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EFFECT OF CRYOGENIC TREATMENT ON DIMENSIONAL STABILITY OF BALL BEARING

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ABSTRACT

Rolling element bearings are of paramount importance to almost all forms of rotating machinery and are among the most common machine elements. Because high contact stress of several GPa is applied to parts of rolling elements of bearings, these parts must be strong enough to withstand high stress, able to resist rolling fatigue, tough enough to resist impact loads, and able to maintain their precision with minimum distortion. The structural and dimensional stability of the bearing components must be satisfactory at the operating temperatures that can be expected. Cryogenic treatment after hardening treatment is a supplementary treatment that influences the entire section of the component and causes improvement in tribological properties. An attempt has been made to study the effect of cryogenic treatment of ball bearing on dimensional stability. Two treatments namely conventionally heat treated (CHT), and cryogenically treated (CT) were considered. Cryogenic treatment leads to reduction in noise level, less in radial clearance of balls, reduction in concentricity error of races, reduction in deviation of sphericity of balls, reduction in variation in diameter of balls and less surface damage of balls after service test. No significant effect of cryogenic treatment on other parameters after service test.

Key words: Ball bearing, Cryogenic treatment, Dimensional stability

1. INTRODUCTION

In addition to conventional heat treatment process of high carbon steels, cryogenic treatment is done nowadays to improve the mechanical properties of materials, in which the hardened samples are cooled to 80K slowly from room temperature, held at that temperature for a long time and then heated back to room temperature. After hardening, the samples are cryogenic treated and finally a low temperature tempering is done. Cryogenic treatment influences the entire section of the components unlike coatings. The effect of cryogenic treatment on the wear resistance of tool steels has been well established [1]. Balls and Rollers in bearings are also undergo high surface fatigue and wear during operation. The wear resistance of such components also can be improved through cryogenic treatment [2]. The wear resistance of various types of alloy steels after cryogenic treatment was found to be improved [3]. Cryogenic treatment of high carbon steel samples were done and the wear resistance has remarkably increased [4]. Dramatic improvement in hardness and wear resistance in alloy steels is due to the effect of cryogenic treatment [5]. Fatigue life of AISI 304L cruciform welded joints by cryogenic treatment improved by a factor of two. The strain induced martensite formed during the cryogenic treatment and the associated generation of compressive stresses in the weld metal are considered to be effective in fatigue life improvement [6]. The present work is to study the effect of dimensional stability of 52100 bearing steel on cryogenic treatment.

2. EXPERIMETNAL PROCEDURE

2.1 SELECTION OF MATERIAL

The great majority of rolling element bearings produced throughout the world are manufactured from steel known as AISI 52100. The material is spheroidize - annealed for ease of formability prior to machining to form both the races and the rolling elements, that is the ball or rollers. Ball bearing (6204) was selected for the study. The composition of the steel is given in Table 1.

2.2 HEAT TREATEMNT

Two types of treatments namely 1)Conventionally heat treated (CHT) and 2) Crygenically treated (CT) were considered. For the first type of treatment bearing components were hardened and tempered. For hardening, it was first heated to austenising temperature of 1123K (850°C) in an electric furnace. The material was kept at this temperature for one hour (soaking period). It was then quenched in an oil bath maintained at a temperature of 323K (50°C). While tempering it was heated to 473K (200°C) and kept at that temperature for one hour (soaking period). Then it was taken out of the furnace and allowed to be air cooled to room temperature.

Table 1 Composition of AISI 52100 steel

Elements	Weight %
Fe	96.89
C	1.040
Si	0.245
Mn	0.328
P	<0.007
S	<0.007
Cr	1.366
Mo	0.017
Ni	0.087
Cu	0.021
V	0.014

For the second type of treatment the components of bearings were hardened using the above procedure and then cryogenic treated followed by tempering.

2.3 CRYOGENIC TREATMENT

Cryogenic treatment involves the soaking of raw materials of bearing components at very low temperatures, 80K (-193 ^{0}C) using liquid nitrogen as the cooling medium. However, the material are gradually ramped down to the holding temperature of 80K (–193 ^{0} C) in six hours to avoid thermal shock due to quick quenching. Once the soak temperature of 80K (–193 ^{0} C) is reached the components are held at that temperature for a period of 24 hours and slowly brought to room temperature in eight hours (ramp up), followed by tempering. The most important parameters of the treatment process are the ramp-down (6 hours), ramp-up (8 hours), and holding time (24 hours) [7]. The cryogenic treatment of the samples were done in the cryogenic chamber which is fully covered with multilayer super insulation and is connected to the liquid nitrogen dewar where the liquid nitrogen is used as the cooling medium. Liquid nitrogen is carefully administrated into the chamber through a microprocessor controlled solenoid valve. The microprocessor has a temperature feedback and accordingly controls the current flowing into the heater, which is placed inside the cryogenic chamber. With these controls, microprocessor can be programmed for any heating rate. After the cryogenic treatment tempering was done by heating the components to 473K (200 ^{0}C) for one hour and cooled in air to room temperature.

2.4 MEASUREMENT OF VARIOUS PARAMETERS

Life test was conducted on custom made accelerated bearing life testing machine. The equipment could be used for testing of ball and roller bearings. Four bearings could be loaded in the shaft. The setup could be used to test different bore size bearings. The test conditions were : load 250 kg, speed 3000 rpm and period 100 hours. The following parameters of the ball bearings were checked before and after test.

1. Outer diameter of outer race (BR.I Special gauge-mechanical comparator)
2. Inner diameter of inner race (BR.I Special gauge-mechanical comparator).
3. Width of the outer and inner races (Mechanical comparator -Height gauge)
4. Radial Runout or Roundness (Talyrond 200-Roundness master)
5. Radial clearance (Mechanical comparator)
6. Noise level test (Anderometer)
7. Concentricity (standard gauge with Mechanical Comparator)
    a. Outer race track groove
    b. Inner race track groove
8. Sphericity of the ball by (Ball Wavi meter)
9. Variation in diameter of the ball (millitron diameter master -mechanical comparator)
10. Roughness of the ball (Talysurf - 5 - 60 - Roughness tester).

A comparison of range of deviations of the above parameters of ball bearings before and after service test for the two treatments 1)conventionally treated (CHT) and 2) Cryogenically (CT) is tabulated in Table 2

A comparison on average deviation of ball bearings (6204) before and after service test for the two treatments is tabulated in Table 3.

A comparison is also made on average deviation of ball bearings (6204) before and after service test for the two treatments is tabulated in Table 3.

3. RESULTS AND DISCUSSION

From the Table 2 it is clear that no significant effect on cryogenic treatment was observed on 1) Outer diameter of outer race, 2) Inner diameter of inner race, 3) Width of outer and inner races and 4) Roundness of outer diameter of outer race and inner diameter of inner race.

The range of deviation of the radial clearance of conventionally heat treated (CHT) samples are 6 to 10 μm and 10 to 16 μm before and after service test. Whereas the corresponding values for Crygenically treated (CT) samples are 5 to 7 μm and 6 to 9 μm. Therefore a range of deviation of 4 μm only is observed in CT samples whereas CHT samples gives a value of 10μm. The probable reasons are due to the transformation of retained austenite into martensite and thereby increase in hardness, wear resistance and dimensional stability.

Similar result is also obtained while comparing the average deviation of the radial clearance of (CHT) and (CT) samples after service test. The values for the two treatments are 14.2μm and 9.6μm. Therefore the radial clearance of CT samples are 46% less than the CHT samples.

The average deviation of noise level measured by Anderometer shows a value of LB13.4 - MB16.2. - HB 19.0 Anderons for CHT samples. Corresponding values for CT samples are LB10 - MB11 - HB12.6 Anderon. The reduction in noise level of CT samples may be due to more dimensional stability and less wear of cryogenic treated sample.

The average deviation of the concentricity error of outer race track groove after service test is 4.1μm and 3μm for CHT and CT samples respectively as shown in table 3. Therefore 25% reduction in concentricity error in the outer races of bearing subjected to cryogenic treatment after service test is obtained. Similar result is obtained for average deviation of the concentricity error of inner race track groove. The values are 3.4μm and 2.5μm for CHT and CT samples respectively

The average deviation surface roughness of the balls subjected to cryogenic treatment (CT) after service test is 0.32μm whereas conventional treated(CHT) balls the value is 0.575μm. Significant improvement in resistant to surface damage CT of balls may be due to conversion of retained austenite to martensite in cryogenic treatment thereby dimensional stability of balls are improved.

The average deviation of variation in the ball diameter of CT samples after service test is 1.4 μm and 1.8 μm for CHT samples. Therefore variation in ball diameter of balls treated by cryogenic treatment is reduced.

The average deviation of sphericity of the balls subjected to CT is 0.36μm whereas CHT samples gives a value of 0.5μm. Therefore deviation in sphericity of balls subjected to cryogenic treatment is less.

Table 2 Comparison of range of deviation of various parameters of 6204 (AISI 52100) ball bearing in hardened and tempered (CHT) and hardened, cryogenic treated and tempered(CT) samples

Sl. No.	**Parameters**	**Hardened and tempered samples (CHT), (μm)**		**Hardened, cryogenic treated and tempered samples (CT), (μm)**	
		Before Service Test	**After service test**	**Before Service Test**	**After service test**
1.	Outer diameter	-2.0 to -5.0	-2.0 to -5.0	2.0 to -4.0	-2.0 to -4.0
2.	Inner diameter	-2.0 to -5.0	-2.0 to -5.0	-2.5 to -4.0	-2.5 to 4.0
3.	Width Outer race Inner race	 -50.6 to -60.0 -39.0 to -50.0	 -48.0 to -60.0 -40.0 to -50.0	 -45.0 to -60.0 -40.0 to -52.0	 -46.0 to -58.0 -41.0 to 51.0
4.	Roundness Outer diameter Inner diameter	 3.0 to 7.0 3.0 to 6.0	 4.0 to 7.0 3.0 to 7.0	 3.0 to 5.0 3.0 to 4.0	 3.0 to 4.0 3.0 to 4.0
5.	Radial clearance	6.0 to 10.0	10.0 to 16.0	5.0 to 7.0	6.0 to 9.0
6.	Noise level in Anderons	LB 7 to10 - MB10 to 13- HB12 to 15	LB12 to 15 - MB15to 17- HB18 to 20	LB 7 to 9- MB 8 to 11- HB 10 to 12	LB 9 to 11- MB 11 to 12- HB 12 to 14
8.	Concentricity Outer race track groove Inner race track groove	 2.0 to 4.0 2.0 to 4.0	 3.5 to 5.0 2.5 to 4.0	 2.0 to 3.0 2.0 to 3.0	 2.5 to 3.5 2.0 to 3.0
9.	Sphericity of balls	0.2 to 0.32	0.4 to 0.6	0.2 to 0.3	0.3 to 0.45
10.	Variation in ball diameter	1.5 to 3.0	1.0 to 2.0	1.5 to 3.0	1.0 to 2.0
11.	Surface roughness of the balls	0.2 to 0.4	0.4 to 0.6	0.2 to 0.3	0.25 to 0.4

Table 3 Comparison of average deviation on dimensions of various parameters of 6204 (AISI 52100) ball bearing - After service test

Sl. No.	Parameters	Hardened and tempered (CHT), (μm)	Hardened, cryogenic treated and tempered (CT), (μm)	Observation
1.	Radial clearance	14.2	9.6	Improved wear resistance after CT
2.	Noise level in Anderons	LB13.4 - MB16.2 - HB19.0	LB10 - MB11 - HB12.6	Decreased noise level after CT
3.	Concentricity Outer race track groove Inner race track groove	 4.1 3.4	 3.0 2.5	Marginal improvement in concentricity after CT
4.	Roughness of the ball	0.575	0.32	Reduced Surface damage after CT
5.	Variation in the ball diameter	1.8	1.4	Less variation in ball diameter after CT
6.	Sphericity of the ball	0.5	0.36	Maintenance of Sphericity after CT

4. CONCLUSION

From the experimental study and observed data the following conclusions are arrived.

1. The radial clearance of cryogenic treated ball bearing is 46% less than the conventional heat treated ball bearing.
2. Cryogenic treatment leads to reduction in noise level by 40%.
3. 25% reduction in concentricity error was observed in the outer and inner races of bearings subjected to cryogenic treatment.
4. Deviation in sphericity of balls is reduced after cryogenic treatment.
5. Variation in diameter of balls of the bearings subjected to cryogenic treatment is reduced.
6. Surface damage of the balls subjected to cryogenically treatment is reduced.

5. REFERENCES

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6. NOMENCLATURE

Symbol	Meaning	Unit
T	Temperature	K
LB	Noise level - Low Band	Anderons
MB	Noise level - Medium Band	Anderons
HB	Noise level - High Band	Anderons