Advancement of Ceramic Bearings and its Applications

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Abstract: Rotating and Reciprocating parts are the basic parts of any manufacturing industry. The mechanical problems caused by the electric motors is generally because of vibrations produced by rotating machinery. The efficiency of the motor decreases because of the misalignments and this further leads to failure of bearings and couplings. As, exact alignment is not possible but can be adjusted in acceptable range which can avoid any damage or failure in machines and results in long life of machines. There are various reasons behind misalignment which causes machines instability are thermal distortion of machines, disproportionateness in functional loads, improper assembly of machines, unequal settlement of foundation, etc. The incorrect arrangement of coupling or condition of being out of correct position or something is improperly adjusted is known a misalignment. Hybrid bearings also shows lower coefficient of thermal expansion with high bearing stiffness and greater hardness. This paper describes the type of bearing can be used to replace the old traditional steel bearings which provides comparably better performance. As described above it can be stated that the ceramic bearings perform better in terms of service life. It also increases the lubricant life, reduced wear from vibration and can be operated at lower temperatures.

Keywords: Ceramic bearings, Hybrid bearings, Bearing applications.

1. Introduction

A bearing is a machine segment that compels relative movement between moving parts to just empower the ideal movement. The main function of bearing is to transmit power from one end of the line to another, while reducing friction and handling stress.

Hybrid bearing is advanced version of steel bearings in which the rings are made up of steel whereas the rolling elements consists of bearing grade **Silicon Nitride (Si_3N_4)** which results in better performance. The ceramic bearings offer high speed, improved stiffness and lesser friction. These ceramic bearings are containing ceramic rolling balls which are bounded in a ferrous inner and outer ring. These are also called as hybrid bearings because they are manufactured from different materials [1].

The various ceramic bearings are used for aerospace and space-exploration applications because of their light and optimum weight, improved flight dynamics. Also, the vacuum compatible bearings need not require lubricants for its operation in various applications and can be used in sensitive electrical components. Ceramic bearings are also used in applications which are exposed to chemically exposed areas because these ceramic bearings do not react with the chemicals. Moreover, these bearings are also used in high speed and heavy load applications because of the various enhanced properties over conventional steel bearings. The hybrid ceramic bearings not allow electrical current to run through bearing.

Some real time applications of ceramic bearings can be found in aircraft generators, high speed machines, mills, grinders, pumps, compressors and many more.

2. Discussion

Ceramic bearings balls are approximately 40% lighter than conventional steel balls, this leads to reduce centrifugal loading and skidding and increase the operation speed by 20% - 40%. The less wight of the ceramic balls used in bearings allows them to rotate fast and offers less resistance to maintain speed [2].

There are lot of advantages of ceramic ball bearings over Standard Bearings like Non-Conductive in nature, Greater Hardness, High wear resistance, High bearing stiffness, Long service life, Lower coefficient of thermal expansion and Less lubrication needed in case of ceramic bearings. The ceramic bearings also have low coefficient of friction than conventional bearings which reduces rolling resistance and enhance rotational speed [3].

Zirconia (ZrO_2) bearings can be used in marine applications because of the various properties like non-magnetic in nature, non-conductive, corrosion resistant, water resistant as compared to 316 marine grade bearings but if these bearings are exposed to steam or hot water, material weakens with time [4].
The zirconia bearings or 316 stainless caged bearings can be used at elevated temperature of approximately 400°C but the maximum speed decreases with elevated temperature specifically if the bearing is not lubricated. Bearings with a PEEK (polyether ether ketone) cage are used in applications with maximum elevated temperature up to 250°C. Although PEEK is very durable, but becomes brittle at low temperature, so it is preferred to use PTFE (Polytetrafluoroethylene) or 316 stainless steel cages for temperatures below 70°C [5].
Silicon nitride bearings ca be used for vacuum and high-speed applications as it is 58% lighter than conventional bearings and reduces the centrifugal force during rolling of balls and improve the fatigue life of bearing. These ceramic bearings can be used in all applications where conventional steel bearings are used except in the applications with shock loading because of the hardness of the material [6].

Zirconia was used in space shuttles so that they can enter earth's atmosphere without any harm to space shuttle because of which it is chosen for applications which are exposed to high temperature and highly corrosive environment. The density and thermal expansion of zirconia and steel approximately similar as compared to other ceramic material. It has high fracture toughness as compared to other ceramic bearings like silicon nitride. Also, the high cost of material and difficult to machine, is less frequently used. So, silicon carbide is also preferred because it is heat and corrosion resistant and can be used under low loads [7].

2.1 Hybrid Bearings

From last decade hybrid bearings is used in wide range of applications because of their features as ceramic balls are much harder, less dense, offers resistance to corrosion with reduced lubrication. Hybrid bearing is advanced version of steel bearings in which the rings are made up of steel whereas the rolling elements consists of bearing grade silicon nitride (Si¬3N4) which results in better performance. Some common applications of hybrid ball bearings are spindles, vacuum pumps, dental drills, space shuttle main engines, etc. A comparison between steel bearing and hybrid bearings of same size and dimensions shows that hybrid bearings are electrically insulated,

high wear resistance, high bearing stiffness, long service life, etc. Hybrid bearings have few more remarkable advantages over steel bearings like higher speed capability (as the rolling element of hybrid bearings have less density than steel bearing which leads to low weight), lower coefficient of thermal expansion which results in more stability over temperature change and wear rate of hybrid bearings under contaminated lubrication is comparably very low than steel bearings which makes it suitable for high speed rotatory machines because of low friction [8].

The use of least of four method and sudden death statistics to get the Weibull distribution based upon bivariate model that defines the dependency on load, time and sample size. He found that hybrid bearings have approximately 6.7 times greater bearing life with 90% confidence whereas 12 times greater bearing life with 50% confidence compared to 52100 steel bearings.[10].

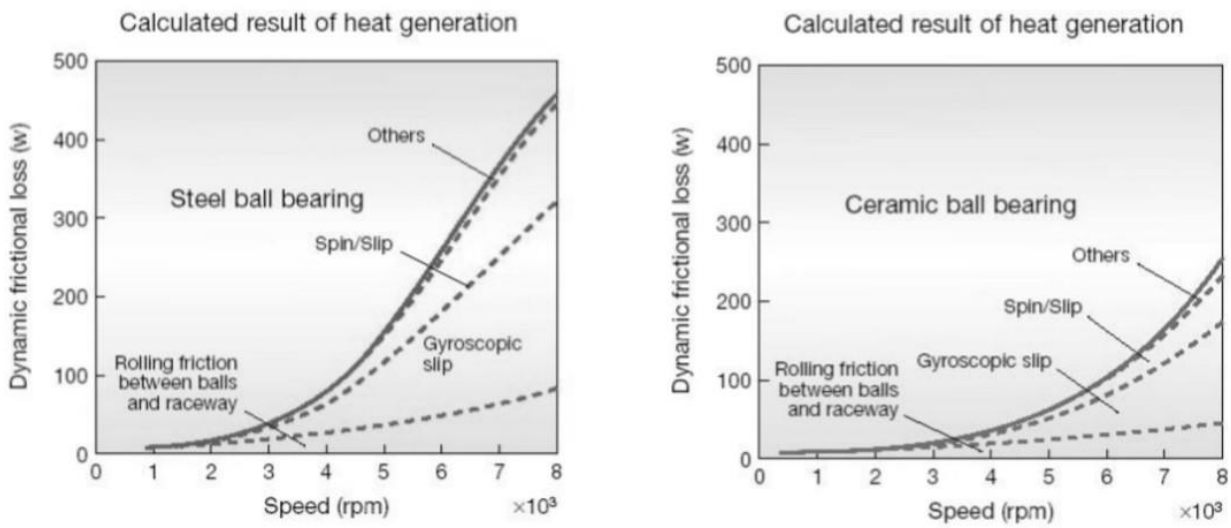

Figure 1. Heat Generation [9].

Fractographic analysis is been done and found that the potential causes of fracture are traced from voids of diameters less than 2 micrometer in hybrid bearings. Analysis the vibration signals obtained by hybrid ceramic bearing balls and compared the results with conventional steel ball bearings. Accelerometer is used to capture the radial and axial vibrations and FFT (Fast Fourier Transformation) analyzer is used for filtering signals. Study shows that the vibratory velocities for hybrid bearings is higher as well as the vibration of hybrid bearing are appeared at the higher peak than steel bearings of same dimensions which concludes that hybrid ceramic ball bearings comparably have bad vibrational properties [11]. The work on the quality criteria for composition of silicon nitride for industrial applications of hybrid ball bearings. Five different silicon nitride balls are tested and found that the bearing lifetime and failure mechanisms varied due to factors like porosity and chemical composition. A method was established to test the behavior of bearing with different material composition and corelates the dependency of bearing life, fatigue and wear rate with surface roughness, chemical composition and microstructure [12].

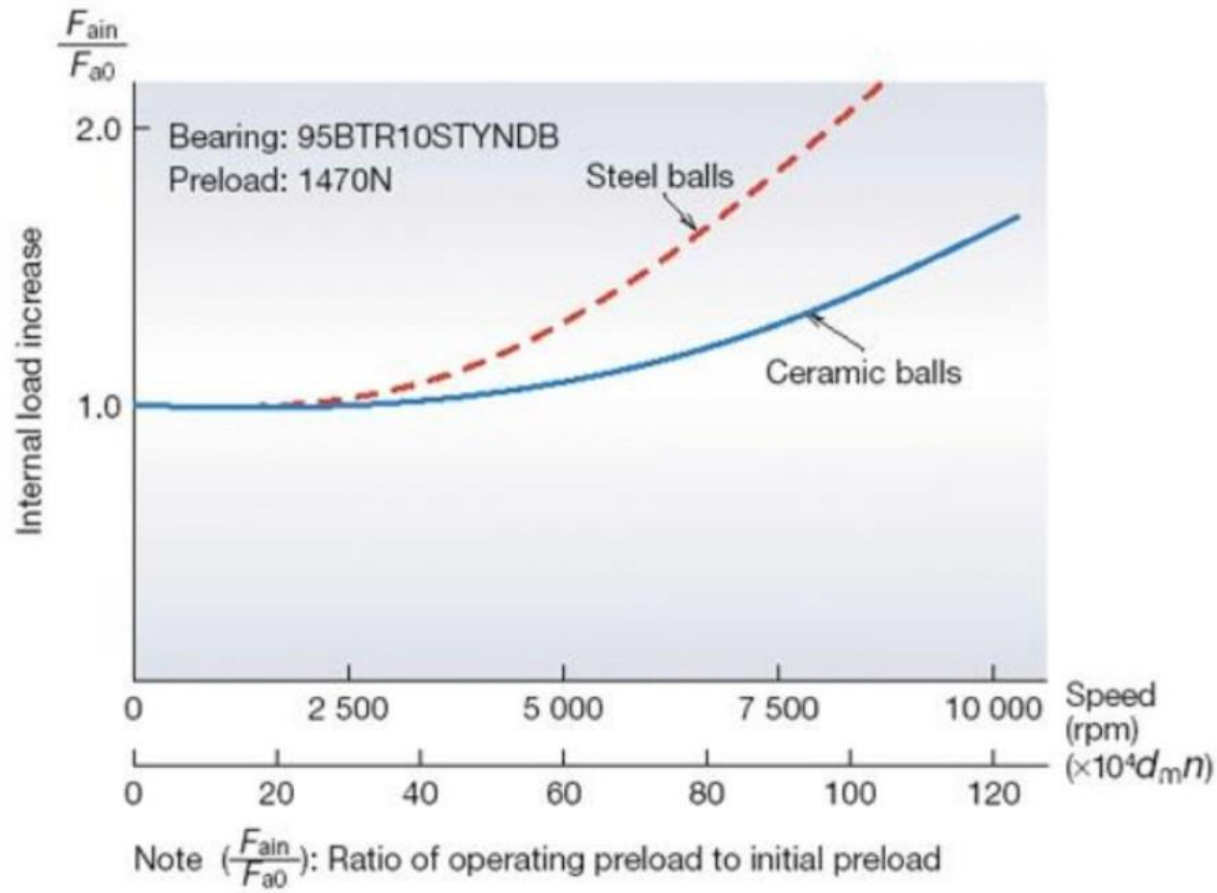

Figure 2. Preload on bearings due to centrifugal force [9].

As technology is surprisingly increasing day by day, which requires addition of power without increasing total weight. To generate extra power through generators or any power generating machines, bearing plays an important role. By keeping this in mind the works on ceramic bearings has been done to increase rotational speed to generate excess required power as ceramic bearings offers comparably less weight with reduced wear [13]**.** Some aspects of power losses in case of hybrid bearings and compared the performance with standard steel bearings. Hybrid bearings that are the combination of steel bearing balls and ceramic ball bearings offers better performance than every steel bearing [14]**.** It is found that the hybrid bearings having better execution for power loss and wear resistance which also results in lesser heat generation and reduced friction in bearings. Hybrids bearing leads in increased bearing life due to higher mechanical strength and comparably less weight. Multi-stage technique for detection of cracks is introduced in hybrid ball bearings using Bayesian Classifier by measuring vibration spectrum using sensors. This method can be able to detect the various crack types and sizes [15]**.**

Bearing with polymer liner is tested which accounts better for misalignment case in shafts due to reduced edge pressure, it can serve better than other standard steel bearings with minimum film thickness and can bear higher pressure. This bearing also shows effect on reduced friction and lower thermal conductivity due to use polymer layer [16]**.**

Poly-Acrylonitrile (PAN) based bearing is used with carbon phenolic woven composite for the fabrication of heavy-duty bearings. Use of near net shape molding process increases the endurance limit by 3 times and

reduced wear depth by 5 times due to addition of 8% carbon black and 10% polyetheretherketone (PEEK) powders [17].

The tribological behavior has been discussed for hybrid bearings using coating of Ni-Cu-Ag based PVD with different lubricating conditions. Different lubricating conditions leads in variable friction coefficients, here test shows that the friction coefficient is higher in case of liquid nitrogen whereas lower for oxygen lubricant. Friction coefficient depends upon the viscosity of lubricant i.e., higher viscosity of lubricants means lower friction coefficient. Wear rate for same contacting load and velocity have more wear rate with liquid nitrogen lubricant than water and lesser wear rate of coatings with liquid oxygen lubricant [18].

A multi-stage technique for detection of cracks is been introduced in hybrid ball bearings using Bayesian Classifier by measuring vibration spectrum using sensors. This method can able to detect the various crack types and sizes [19].

2.2 Bearing Life Estimation

As earlier discussed, bearing damage is one of the major causes of breakdown of machineries, by considering the remaining life adaptation methodology. An adaptive algorithm is developed by comparing the predicted and measured defect sizes through defect propagation model and defect diagnostic model which results in predicting the remaining bearing life [20]. When the serious damage or defect in bearings is diagnosed, the machine is often preferred to shut down at troublesome situation which makes the tremendous loss in time, productivity and overall capital. To overcome this problem, remaining life and growth rate can be calculated using algorithm to make maintenance and replacement of bearing at proper schedule. Modelling of pre-dented hybrid and steel bearings where artificial dents were produced using Rockwell penetrator to analyze the surface damage. Both bearings are tested under same conditions and found that the hybrid bearings are able to re-accommodate or heal the dents by plastic deformation with steel surface which minimizes the pressures faster than steel bearings [21]. Weibull curve for steel and hybrid bearings shows that bearing life of hybrid bearing is comparably higher than all the steel bearings under same load conditions even with comparably worse lubrication and higher contact pressure.

From the microstructures it is observed that there is covalent bonding between non-metal elements, so, they share electrons because of which these materials offer strong attraction force. The high hardness (70-90 HRC) and Young's modulus offers resistant to shape change when loads are applied which leads to improved wear characteristics [22].

In spite of so many advantages these bearings also have some disadvantages. The high processing cost, high temperature for sintering process and high hardness makes it difficult to grind. These are the main reasons to manufacture precision bearings. Ceramic bearings are sensitive to impurities any impurity will lead to early failure so manufacturing of ceramic bearings need skilled workforce [23].

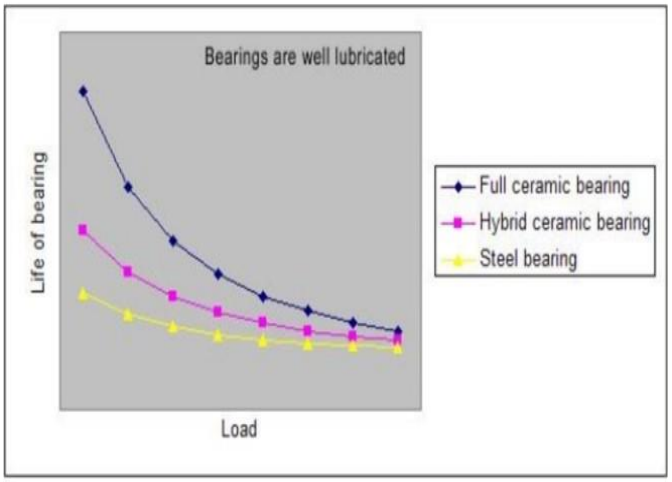

Figure 3. Bearing Life [24].

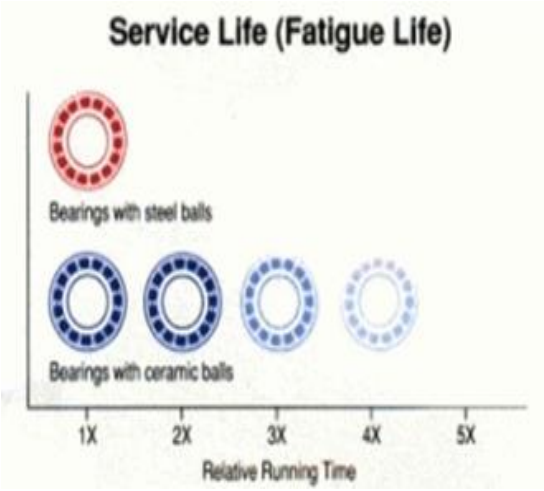

Figure 4. Service Life [9].

3. Conclusion

The life of rotating and reciprocating mechanical device depends upon type of operation like fatigue, wear and deformation which may cause increment in gap between coupling parts as well as misalignments. This can lead initiation of cracks and rise in vibration. Imbalance creates crack growth and increases the level of vibration. Faults that lead to increase in level of vibration are eccentric shafts, bent shafts, misaligned shafts, loose mechanical parts, etc. By eliminating these faults can results in efficient operations, increases productivity, minimizes downtime, saves money and even helps environment. These faults can be monitored and eliminated by analyzing and monitoring signals produced by machines.

In manufacturing plants or industry, rotating machines is the main part. Focusing on this problem leads in growth of industry as it will increase productivity, reduce downtime and also reduces maintenance cost after breakdown.

As slowly increasing technology starts replacing the steel bearings with ceramic bearings or hybrid bearings, in coming future it can be seen that the all the steel bearings can be replaced with different types of hybrid bearings according to application. As one of the benefits of hybrid bearings is that the properties of hybrid bearings can be altered according to need of application.

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