Model And Fatigue Behaviour Of Bearings In Sub-Zero And Elevated Temperatures

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Abstract- *Bearings are one of the key components that determine the service interval for rotating machinery; they can even limit the life of the machine. Therefore, knowledge and understanding of bearings are important to both designers and users. In selecting the bearing to be used, one must consider a variety of factors: Loads, static and dynamic factors, Speed and running pattern, Stiffness, Temperature levels and gradients, heat conduction, Lubrication: viscosity, stiffness, durability, Degree of contamination. Shielding, Mounting, Maintenance, Lifetime and service time.*

To ensure the long life of a product, many factors have to be taken into account. A poor installation with unfavorable inlet conditions, unfavorable duty points, bad anchoring etc can cause structural disturbances that may be detrimental. While natural frequencies in the structure from poorly designed supports of the pump, pipes, valves etc are often the cause of high vibration levels. These factors describe some of the knowledge and experience including the precautions to be taken into consideration in the design and analysis of shaft and bearings. In this project the model behaviour and fatigue character of the bearings are studied from sub-zero to elevated temperature

Keywords- Wi-Fi modem, Arduino microcontroller, Application Resource Manager (ARM), Solids Waste management.

I. INTRODUCTION

For centuries, man had to rely on his own power to push or pull large objects over the earth. The concept of a bearing – to lessen friction between an object and the surface over which it is moved – is nearly as old as man himself. The first solution to relieving some of this sliding friction was recorded as early as 3,500 B.C. It was then that Mesopotamians were using one of the first bearings known to man, an invention called the wheel. Where the wheel and axle touched, they put a bearing made of leather or wood and lubricated it with animal fat. Ancient drawings from 1,100 B.C. show the Assyrians and Babylonians moving huge rocks for their monuments and palaces with rollers, illustrating the basic bearing principle – to lessen friction. But this was sliding – not rolling – friction.

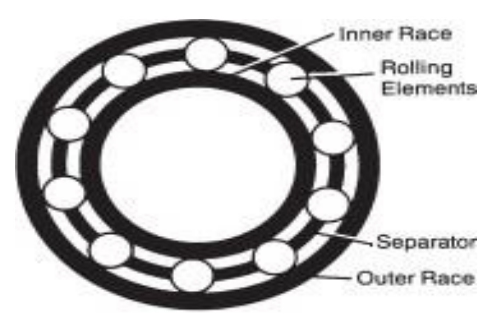
The roller and ball bearings of today may bear little resemblance to their predecessors but the concept has remained the same: to lessen friction. Today, bearings are used in almost every imaginable application, such as roller skates and bicycles, where two surfaces are turning or moving against each other. They are used in thousands of ways, from the minute internal workings of a clock to large turbine engines in a ship. The bearings with which we are concerned fit two basic categories – ball and roller. We will discuss both categories, and cover bearing types, installation, operating conditions, maintenance and troubleshooting. In addition, we will feature one particular type – the tapered roller bearing – which has numerous fleet applications.

The parts of a bearing

A bearing's smooth performance is assured by a combination of four basic working parts :

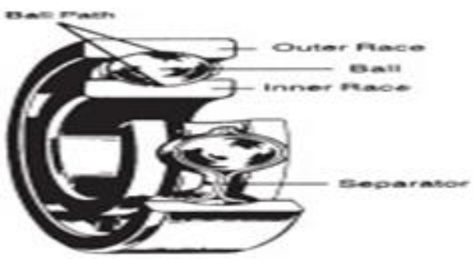
- Outer race (also called outer ring or cup)
- Inner race (also called inner ring or cone)
- Rolling elements (either balls or rollers)
- Separator (also called cage or retainer)

The outer race, or cup, is the bearing's exterior ring. Since it protects the bearing's internal parts, it must be machined smoothly and accurately. The inner race, or cone, is the part of the bearing that sits directly on the shaft.



Bearing parts

The rolling elements, shaped as balls or rollers, provide the cushion that eases the moving friction of the shaft within its housing. These elements keep the outer and inner races separated and enable them to move smoothly and freely. The shape of the rolling elements depends on the type of load, operating conditions and particular applications. It is the rolling elements that distinguish the two basic bearing categories – ball bearings and roller bearings.



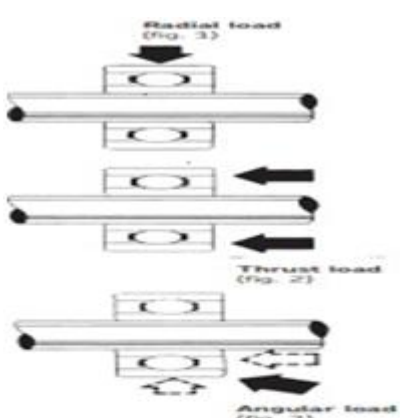
Ball bearing components (fig. 2)

A bearing is designed to:

- Reduce friction
- Support a load
- Guide moving parts – wheel, shafts, pivots

There are three types of loads:

1. When the direction of the load (weight being moved) is at right angles to the shaft, it is called a "radial" load. The load pushes down on the bearing.
2. When the direction of the load is parallel to the shaft, it is called a "thrust" load. The load pushes sideways on the bearing.
3. When the direction of the load is a combination of radial and thrust, the load pushes down sideways on the bearing. This combination is called an "angular" load



Fatigue

In materials science, fatigue is the initiation and propagation of cracks in a material due to cyclic loading. Once a fatigue crack has initiated, it grows a small amount with each loading cycle, typically producing striations on some parts of the fracture surface. The crack will continue to grow until it reaches a critical size, which occurs when the stress intensity factor of the crack exceeds the fracture toughness of the material, producing rapid propagation and typically complete fracture of the structure. It is, evident that fatigue failure is neither sudden nor hidden. For this reason, fatigue is often referred to as "progressive fractures". This sequence of events makes it clear that fatigue is a result of cumulative process involving slip. High temperature increases the mobility of atoms, facilitating greater slip and deformation before fracture.

Highly localised stress is also developed at:

(i) Abrupt changes in cross-section,
(ii) Base of surface scratches,
(iii) Root of a screw thread,
(iv) Edge of small inclusion of foreign substances, and Minute blow hole etc

Theories of Fatigue:

1. Orowan theory.
2. Fatigue limits theory.
3. Wood's theory
4. Dislocation movement theory.

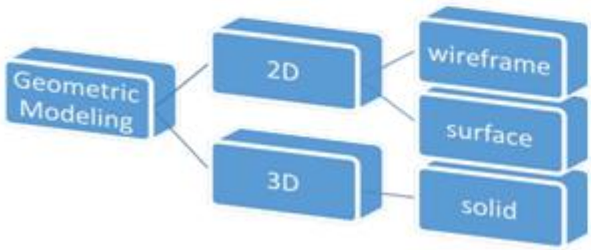
Vibrations: Vibration is a mechanical phenomenon whereby oscillations occur about an equilibrium point. The word comes from Latin *vibration* ("shaking, brandishing"). The oscillations may be periodic, such as the motion of a pendulum—or random, such as the movement of a tire on a gravel road.

GEOMETRIC MODELLING:

The computer compatible mathematical description of geometry of an object is called geometric modelling. The CAD software allows the mathematical description of the object to be displayed as an image on the computer. Various steps for creating a geometric modelling are:

- Creation of basic geometric elements by using commands like points, lines and circles.

- Transformation of the basic elements based on requirements by using commands like scaling, rotating and joining.
- Creation of geometric model by using various commands that cause the integration of the elements into desired shape.



SOLID MODELLING:

It is a type of 3d modelling that contains volumetric information about the model to be generated. It gives complete representation about the model..Solid modelling can be created and modified very quickly when compared to other types of modelling. Three approaches that are generally used for creating a solid model are :

1. Constructive Solid Geometry
2. Boundary representation
3. Hybrid scheme

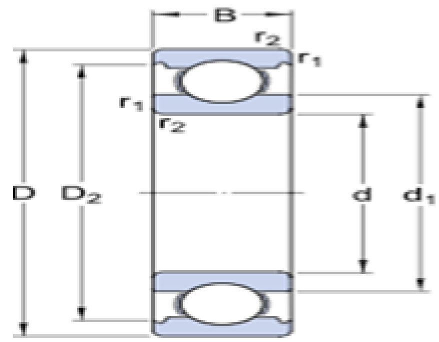
STRUCTURAL ANALYSIS

- **Static Analysis** - Used to determine displacements, stresses, etc. under static loading conditions. ANSYS can compute both linear and nonlinear static analyses. Nonlinearities can include plasticity, stress stiffening, large deflection, large strain, hyper elasticity, contact surfaces, and creep.
- **Transient Dynamic Analysis** - Used to determine the response of a structure to arbitrarily time-varying loads. All nonlinearities mentioned under Static Analysis above are allowed.
- Buckling Analysis - Used to calculate the buckling loads and determine the buckling mode shape. Both linear (Eigen value) buckling and nonlinear buckling analyses are possible.

THERMAL ANALYSIS

ANSYS can be used to Determine temperatures, thermal gradients, heat flow rates, and heat fluxes in an object that are caused by thermal loads that do not vary over time. Such loads include the following:

- Convection
- Radiation
- Heat flow rates
- Heat fluxes (heat flow per unit area)
- Heat generation rates (heat flow per unit volume)
- Constant temperature boundaries

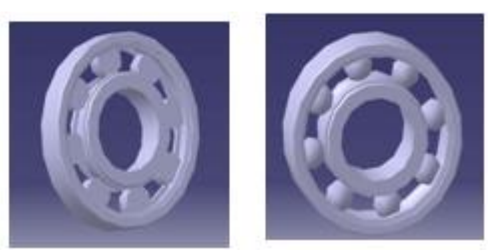


Model specifications

6001 Deep groove ball bearings.

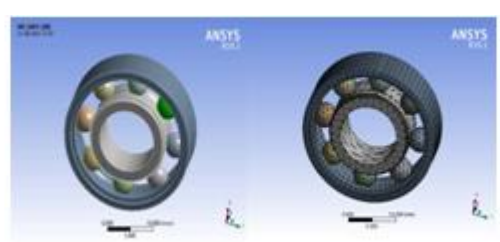
DIMENSIONS

d	12 mm	Bore diameter
D	28 mm	Outside diameter
B	8 mm	Width
d_1	≈17 mm	Shoulder diameter
D_2	≈24.72 mm	Recess diameter
$r_{1,2}$	min.0.3 mm	Chamfer dimension



Cad models

Roller bearing Ball bear

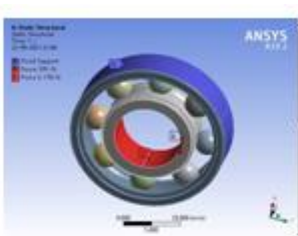


Details of "Mesh"	
Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	Mechanical
Element Order	Program Controlled
Element Size	Default
Sizing	
Use Adaptive Sizi...	Yes
Resolution	Default (2)
Mesh Defeaturing	Yes
Defeature Size	Default
Transition	Fast
Span Angle Center	Coarse
Initial Size Seed	Assembly
Bounding Box Di...	40.398 mm
Average Surface ...	52.161 mm²
Minimum Edge L...	0.16 mm
Quality	
Check Mesh Qua...	Yes, Errors
Error Limits	Standard Mechanical
Target Quality	Default (0.050000)
Smoothing	Medium
Mesh Metric	None
Inflation	
Advanced	
Statistics	
Nodes	18124
Elements	7132

Material properties

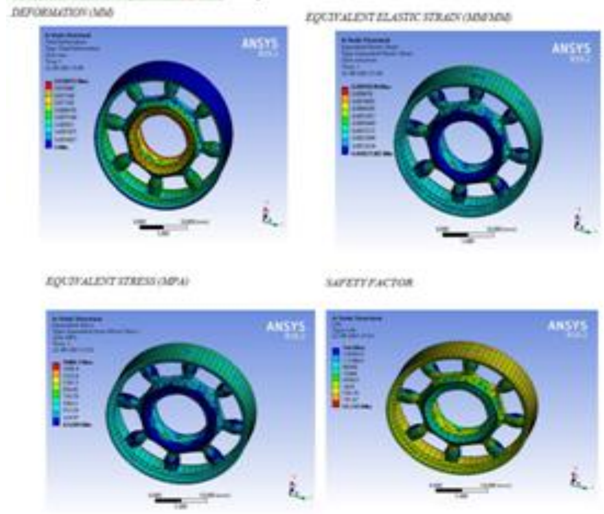
Properties of Outline Row 3: sae 52100

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	7850	kg m^-3		
4	Isotropic Secant Coefficient of Thermal Expansion				
5	Coefficient of Thermal Expansion	1.2E-05	C^-1		
6	Isotropic Elasticity				
7	Derive from	Young's Mo...			
8	Young's Modulus	2E+11	Pa		
9	Poisson's Ratio	0.3			
10	Bulk Modulus	1.6667E+11	Pa		
11	Shear Modulus	7.6923E+10	Pa		
12	Strain-Life Parameters				
13	Display Curve Type	Strain-Life			
14	Strength Coefficient	9.2E+08	Pa		
15	Strength Exponent	-0.106			
16	Ductility Coefficient	0.213			
17	Ductility Exponent	-0.47			
18	Cyclic Strength Coefficient	1E+09	Pa		
19	Cyclic Strain Hardening Exponent	0.2			
20	S-N Curve	Tabular			
21	Interpolation	Log-Log			
22	Scale	1			
23	Offset	0	Pa		
24	Tensile Yield Strength	2.5E+08	Pa		
25	Compressive Yield Strength	2.5E+08	Pa		
26	Tensile Ultimate Strength	4.6E+08	Pa		
27	Compressive Ultimate Strength	0	Pa		



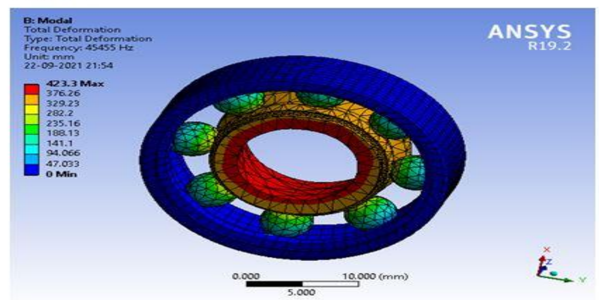
speed (rpm)	Hub load (N)	% Use	Water Pump Temperature
1500	591	19.7	-30°C

Structural and model analysis at -150 °C. roller bearing

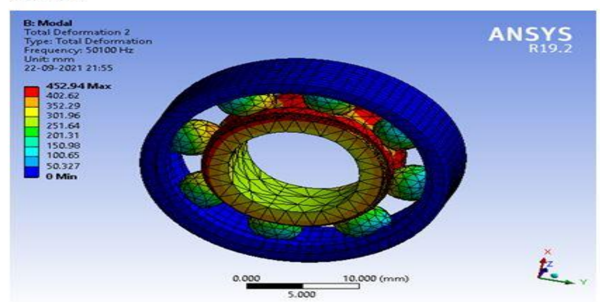


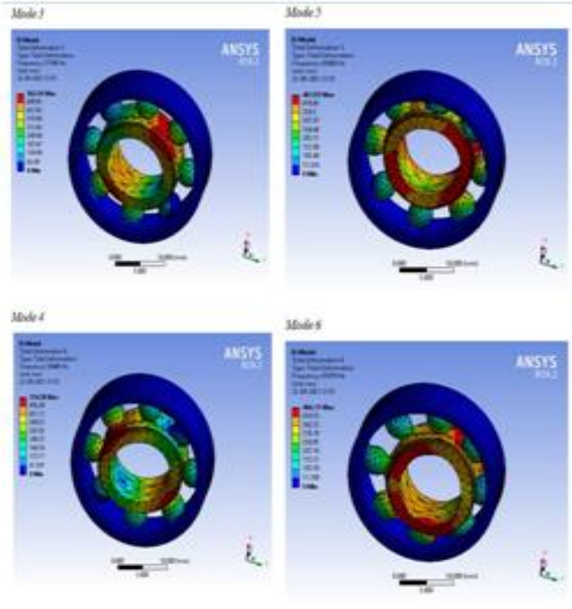
Natural frequency

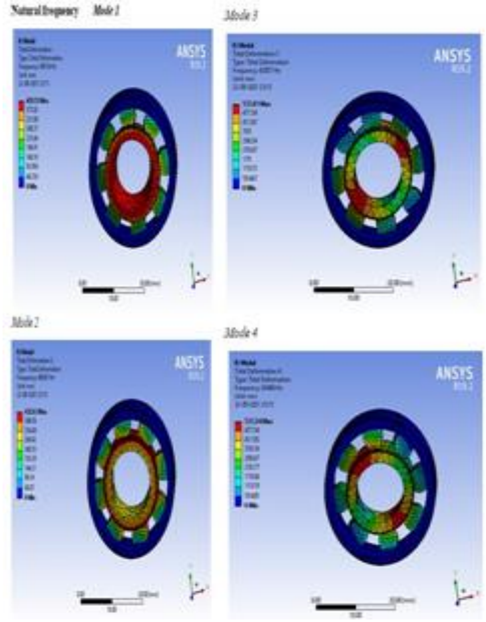
Mode 1



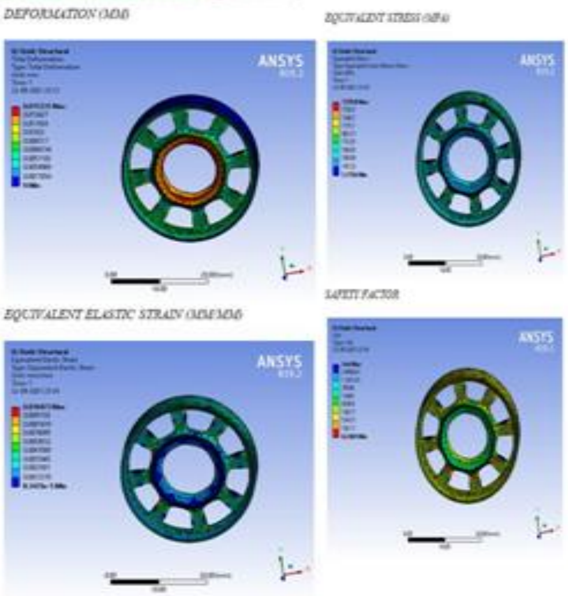
Mode 2



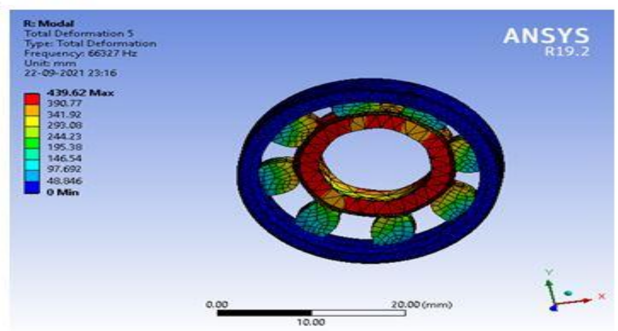




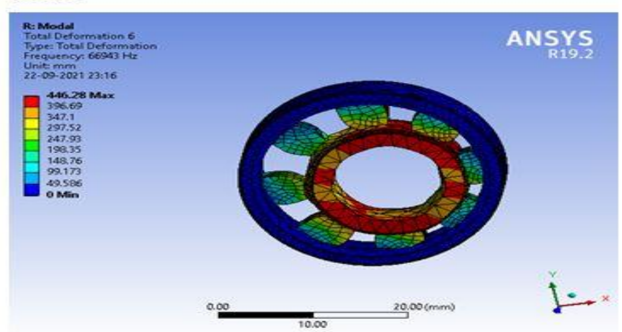
Structural and model analysis at -150 oC. Roller bearing



Mode 5



Mode 6



Result tables for ball bearing

Structural

static structural	-150 degree	-100 degree	-50 degree	0 degree	50 degree	100 degree	150 degree	200 degree
Total Deformation (mm)	6.37E-03	4.53E-03	2.69E-03	8.73E-04	1.06E-03	2.88E-03	4.72E-03	6.57E-03
Equivalent Elastic Strain (mm/mm)	2.17E-03	1.54E-03	9.08E-04	2.78E-04	3.53E-04	9.83E-04	1.61E-03	2.24E-03
Equivalent (von-Mises) Stress (Mpa)	382.88	271.61	160.35	49.139	62.315	173.54	284.81	396.08

Fatigue

static structural	-150 degree	-100 degree	-50 degree	0 degree	50 degree	100 degree	150 degree	200 degree
fatigue life	37753	80249	3.02E+05	9.77E+05	8.77E+05	2.49E+05	72852	34660

Natural frequency

model analysis	Frequency							
	-150 degree	-100 degree	-50 degree	0 degree	50 degree	100 degree	150 degree	200 degree
mode 1	45455	45376	45296	45216	45136	45056	44975	44895
mode 2	50100	49944	49788	49631	49473	49315	49156	48996
mode 3	57344	57237	57129	57021	56913	56804	56695	56586
mode 4	58446	58340	58234	58127	58020	57913	57805	57697
mode 5	65688	65647	65606	65564	65523	65481	65439	65397
mode 6	67678	67640	67602	67564	67526	67487	67448	67409

Result tables for roller bearing

Structural

static structural	-150 degree	-100 degree	-50 degree	0 degree	50 degree	100 degree	150 degree	200 degree
Total Deformation (mm)	6.03E-03	4.28E-03	2.54E-03	8.12E-04	1.01E-03	2.74E-03	4.49E-03	6.23E-03
Equivalent Elastic Strain (mm/mm)	2.33E-03	1.65E-03	9.75E-04	2.98E-04	3.80E-04	1.06E-03	1.73E-03	2.41E-03
Equivalent (von-Mises) Stress (Mpa)	404.94	287.24	169.54	51.902	65.972	183.63	301.33	419.03

Fatigue

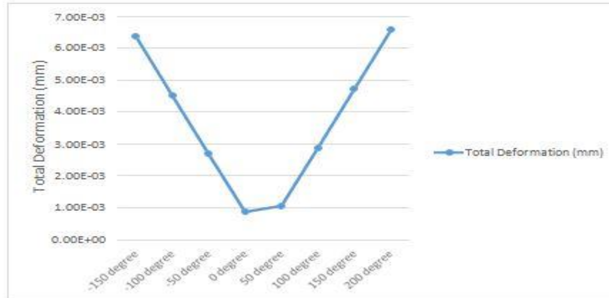
static structural	-150 degree	-100 degree	-50 degree	0 degree	50 degree	100 degree	150 degree	200 degree
fatigue life	46956	69494	1.86E+05	9.76E+05	9.09E+05	1.52E+05	65214	45365

Natural frequency

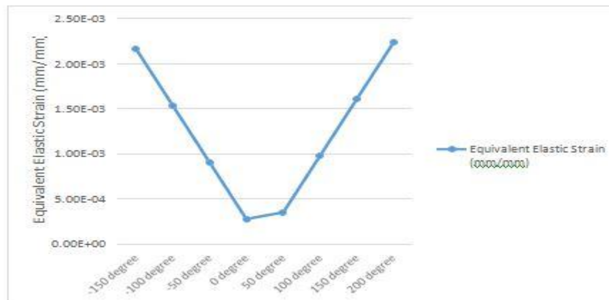
model analysis	Frequency							
	-150 degree	-100 degree	-50 degree	0 degree	50 degree	100 degree	150 degree	200 degree
mode 1	48516	48400	48240	48078	47915	47751	47586	47420
mode 2	48567	48455	48386	48318	48250	48182	48114	48045
mode 3	63057	62966	62875	62783	62692	62600	62508	62415
mode 4	63468	63378	63287	63196	63105	63014	62922	62831
mode 5	66327	66287	66247	66206	66166	66125	66084	66043
mode 6	66943	66902	66862	66821	66780	66739	66698	66657

Graphical representation of ball bearing

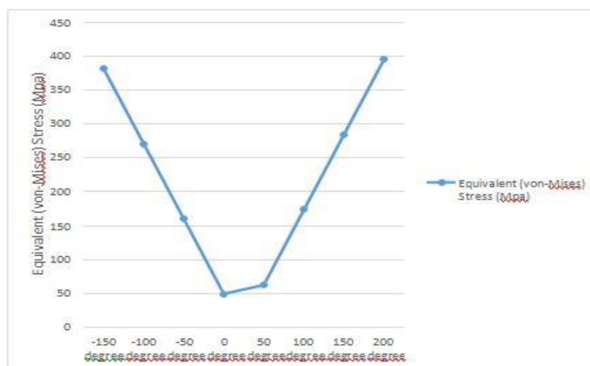
Total Deformation (mm)



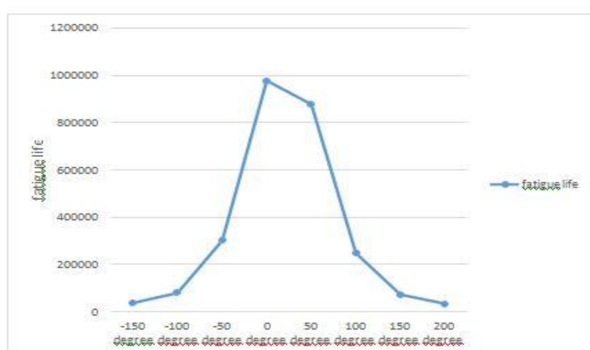
Equivalent Elastic Strain (mm/mm)



Equivalent (von-Mises) Stress (Mpa)

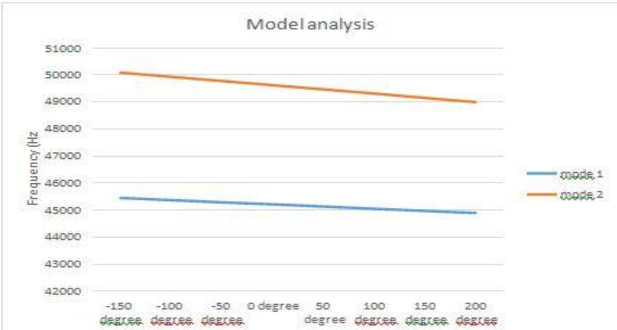


FATIGUE LIFE

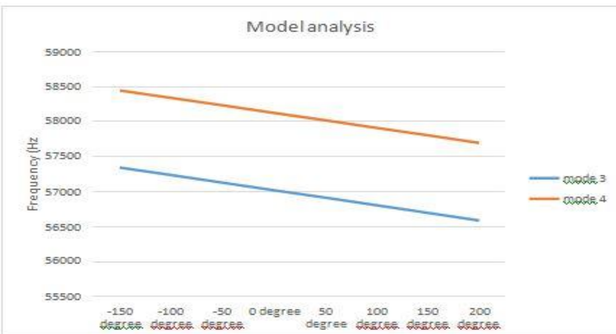


Natural frequency

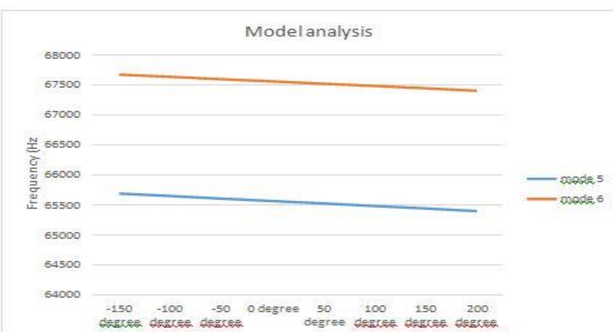
Mode 1&2



Mode 3&4

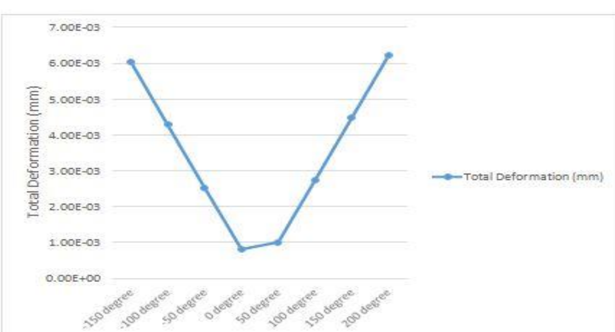


Mode 5&6

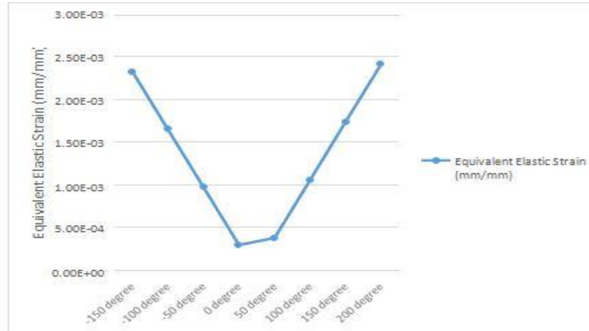


Graphical representation of roller bearing

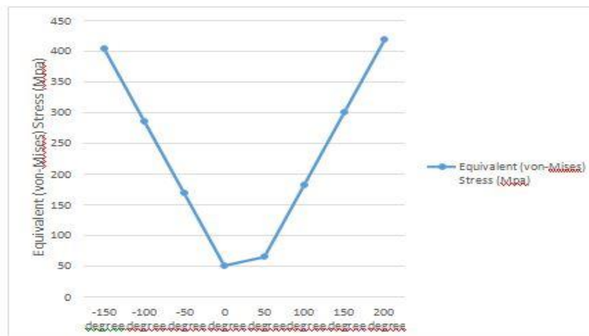
Total Deformation (mm)



Equivalent Elastic Strain (mm/mm)



Equivalent (von-Mises) Stress (Mpa)

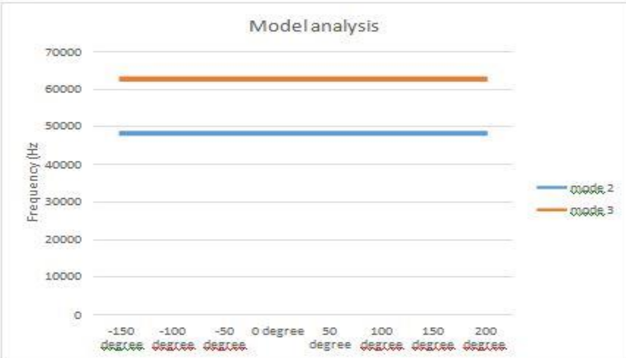


Fatigue life

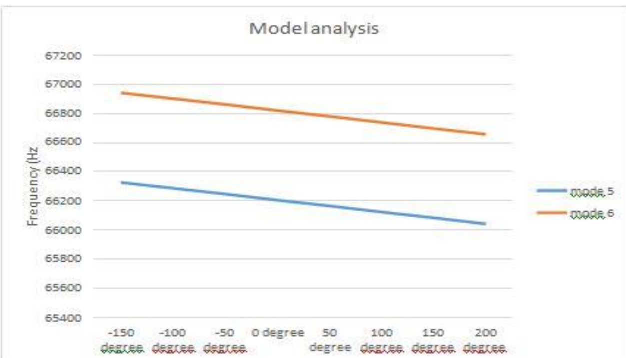
Natural frequency

Mode 1&2

Mode 3&4



Mode 5&6



II. CONCLUSION

In this project the model behaviour and fatigue character of the bearings are studied from sub-zero to elevated temperature, two models of bearing are studied in thesis work, skf-6001 model dimensions are used to develop cad models, cad models are developed in Catia v5 and studied using ansys workbench 19.0, this study is carried by coupled field analysis, static structural and model analysis modules are coupled to calculate the combined effect of mechanical load and thermal load on the natural frequencies of the bearings, also fatigue life id estimated under mechanical and thermal load. The observations are discussed

1. Natural frequencies increase with increase in temperature from -150^{o}C to 200^{o}C.
2. At subzero temperatures the models are much stiffer
3. The fatigue life of the bearings is very low at subzero temperatures and slowly increased towards room temperature.
4. Increase in temperature also depletes fatigue life of the component but not as much as subzero temperatures
5. Stress and strain follows same as fatigue life pattern but they degrease towards room temperature and increase towards subzero and elevated temperature.

III. FUTURE SCOPE

This entire study is based on simulation results, and many assumptions are taken for running the simulation, same study with some practical experimentations suggested, non-destructive and distractive testing of bearings at different temperatures is suggested

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