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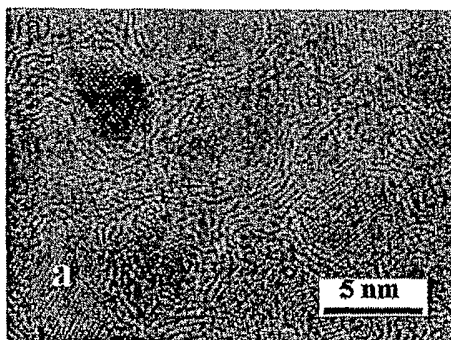
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(54) Title: PROCESS FOR FINISHING CRITICAL SURFACES OF A BEARING



HRTEM images of nanostructured coatings: (a) nanocrystalline carbides in an amorphous matrix, and (b) multi-layer arrangement of nano-scale elastic and hard materials.

(57) Abstract: The performance of hybrid rolling element bearings is improved by the combined use of three surface engineering technologies. Critical surfaces on a bearing ring are finished or treated by (1) grinding the ring along its critical surface; (2) subjecting the ground critical surface to high energy mass finishing to produce a generally isotropic finish; (3) subjecting the critical surface having the isotropic finish to ion-implantation to improve corrosion resistance; and (4) covering the ion-implanted critical surface with a nano-structured thin film coating.

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PROCESS FOR FINISHING CRITICAL SURFACES OF A BEARING

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional App. No. 5 60/562,179 filed April 14, 2004, and which is incorporated herein by reference.

TECHNICAL FIELD

Hybrid bearings include steel races or rings, a retainer or cage, and ceramic rolling elements. Hybrid bearings can achieve higher 10 speeds, reduced vibration, increased stiffness, reduced friction and temperature, less wear, operate with less lubrication, and have a longer service life than all-steel bearings. These characteristics are why hybrid bearings are finding increased usage in a wide variety of engineered applications today. These applications include machine tool spindles, 15 automotive engines and transmissions, electro-mechanical systems, semiconductor processing equipment, medical instruments, dental hand-pieces, food processing equipment, pulp and paper manufacturing equipment, pumps, sporting goods, textile equipment, and wind energy machines.

20 BACKGROUND ART

A major concern confronting the next generation of aircraft gas turbine engines is the development of a suitable rotor support/rolling element bearing system which can accommodate the high loads, speeds, and thermal stresses projected. At the same time, it is desirable 25 for the bearing to meet certain durability requirements of corrosion resistance, fatigue life, and wear resistance. Although hybrid bearings will be utilized in these demanding applications, existing technology of M50-NiL bearing rings, silver-plated retainers, and silicon nitride balls will not meet the requirements with the projected speeds and 30 temperatures in such applications. New steel alloys, with improved wear

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resistance, corrosion resistance, and fatigue life are being developed to replace M50-NiL bearing rings for these applications. However, it is not always possible to engineer a material to meet, or surpass, all application specific requirements.

5 SUMMARY OF THE INVENTION

Briefly, the present invention relates to surface engineering technologies that enhance the operational performance characteristics of rolling element bearings. Engineered surfaces technologies have the potential when applied to the inner and outer rings to increase bearing
10 life and load rating, provide corrosion resistance, and offer extended oil-off wear protection. In accordance with one aspect of the invention, critical surfaces on a bearing ring are finished or treated by (1) grinding the ring along its critical surface; (2) subjecting the ground critical surface to high energy mass finishing to produce a generally isotropic
15 finish; (3) subjecting the critical surface having the isotropic finish to ion-implementation to improve corrosion resistance; and (4) covering the ion-implanted critical surface with a nano-structured thin film coating.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1a is a bar graph showing Ra values of M50 bearing raceways honed (A), honed and burnished (B), and honed and HEMF-treated
20

FIG. 1b is a graph plotting the residual stress profile of M50 standard and HEMF-treated bearing raceways

FIGS. 2a and 2b are HRTEM images of nanostructured coatings:
25 (a) nanocrystalline carbides in an amorphous matrix, and (b) multi-layer arrangement of nano-scale elastic and hard materials.

Corresponding reference numerals will be used throughout the several figures of the drawings.

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BEST MODES FOR CARRYING OUT THE INVENTION

The following detailed description illustrates the invention by way of example and not by way of limitation. This description will clearly enable one skilled in the art to make and use the invention, including what I presently believe is the best mode of carrying out the invention. Additionally, it is to be understood that the invention is not limited in its application to the details of construction and the arrangements of components set forth in the following description or illustrated in the drawings. The invention is capable of other embodiments and of being practiced or being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting.

This invention describes the combined use of three surface engineering technologies to enhance the performance of hybrid rolling element bearings. These technologies include: (1) a high-energy, mass finishing (HEMF) process, (2) ion-implantation, and (3) nano-structured thin film coatings. The combination of these specific technologies has never been applied to the rings of hybrid bearings. The combination of these surface engineering technologies on the rings of hybrid bearings provides a unique approach to meet, for example, the application demands of advanced turbine engines.

High-Energy Mass Finishing

After heat-treatment and final grinding of the raceways on bearing rings, a high-energy, mass finishing (HEMF) process is used to treat the surfaces of the inner and outer bearing rings. The HEMF process provides isotropic surfaces and significant surface residual compressive stresses to bearing races. An isotropic surface is defined to be a surface where features such as those associated with machining processes are either absent or have no directionality. Isotropic surfaces are characterized by increased load bearing area, increased lambda ratios (ratio of lubricant film thickness to surface roughness) and

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reduced asperity slopes, all of which are conducive to (a) a reduced propensity for micro-crack initiation, and (b) reduced friction. Elevated residual compressive stresses on the surfaces of bearing races are beneficial in inhibiting micro-crack propagation along Hertzian stress contours. These attributes of the HEMF process should be beneficial to extending fatigue life and reducing operating temperatures of the hybrid bearing.

High-energy finishing describes any form of abrasive media-based parts finishing that uses more than the force of gravity (rather than a tumbling process or a vibratory deburring process) to deburr, radius, smooth, burnish, descale or otherwise prepare parts. The HEMF process of the present invention utilizes centrifugal forces more than 15 times the force of gravity. Mixtures of 1000 grit (6.8 – 9.3 micrometers) alumina and walnut shell polishing media are used in a cutting or polishing procedure.

The metrological results of one HEMF process recipe are shown in Figure 1a, where Ra values of bearing raceways, which were honed, honed and burnished, and honed and HEMF finished are shown. Data in the figure indicate that the HEMF process can eliminate the standard burnishing process used in the manufacture of the current generation of M50 turbine engine bearings, and at the same time, produce a superior surface finish. Stress profiles measured by x-ray diffraction techniques of the same bearing raceways are shown in Figure 1b. The magnitude of the compressive stress at the surface of the finished sample is almost 160 ksi, comparable to the values achievable by precision shot peening. The HEMF process not only improves the surface finish of the bearing races, but also imparts ~200ksi of compressive residual stress into the near surface region of the races. The combination of high surface compressive stress and decreased asperity slopes yields increased fatigue life and load bearing capability of rolling element bearings. The

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incorporation of this process in the bearing manufacturing process may reduce the opportunities for grinding related bearing injury to the races.

An additional benefit imparted by the HEMF process to precision steel components such as bearings is an enhancement in their resistance to environmental corrosion that can occur during storage or installation when protective oil films are removed. Although HEMF-treated surfaces are not expected to be resistant to severe forms of corrosion (high temperature oxidation, seawater, etc.), dry surfaces can be exposed to typical environmental conditions (temperature and humidity) for years without exhibiting corrosion.

Ion-Implantation

It is anticipated that advanced steel alloys such as CSS42L (a carburizable stainless steel alloy available from The Timken Company of Canton, Ohio) or Pyrowear 675 (a carburising stainless steel available from Carpenter Technology Corp. of Reading, Pennsylvania) will provide enhanced corrosion resistance over M50 or M50NiL. However, even this enhanced corrosion resistance may not be sufficient for the operating environments of hybrid bearings for advanced turbine engines for example.

The second step of this invention is to implant corrosion inhibiting ions into the bearing rings after they have been processed by HEMF to impart resistance to severe forms of corrosion such as high temperature oxidation, seawater, and low pH lubricants. Ion implantation is not a coating process, but is an environmentally clean technology that can be used to control the surface composition of an alloy without detectable change in dimensions or surface finish. Further, the process can be carried out at temperatures well below the tempering limit for bearing steels. Ion implantation is not constrained by solubility limits or diffusivities and the surface alloys produced cannot be obtained by conventional metallurgy. Implantation of chromium ions into M-50 bearing races has been reported¹ to enhance the aqueous corrosion

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resistance of M-50 approaching that of stainless steel. Although ion-implantation has been touted by many as a surface engineering technology that provides wear resistance and fatigue life to precision steel components, experiments do not universally support these
5 assertions. The only impact verified by Timken that ion implantation can have on precision steel components is enhanced corrosion resistance.

Ion implantation is a surface modification process in which ions are injected into the near-surface region of a substrate. High-energy ions, typically 10–200 kiloelectron volts (KeV) in energy, are produced in
10 an accelerator and directed as a beam onto the surface of the substrate. The ions impinge on the substrate with kinetic energies 4–5 orders of magnitude greater than the binding energy of the solid substrate and form an alloy with the surface upon impact. Virtually any element can be injected into the near-surface region of any solid substrate. Commonly
15 implanted substrates include metals, ceramics, and polymers. The most commonly implanted metals include steels, titanium alloys, and some refractory metals.

During the conventional Ion Implantation Process, a beam of positively charged ions of the desired element (either a gas such as
20 nitrogen or a metal such as chromium) is formed. Beam formation of a gas (e.g., nitrogen, oxygen, carbon, and inert gases) occurs by feeding a gas into an ion source. In the ion source, electrons, emitted from a hot filament, ionize the gas to form plasma. Ionization of the element is performed for the purpose of acceleration. Incorporation of an
25 electrostatic field results in the acceleration of the positive ions at high energies under high vacuum (pressures below about 10 Torr to about 5 Torr). The ions penetrate the component surface, typically to a depth not exceeding 0.1 μm . The near-surface alloy produced by implantation is different from conventional coatings in that the implanted ion is
30 surrounded by atoms of the original surface material. Alloying at the surface can be as high as 50 atomic percent of the implanted element. It

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produces no discrete coating, nor will delamination of the altered surface occur.

Forming a beam of a solid element (e.g. metals, metalloids, and certain non-metals) can occur by one of four methods. In one method a
5 reactive gas, such as chlorine, is used to form the plasma. A metal chloride is generated as the chlorine ions chemically react with the metal walls of the ion source. The metal chloride then is ionized to form plasma of metal and chlorine ions. An analyzing magnet is used to separate the chlorine ions from the desired metal ion beam. A second
10 method employs sputtering to generate metal ions. In this method, inert argon gas is ionized. The positively charged ions are attracted to a negatively biased metal target. As the argon ions strike the target, pure metal atoms and ions are dislodged from the target. The metal ions are extracted, focused into a beam, and directed toward the part to be
15 implanted. The two other methods of forming a beam of a solid are similar to that of the sputtering method. Variations of the sputtering method use thermal or electron beam evaporation, or cathodic arc (initiating an arc on the surface of a metal target to evaporate the metal) to generate the metal vapors. These methods of generating beams of
20 solids do not require the costly analyzing magnets and provide very high ion currents.

A newer form of ion implantation involves using a plasma within the chamber from which gaseous ions are extracted. Similar to the beamline method, the gas is excited to form a plasma, typically through
25 the use of an radio frequency (RF) antenna. The positively charged gas ions are accelerated towards the substrate by subjecting the substrate to high voltage pulsed biasing. This method of implantation is referred to as plasma source ion implantation (PSII) and circumvents some of the line-of-sight issues associated with conventional beamline methods.

30 Possible products of an ion implantation process are the formation of nitrides, borides or carbides, or the occurrence of localized

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alloying. With this process, properties such as hardness, wear resistance, corrosion resistance, and fatigue may be altered according to the selected implantation element. Ion implantation can provide 2–100-fold improvements in wear life, depending on the type of wear and service environment.

Nano-Structured Thin Film Coatings

To be a successful thin film coating for hybrid bearing rings, the coating must be highly adherent to the steel races, able to withstand high temperatures, provide wear resistance against the Si_3N_4 balls, and increase bearing fatigue life including resistance to periods of marginal lubrication.

Adhesion between thin film coatings and steel alloys can be well attained through competent cleaning of the steel, plasma etching, and a judicious choice of an adhesion enhancing material layer. The adhesion enhancing material layer is usually required because a desirable attribute of the thin film coating is that it does not readily adhere to steel, thereby becoming an adhesive wear barrier. Materials such as Ti, Cr, and Si work well as adhesion enhancing layers because they readily adhere to steel alloys and most coating materials. Interlayer thicknesses are typically in the range of about $0.1\ \mu\text{m}$. To present a wear resistance surface to the Si_3N_4 balls, the coating material must not chemically react with the Si_3N_4 at contact temperatures experienced by the surface asperities during operation (adhesive wear resistance), and should not be considerably softer than the Si_3N_4 (abrasive wear resistance).

In order for the thin film coating to withstand cyclic Hertzian contact, the coating should have a well-controlled microstructure, and form a barrier to adhesive contact of the asperities. Although the coatings will be hard, they should not have large elastic moduli, so they will not be prone to fracture and crack propagation. A thin film coating with a composite or layered microstructure comprised of nanometer-sized crystallites and an amorphous matrix is exceptionally resistant to

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crack propagation and fracture, especially if the volumetric density of the nanocrystalline phase is near, but below, a percolation threshold for crack propagation.

Nano-structured coatings are known to enhance wear resistance and fatigue life of rolling element bearings². Nano-structured coatings are defined as materials where at least one constituent has characteristic dimensions less than 100 nm. A coating comprised of nanometer-sized crystallites embedded in a matrix of another material is an example of a nano-structured coating. A high-resolution transmission electron microscopy image (HRTEM) of such a coating microstructure is shown in Figure 2a. Another example of a nano-structured coating is a multi-layered arrangement of two or more materials where the thickness of the individual layers is less than 100 nm. An example of this type of coating lamellar microstructure, comprised of alternating sub-micron thick layers of hard and elastic materials is shown in the HRTEM image in Figure 2b. In this example, the lamellae are obtained through the motion of the substrate as it passes by metallic sputtering targets. The bright and dark bands in the image in Figure 2a correspond to the layers that are rich and poor in metal content, respectively.

Nano-structured coatings suitable for bearing applications can be applied using two or more deposition processes: chemical vapor deposition (CVD), physical vapor deposition (PVD), and a combination of the two. A preferred embodiment of a nano-structured coating can be characterized by consisting of (1) a hard and (2) an elastic phase. The characteristic dimension of the individual elements (such as those shown in Figures 2a and b) comprising the hard phase is less than 100 nm, and ideally less than 10 nm. Materials with characteristic dimensions less than 10 nm are theoretically devoid of defects, so it is difficult to either initiate or propagate cracks through nano-sized materials. A desirable elastic phase is characterized as being amorphous (with no crystallographic order larger than 1 nm), completely

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surrounding the hard phase, and with an elastic modulus less than that of the hard phase. These attributes of the elastic phase are detrimental to crack propagation through the coating since (1) cracks are more difficult to propagate through an elastic medium, and (2) cracks
 5 propagating through the elastic phase have to take a tortuous path around the hard phase nano-sized particles or layers.

Examples of nano-structured coating systems comprised of hard and elastic phases are gathered in Table below. Stoichiometries of the constituents presented in the table are not meant to be exact. C_g means
 10 an amorphous carbon with graphitic bonding, DLC means diamond-like carbon or an amorphous hydrocarbon, and alumina and magnesia are oxides of aluminum and magnesium, respectively with or without carbon and other oxide forming metals added.

Hard Phase	Elastic Phase
CrC	C _g or DLC
CrCN	CN _x
SiC	C _g or DLC
TiC	C _g or DLC
TiN	C _g & CN _x
CrBC	BCN
CrN _x	BCN
CrC	C _g or CN _x
TiC	C _g or CN _x
WC	C _g or CN _x
Si ₃ N ₄	Alumina or Magnesia

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CLAIMS:

1. A process for finishing a critical surface on a bearing ring;
5 said process
 comprising:
 grinding the ring along its critical surface;
 subjecting the ground critical surface to high energy mass
finishing to produce a generally isotropic finish;
10 subjecting the critical surface having the isotropic finish to ion-
implementation to improve corrosion resistance; and
 covering the ion-implanted critical surface with a nano-structured
thin film coating.
2. The process of claim 1 wherein said step of subjecting the
15 ground critical surface to high energy mass finishing comprises a single
step using a mixture of 1000-grit abrasive and binder particles.
3. The process of claim 1 wherein said thin film coating is
comprised of hard and elastic materials.
4. The process of claim 3 wherein the nano-structured thin
20 film coating comprises alternating sub-micron thick layers of hard and
elastic materials.
5. The process of claim 4 wherein the coating has a thickness
of about 0.1 μm .

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6. The process of claim 3 wherein the thin film coating comprises a hard crystalline phase contained within an elastic amorphous phase.

7. The process of claim 5 wherein the hard crystalline phase is comprised of materials less than 100 nm in size and wherein the elastic phase is comprised of materials less than 1 nm in size.

8. The process of claim 3 wherein the hard phase is chosen from the group consisting of CrC, CrCN, SiC, TiC, TiN, CrBC, CrN_x, CrC, TiC, WC, Si₃N₄ and combinations thereof and wherein the elastic phase is chosen from the group consisting of C_g, DLC, CN_x, BCN, C_g, Alumina or Magnesia and combinations thereof.

9. The process of claim 3 wherein the elastic modulus of the elastic phase is less than the elastic modulus of the hard phase.

10. A bearing having an outer ring, an inner ring, and a plurality of rolling elements positioned between the inner and outer ring, the critical surfaces of the bearing ring having an isotropic finish..

11. The bearing of claim 10 wherein the isotropic surfaces of the bearing ring are formed by:

- (a) grinding the ring along its critical surface;
- (b) subjecting the ground critical surface to high energy mass finishing to produce a generally isotropic finish;
- (c) subjecting the critical surface having the isotropic finish to ion-implantation to improve corrosion resistance; and

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(d) covering the ion-implanted critical surface with a nano-structured thin film coating.

12. The process of claim 11 wherein said thin film coating is comprised of hard and elastic materials.

5 13. The process of claim 12 wherein the nano-structured thin film coating comprises alternating sub-micron thick layers of hard and elastic materials.

14. The process of claim 13 wherein the coating layers have a thickness of about 0.1 μm .

10 15. The process of claim 12 wherein the thin film coating comprises a hard crystalline phase contained within an elastic amorphous phase.

16. The process of claim 14 wherein the hard crystalline phase is comprised of materials less than 100 nm in size and wherein the
15 elastic phase is comprised of materials less than 1 nm in size.

17. The process of claim 12 wherein the hard phase is chosen from the group consisting of CrC, CrCN, SiC, TiC, TiN, CrBC, CrN_x, CrC, TiC, WC, Si₃N₄ and combinations thereof and wherein the elastic phase is chosen from the group consisting of C_g, DLC, CN_x, BCN, C_g, Alumina
20 or Magnesia and combinations thereof.

18. The process of claim 12 wherein the elastic modulus of the elastic phase is less than the elastic modulus of the hard phase.

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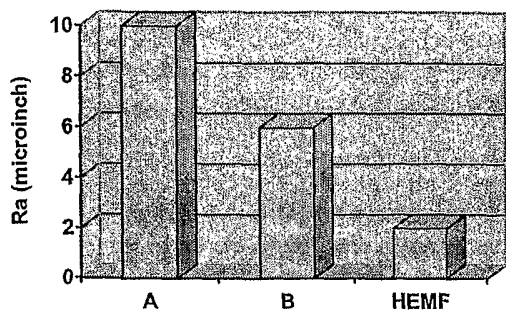


Figure 1a

Ra values of M50 bearing raceways honed (A), honed and burnished (B), and honed and HEMF.

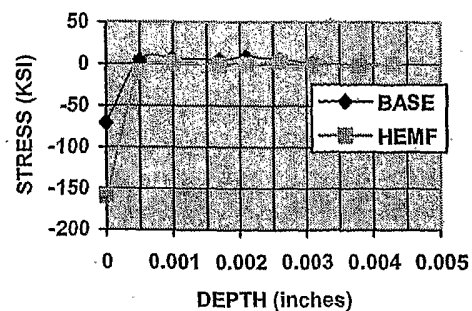


FIG 1b

Residual stress profile of M50 standard and HEMF bearing raceways.

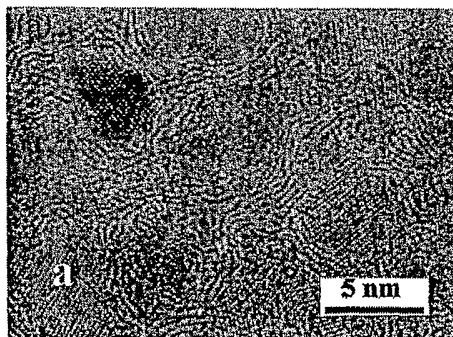


FIG. 2a

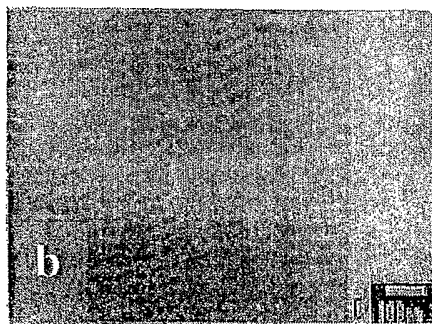


FIG. 2B

- 5 Figure 2: HRTEM images of nanostructured coatings: (a) nanocrystalline carbides in an amorphous matrix, and (b) multi-layer arrangement of nano-scale elastic and hard materials.

INTERNATIONAL SEARCH REPORT

Int ional Application No
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A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F16C33/64

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 F16C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	EP 0 657 658 A (THE TIMKEN COMPANY; REM CHEMICALS, INC) 14 June 1995 (1995-06-14) abstract; claims 1,3,6,13,14,17-21 -----	10 1,11

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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