact area diameter 2a

Sr.No.		Load	Stainless steel		ceramic
ceramic		Ceramic			
	(N)		Si3N4	ZrO2	Al2O3
1	1000	0.461	0.397	0.453	0.378
2	2000	0.581	0.500	0.571	0.476
3	3000	0.665	0.573	0.654	0.545
4	4000	0.731	0.630	0.720	0.599
5	5000	0.788	0.679	0.775	0.646



5.CONCLUSIONS

In this paper we are going to do the proper material selection which is a most important in ball bearing design, for its reliable performance. We select different ceramic materials for bearing ball according to this; FEA simulation & experimentally to optimize the bearing ball material. As per Analytical Modeling we see that **ceramic Zirconium oxide ZrO_2 material having less density, high wear resistance, lower coefficient of thermal expansion** as that of steel material for bearing ball within approximate same stresses field of Maximum contact pressure & Maximum shear stress by using Hertz contact theory which will further validates by using FEA simulation & experimentally.

- Steel has a less density,
- high wear resistance,
- Steel lower coefficient of thermal expansion

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