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(54) **TITANIUM CARBIDE PLUS SILVER COATED BALLS FOR X-RAY TUBE BEARINGS**

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(51) **Int. Cl.**
H01J 35/28 (2006.01)

(52) **U.S. Cl.** **378/132**; 378/133

(58) **Field of Classification Search** 378/119, 378/131–133
See application file for complete search history.

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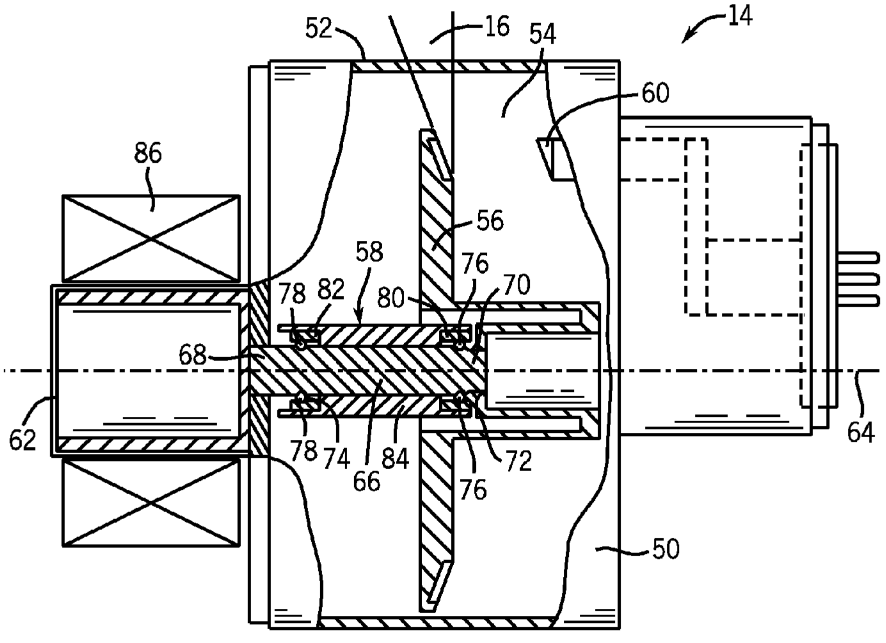
(57) **ABSTRACT**

A bearing assembly for an x-ray tube is disclosed that includes a bearing race, a bearing ball positioned adjacent to the bearing race, and a combination coating deposited on one of the bearing race and the bearing ball. The combination coating includes titanium carbide and a solid lubricant.

22 Claims, 6 Drawing Sheets



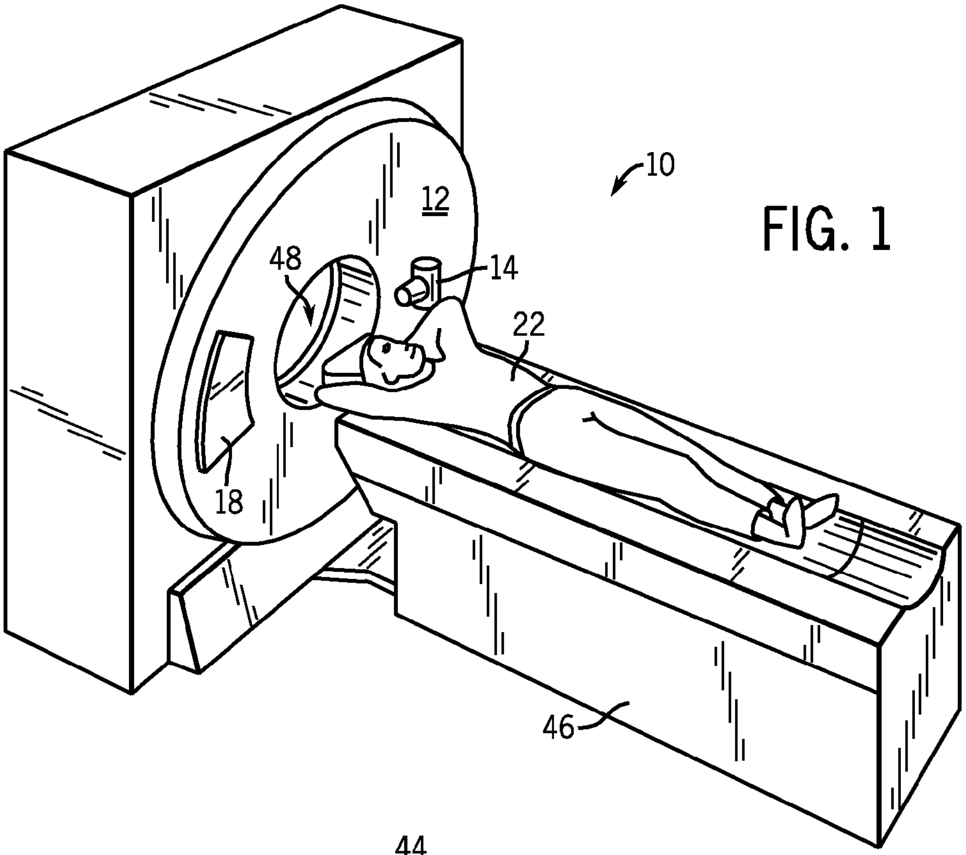
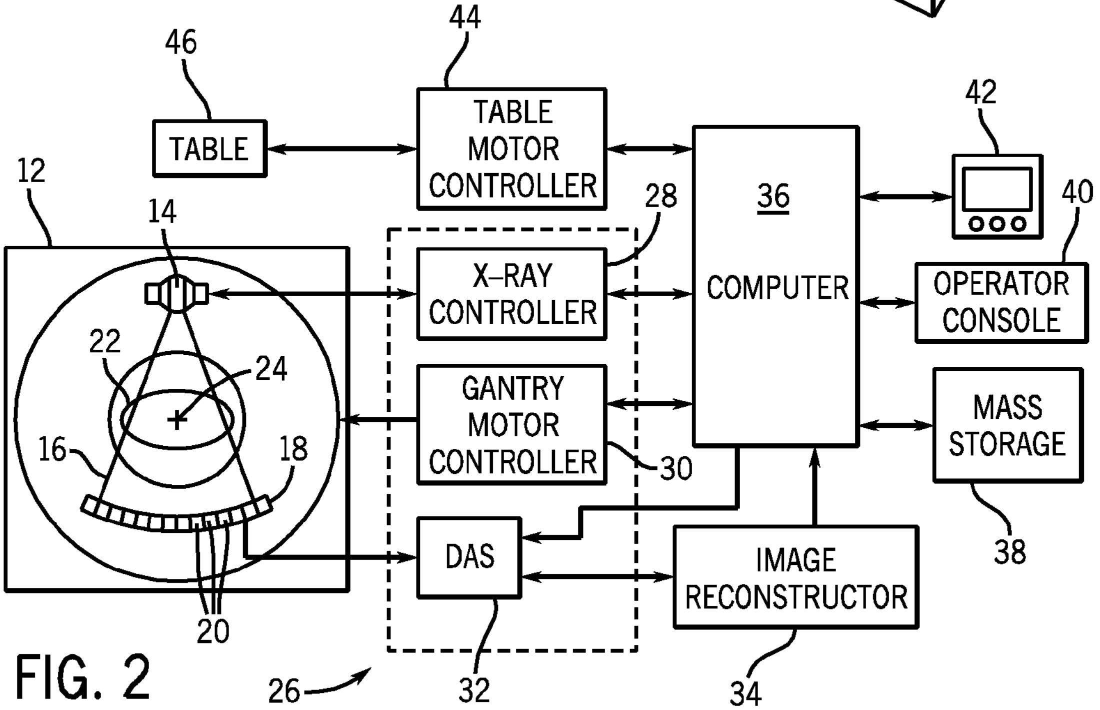

10
12
14
48
22
18
46

FIG. 1


46
TABLE
44
TABLE MOTOR CONTROLLER
12
14
28
X–RAY CONTROLLER
36
COMPUTER
42
40
OPERATOR CONSOLE
22
24
16
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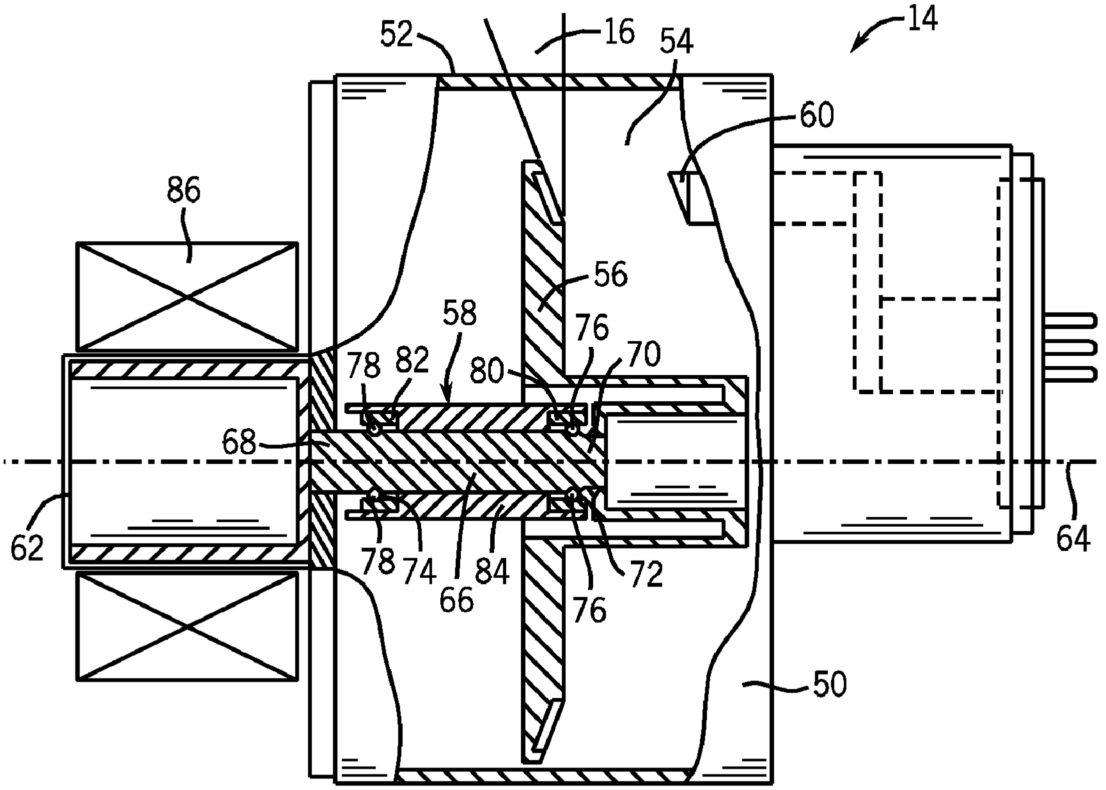
GANTRY MOTOR CONTROLLER
30
MASS STORAGE
38
DAS
IMAGE RECONSTRUCTOR
20
26
32
34

FIG. 2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52
16
54
60
86
56
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76
70
78
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80
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62
78
74
66
84
76
72
64
50

FIG. 3

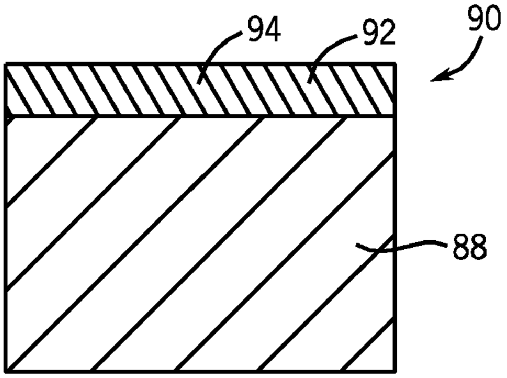
94
92
90
88

FIG. 4

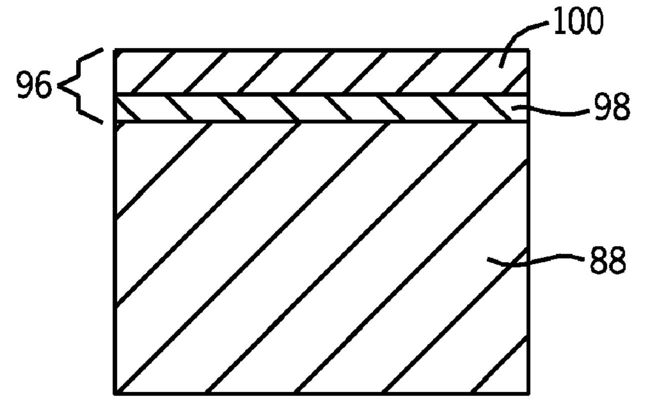

FIG. 5

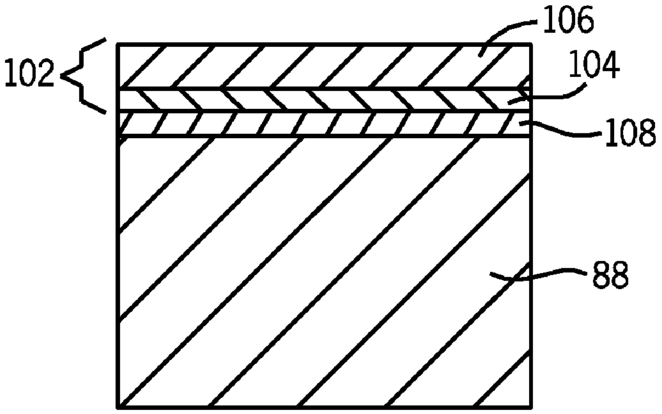

FIG. 6

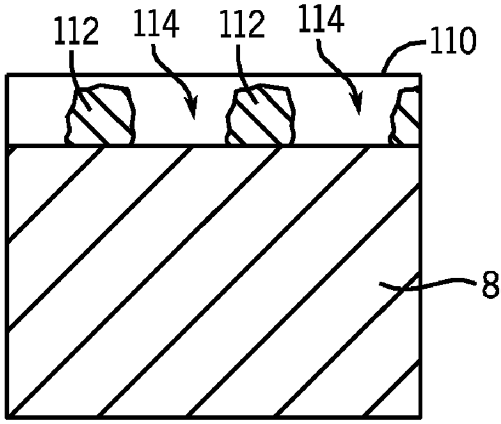

FIG. 7

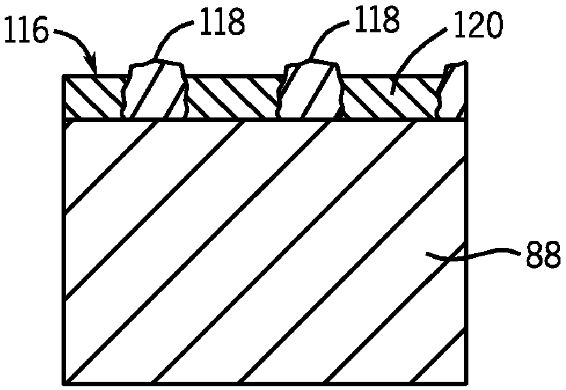

FIG. 8

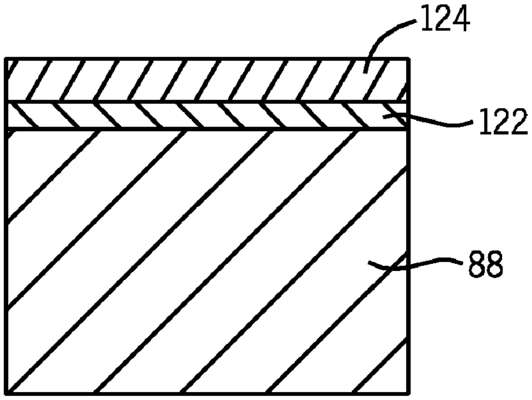

FIG. 9

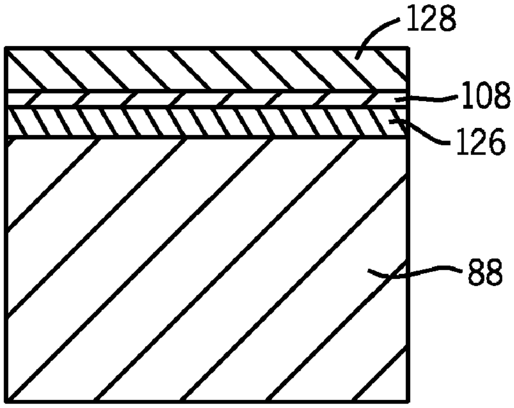

FIG. 10

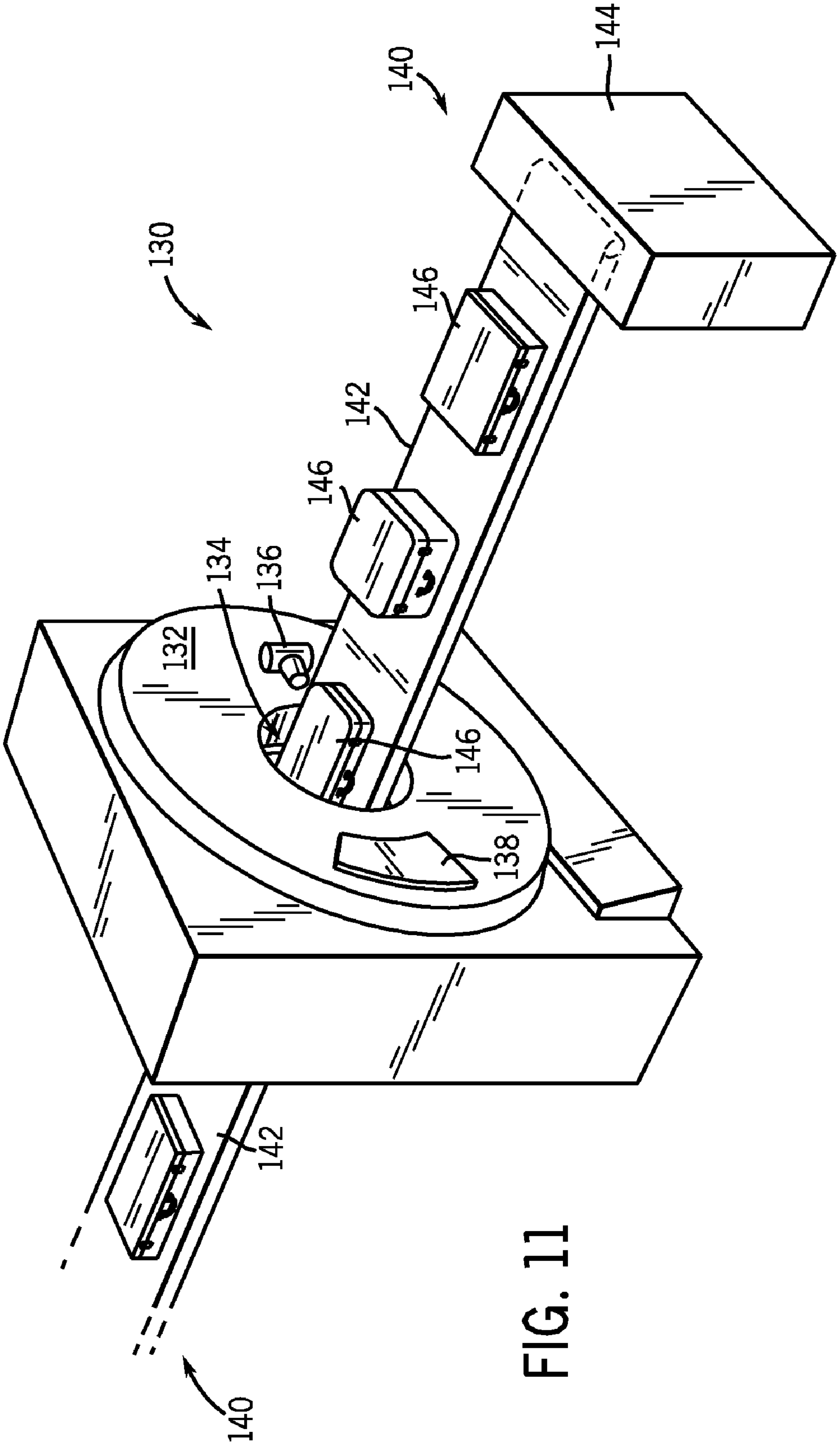

FIG. 11

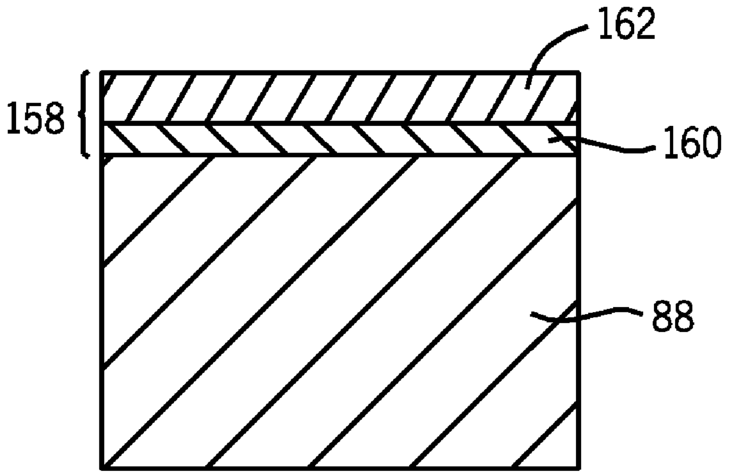

FIG. 12

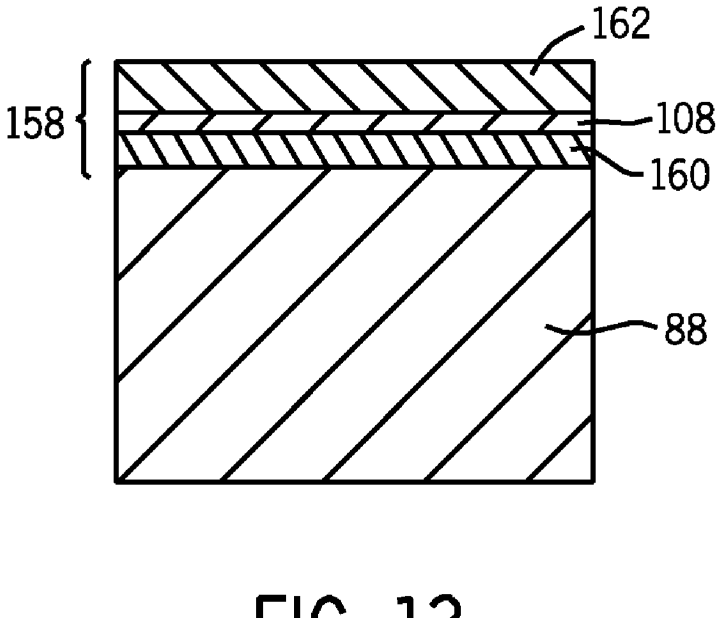

FIG. 13

TITANIUM CARBIDE PLUS SILVER COATED BALLS FOR X-RAY TUBE BEARINGS

CROSS-REFERENCE TO RELATED APPLICATION

The present application is a continuation in part of and claims priority of U.S. patent application Ser. No. 11/551,846 filed Oct. 23, 2006, the disclosure of which is incorporated herein.

BACKGROUND OF THE INVENTION

The present invention relates generally to x-ray tubes and, more particularly, to a hard coating and lubricant deposited on an x-ray tube bearing assembly.

X-ray systems typically include an x-ray tube, a detector, and a bearing assembly to support the x-ray tube and the detector. In operation, an imaging table, on which an object is positioned, is located between the x-ray tube and the detector. The x-ray tube typically emits radiation, such as x-rays, toward the object. The radiation typically passes through the object on the imaging table and impinges on the detector. As radiation passes through the object, internal structures of the object cause spatial variances in the radiation received at the detector. The detector then emits data received, and the system translates the radiation variances into an image, which may be used to evaluate the internal structure of the object. One skilled in the art will recognize that the object may include, but is not limited to, a patient in a medical imaging procedure and an inanimate object as in, for instance, a package in a computed tomography (CT) package scanner.

X-ray tubes include a rotating anode structure for the purpose of distributing heat generated at a focal spot. The anode is typically rotated by an induction motor having a cylindrical rotor built into a cantilevered axle that supports a disc-shaped anode target and an iron stator structure with copper windings that surrounds an elongated neck of the x-ray tube. The rotor of the rotating anode assembly is driven by the stator. An x-ray tube cathode provides a focused electron beam that is accelerated across a cathode-to-anode vacuum gap and produces x-rays upon impact with the anode. Because of the high temperatures generated when the electron beam strikes the target, it is necessary to rotate the anode assembly at high rotational speed. This places stringent demands on the bearing assembly, which includes tool steel ball bearings and tool steel raceways.

Bearings used in x-ray tubes are required to operate in a vacuum, which precludes lubricating with conventional wet bearing lubricants such as grease or oil. X-ray tube bearing rolling elements are typically coated with a solid layer, or tribological system, of a metal with lubricating properties, such as silver, lead, or lead-tin. Silver, applied by an ion plating or an electroplating process, has been used as a lubricating coating for tool steel bearings in x-ray tube applications where the tubes operate under vacuum and at temperatures in the range of 300-500 degrees Celsius. The performance of the silver coating is optimum at an operating stress level of up to 2.5 GPa and a temperature of 400 to 500 degrees Celsius. Failure of a bearing in an x-ray tube is typically by wear of the plated silver and loss of the silver from the contact region.

Silver is also used because of its electrical characteristics. Tube current flows in the x-ray tube from cathode to anode as an electron beam. The tube electrical circuit requires tube current to flow through the bearing assembly, and as such, the current flows through the rolling contact points of the bearing. The electrical circuit may include the races, the balls, and any lubricant or other material that is deposited on the bearing assembly or its components to enhance the life of the bearing. As such, the tribological system on the balls or races must be sufficiently electrically conductive in order for the x-ray tube to operate.

Silver derives its lubricity from the fact that it is a highly ductile single phase noble metal. This property is dependent on operating at temperatures above the recrystallization temperature of silver, which is 0.4 to 0.5 times the melting point of silver. Therefore, silver is not as effective for bearing lubrication when operating below these temperatures, and other soft metals such as Pb and combinations of Pb and Sn have instead been used to lubricate ball bearings in x-ray applications.

Silver lubricant distributes between the balls and races during initial processing and operation of the x-ray tube to form a thin coating on the rolling contact region. The thin silver coating serves as a lubricant during the life of the bearing. Once the silver coating is worn, wear of the base material commences, which leads to increased noise, failure of the lubricant, and which can ultimately lead to catastrophic failure of the bearing. Furthermore, micro-welding may occur at contact points between balls and raceways.

The operating conditions of newer generation x-ray tubes have become increasingly more aggressive in terms of stresses because of g forces imposed by higher gantry speeds and higher anode runspeeds. As a result there is greater emphasis in finding materials solutions for improved performance and higher reliability of the bearing tribological system under the more stringent operating conditions.

Therefore, it would be desirable to have a method and apparatus to improve reliability of the lubricant and the base material in the rolling contact region and to improve the useful life of the x-ray bearing.

BRIEF DESCRIPTION OF THE INVENTION

The present invention provides a method and apparatus for enhancing x-ray tube bearing lubricants that overcome the aforementioned drawbacks. A coating between the ball and race of a bearing assembly includes at least a lubrication material that increases the lubricity on the base metal of an x-ray tube bearing over a single lubricating material. The coating includes a non-lubricant material to reduce wear of the base metal of an x-ray bearing.

According to one aspect of the present invention, a bearing assembly for an x-ray tube is disclosed that includes a bearing race, a bearing ball positioned adjacent to the bearing race, and a combination coating deposited on one of the bearing race and the bearing ball. The combination coating includes titanium carbide and a solid lubricant.

According to another aspect of the present invention discloses a method of manufacturing an x-ray tube bearing assembly. The method includes depositing titanium carbide on one of a bearing race and a bearing ball and depositing a solid lubricant on the titanium carbide.

According to yet another aspect of the present invention, an imaging system is disclosed including an x-ray detector, an x-ray tube having a rotatable shaft, and a bearing assembly supporting the rotatable shaft. The bearing assembly includes a bearing race, a bearing ball positioned adjacent to the bearing race, and a combination coating deposited on one of the bearing race and the bearing ball. The combination coating includes titanium carbide and a lubricant.

Various other features and advantages of the present invention will be made apparent from the following detailed description and the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawings illustrate one preferred embodiment presently contemplated for carrying out the invention.

In the drawings:

FIG. **1** is a pictorial view of a CT imaging system that can benefit from incorporation of an embodiment of the present invention.

FIG. **2** is a block schematic diagram of the system illustrated in FIG. **1**.

FIG. **3** is a cross-sectional view of an x-ray tube useable with the system illustrated in FIG. **1**.

FIG. **4** is a partial cross-sectional view of a base material having a combination material according to one embodiment of the present invention.

FIG. **5** is a partial cross-sectional view of a base material having a combination material according to another embodiment of the present invention.

FIG. **6** shows the embodiment of FIG. **5** having an improved interlayer adhesion between the base material and the first layer.

FIG. **7** is a partial cross-sectional view of a base material having improved mechanical support of the silver according to another embodiment of the present invention.

FIG. **8** is a partial cross-sectional view of a base material having islands of silver in a hard metal according to another embodiment of the present invention.

FIG. **9** is a partial cross-sectional view of a base material with hard coating and lubricant according to one embodiment of the present invention.

FIG. **10** shows the embodiment of FIG. **9** having an improved interlayer adhesion.

FIG. **11** is a pictorial view of a CT system for use with a non-invasive package inspection system.

FIG. **12** is a partial cross-sectional view of a base material with hard coating and lubricant according to one embodiment of the present invention.

FIG. **13** shows the embodiment of FIG. **12** having an improved interlayer adhesion.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The operating environment of the present invention is described with respect to the use of an x-ray tube as used in a computed tomography (CT) system. However, it will be appreciated by those skilled in the art that the present invention is equally applicable for use in other systems that require the use of an x-ray tube. Such uses include, but are not limited to, x-ray imaging systems (for medical and non-medical use), mammography imaging systems, and RAD systems.

Moreover, the present invention will be described with respect to use in an x-ray tube. However, one skilled in the art will further appreciate that the present invention is equally applicable for other systems that require operation of a bearing in a high vacuum, high temperature, and high contact stress environment, wherein a solid lubricant, such as silver, is plated on the rolling contact components. The present invention will be described with respect to a "third generation" CT medical imaging scanner, but is equally applicable with other CT systems, such as a baggage scanner.

Referring to FIGS. **1** and **2**, a computed tomography (CT) imaging system **10** is shown as including a gantry **12** representative of a "third generation" CT scanner. Gantry **12** has an x-ray tube **14** that projects a beam of x-rays **16** toward a detector array **18** on the opposite side of the gantry **12**. Detector array **18** is formed by a plurality of detectors **20** which together sense the projected x-rays that pass through a medical patient **22**. Each detector **20** produces an electrical signal that represents the intensity of an impinging x-ray beam and hence the attenuated beam as it passes through the patient **22**. During a scan to acquire x-ray projection data, gantry **12** and the components mounted thereon rotate about a center of rotation **24**.

Rotation of gantry **12** and the operation of x-ray tube **14** are governed by a control mechanism **26** of CT system **10**. Control mechanism **26** includes an x-ray controller **28** that provides power and timing signals to an x-ray tube **14** and a gantry motor controller **30** that controls the rotational speed and position of gantry **12**. A data acquisition system (DAS) **32** in control mechanism **26** samples analog data from detectors **20** and converts the data to digital signals for subsequent processing. An image reconstructor **34** receives sampled and digitized x-ray data from DAS **32** and performs high speed reconstruction. The reconstructed image is applied as an input to a computer **36** which stores the image in a mass storage device **38**.

Computer **36** also receives commands and scanning parameters from an operator via console **40** that has a keyboard. An associated cathode ray tube display **42** allows the operator to observe the reconstructed image and other data from computer **36**. The operator supplied commands and parameters are used by computer **36** to provide control signals and information to DAS **32**, x-ray controller **28** and gantry motor controller **30**. In addition, computer **36** operates a table motor controller **44** which controls a motorized table **46** to position patient **22** and gantry **12**. Particularly, table **46** moves portions of patient **22** through a gantry opening **48**.

FIG. **3** illustrates a cross-sectional view of an x-ray tube **14** that can benefit from incorporation of an embodiment of the present invention. The x-ray tube **14** includes a casing **50** having a radiation emission passage **52** formed therein. The casing **50** encloses a vacuum **54** and houses an anode **56**, a bearing assembly **58**, a cathode **60**, and a rotor **62**. X-rays **16** are produced when high-speed electrons are suddenly decelerated when directed from the cathode **60** to the anode **56** via a potential difference therebetween of, for example, 60 thousand volts or more in the case of CT applications. The x-rays **16** are emitted through the radiation emission passage **52** toward a detector array, such as detector array **18** of FIG. **2**. To avoid overheating the anode **56** from the electrons, an anode **56** is rotated at a high rate of speed about a centerline **64** at, for example, 90-250 Hz.

The bearing assembly **58** includes a center shaft **66** attached to the rotor **62** at first end **68** and attached to the anode **56** at second end **70**. A front inner race **72** and a rear inner race **74** of center shaft **66** rollingly engage a plurality of front balls **76** and a plurality of rear balls **78**, respectively. Bearing assembly **58** also includes a front outer race **80** and a rear outer race **82** configured to rollingly engage and position, respectively, the plurality of front balls **76** and the plurality of rear balls **78**. Bearing assembly **58** includes a stem **84** which is supported by the x-ray tube **14**. Stator **86** drives rotor **62**, which rotationally drives anode **56**.

In addition to rotation of the anode **56** within x-ray tube **14**, the x-ray tube **14** as a whole is caused to rotate about gantry **12** at rates of, typically, 1 Hz or faster. The rotational effects of both the x-ray tube **14** about the gantry **12** and the anode **56** within the x-ray tube **14** cause the anode **56** weight to be compounded significantly, hence leading to operating contact stresses in the races **72**, **74**, **80**, **82** and balls **76**, **78** of up to 2.5 GPa. Additionally, heat generated from operation of the cathode **60**, the resulting deceleration of electrons in anode **56**, and heat generated from frictional self-heating of the races **72**, **74**, **80**, **82** and balls **76**, **78**, cause the races **72**, **74**, **80**, **82** and balls **76**, **78** to operate typically above 400 degrees Celsius. Operation at such high temperatures and operation at high rotational speeds require a lubricant to be applied between races **72**, **74**, **80**, **82** and balls **76**, **78** in order to reduce friction therebetween.

Silver is typically used as the lubricant when operating temperatures of the components of the bearing assembly **58** of the x-ray tube **14** exceed 400 degrees Celsius. Silver may be applied to the races **72**, **74**, **80**, **82** or balls **76**, **78** or to both in x-ray tube applications. When applied to balls **76**, **78** silver is usually applied by, for instance, ion plating or electroplating. Silver minimizes formation of adhesive junctions between the base materials of the **72**, **74**, **80**, **82** and balls **76**, **78**. Being a relatively soft coating, silver is able to transfer from, for example, the lubricated balls **76**, **78** to races **72**, **74**, **80**, and **82** and maintain low friction therebetween. Optimal operating stresses of an x-ray tube typically range from 1-2.5 GPa with optimal temperatures typically ranging from 400-500 degrees Celsius.

Silver is a face-centered cubic (FCC) alloy which minimally work hardens above 400 degrees Celsius. Additionally, silver plastically flows easily to form a transfer film that prevents tool steel to tool steel adhesive wear processes between bearing balls **76**, **78** and races **72**, **74**, **80**, and **82**. As such, silver is a preferred lubricant when the operating temperature is above 400 degrees Celsius. However, the ability of silver to plastically flow is not retained at lower temperatures (e.g. <400 degrees Celsius). To improve the lubricity and enhance the performance of silver over a wider temperature range, other solid lubricants may be added thereto.

FIGS. **4**-**10** illustrate embodiments of the present invention that include a partial cross-sectional view of a base material in bearing assembly **58** to which the embodiments may be applied. One skilled in the art would recognize that the base material may pertain to a tool steel ball **76**, **78** a race **72**, **74**, **80**, and **82** or both. The base material may include tool steels typically used for bearing materials, such as Rex® 20, T5, T15 tool steels, and the like. Rex is a registered trademark of Crucible Materials Corporation, Solvay, N.Y.

Referring to FIGS. **4**-**6**, a combination of silver and another lubricant is applied to the base material for improved lubricity. The silver may be applied before the second lubricant, or the silver may be applied simultaneously with the second lubricant. An adhesion promoter is also disclosed to enhance adhesion between the lubricant and the base material.

FIG. **4** is a partial cross-sectional view of a base material **88** having a combination material **90** applied thereto, according to one embodiment of the present invention. The combination material **90** includes silver **92** and another lubricant **94** such as tungsten disulfides (WS2), molybdenum disulfide (MoS2), calcium fluoride (CaF2), and the like. In a preferred embodiment, combination material **90** may be co-sputtered or composite plated simultaneously on base material **88**. In co-sputtering, silver and lubricants are sputtered in a physical vapor deposition (PVD) system, accelerated in a plasma, and deposited on a tool steel ball to form combination material **90**. In composite plating, the base material **88** to be coated serves as a cathode in a silver-based electrolytic bath and solid particles of 1 to 5 microns in size are suspended in the electrolyte for co-depositing on the cathode. The combination material **90** deposited on base material **88** enhances lubrication performance, which improves the life of the bearing assembly **58**.

FIG. **5** is a partial cross-sectional view of a base material **88** having a combination material **96** applied thereto, according to another embodiment of the present invention. A first layer **98** of silver is deposited on base material **88**, and a second layer **100** is deposited on the first layer **98**. Second layer **100** includes a lubrication material other than silver such as WS2, MoS2, CaF2, CaF2BaF2 eutectics, and the like. In a preferred embodiment, the second layer **100** is sputtered on the first layer **98** as a thin film. In this manner, the second layer **100**, together with the first layer **98**, enhances the lubrication performance and life of the bearing assembly **58**.

FIG. **6** shows the embodiment of FIG. **5** having an improved interlayer adhesion between the base material **88** and a combination material **102**. An adhesion layer **108** of a Ti or a Cr metal is deposited on base material **88** prior to depositing the first layer **104** of silver and a second layer of lubricant **106** that includes a lubrication material other than silver such as WS2, MoS2, CaF2, CaF2BaF2 eutectics, and the like. Ti and Cr metals promote adhesion between the first layer **104** of silver and the base material **88** through a finite mutual solubility with silver and the base metal. Ti and Cr metals **108** provide both mechanical adhesion provided through the deposition process and chemical adhesion between base material **88** and first layer **104** of silver. The adhesion layer **108** is preferably deposited on base material **88** with a thickness from 10 to 100 nm. The adhesion layer **108** improves adhesion uniformity of the first layer **104** across the surface of the base material **88** over the underlying multi-phase microstructure of the base material **88** alone.

Referring to FIGS. **7**-**10**, an improved wear resistance to the base metal is achieved by applying a hard material to the base material and applying lubricant thereto.

FIG. **7** is a partial cross-sectional view of base material **88** having a coating of silver **110** and low friction, hard particulates **112** according to one embodiment of the present invention. Silver **110** is entrapment-plated onto base material **88** with the hard particulates **112** of submicron size, for example, 20 to 250 nm in diameter. The hard particulates **112** include materials such as TiN, TiAlN, diamond, silicon nitride, silicon carbide, nickel-diamond, and the like having a higher hardness, at x-ray tube operating temperatures, than the base material **88**. The hard particulates **112** constrain the silver **110** in valleys **114** between the hard particulates **112** and assist the silver **110** when undergoing bearing rolling contact forces. The adhesion of the silver **110** to hard particulates **112** can be improved by first applying ion beam assisted deposition (IBAD) Cu+IBAD Ag, or Ni/Cu-D+IBAD Ag before depositing silver **110**.

FIG. **8** is a partial cross-sectional view of a base material **88** having a coating **116** including islands of silver **118** co-deposited with a low soluble hard metal **120** according to one embodiment of the present invention. The hard metal **120** includes iron, cobalt, molybdenum, nickel, and the like which have limited mutual solubility at deposition and use temperatures, typically up to 550 degrees Celsius. Hard metals **120** are harder than the lubricant, and inhibit loss of lubricant during operation of the bearing. Molybdenum, when co-deposited with the islands of silver **118**, may be selectively sulphidized to MoS2, which has extremely low friction in a vacuum. The islands of silver **118** having, for example, diameters from 10 to 1000 nm, are dispersed in a matrix of the hard metal **120**. During rolling contact, silver **118** is dispersed about the hard metal **120** to form a lubrication film thereon. Deformation of the coating **116** is low due to the hardness of the hard metal **120**.

FIG. **9** is a partial cross-sectional view of base material **88** having a layer of hard coating **122** and a layer of lubricant **124** deposited thereon according to one embodiment of the present invention. The layer of hard coating **122** is deposited on the base material **88** as described hereinbelow and is harder than base material **88**. The layer of hard coating **122** reduces slip by maintaining curvature of the base material **88** during the life of the bearing assembly **58**. Lubricant **124** is deposited on the layer of hard coating **122** and includes silver, WS2, MoS2, CaF2, CaF2BaF2 eutectics, and the like, or combinations thereof.

In one embodiment, the hard coating **122** includes a monolithic nitride coating deposited by PVD, chemical vapor deposition (CVD) or deposited through ion nitriding. Nitride coatings can be doped with Cl ions by injecting traces of additional TiCl4 during processing. The nitrides can include TiN or other metallic alloyed nitrides. An advantage of the CVD process is that it can be integrated with the tool steel heat treatment cycle, then air quenched and tempered.

In another embodiment, hard coating **122** includes multiple layers of nitride such as TiNZrN. Nitrides enhance overall adhesion between the base material **88** and the lubricant **124**. The thickness of each layer is preferably 100 nm or lower, while the thickness of the combined layers is preferably not greater than 10 microns.

In yet another embodiment, hard coating **122** includes carbide and oxide coatings with lubricating phases. A CerMet (ceramic and metal) coating such as WC-Co(Cr) or Metal matrix/alumina is co-deposited with a moderate temperature lubricant phase capable of operating in vacuum, such as MoS2, WS2, CaF2, CaF2BaF2 eutectics. These coatings can be deposited by a High Velocity Oxygen Fuel (HVOF) process, to produce a dense adherent coating.

FIG. **10** shows the embodiment of FIG. **9** having an improved interlayer adhesion. A layer of hard ceramic **126**, such as mono- or nanomulti-layer nitrides, carbides, or borides, is deposited on the base material **88**. An adhesion layer **108** of a Ti or a Cr metal is deposited on the layer of hard ceramic **126** as an adhesion promoting interlayer to a thickness of, for example, 10 to 100 nm. A layer of silver **128** is then deposited on the adhesion layer **108**. Ti and Cr metals **108** have solubility both in the layer of hard ceramic **126** as well as the layer of silver **128** layer, thus providing a chemically enhanced adhesion between the silver **128** and the layer of hard ceramic **126**.

FIG. **11** is a pictorial view of a CT system for use with a non-invasive package inspection system. Package/baggage inspection system **130** includes a rotatable gantry **132** having an opening **134** therein through which packages or pieces of baggage may pass. The rotatable gantry **132** houses a high frequency electromagnetic energy source **136** as well as a detector assembly **138** having scintillator arrays comprised of scintillator cells. A conveyor system **140** is also provided and includes a conveyor belt **142** supported by structure **144** to automatically and continuously pass packages or baggage pieces **146** through opening **134** to be scanned. Objects **146** are fed through opening **134** by conveyor belt **142**, imaging data is then acquired, and the conveyor belt **142** removes the packages **146** from opening **134** in a controlled and continuous manner. As a result, postal inspectors, baggage handlers, and other security personnel may non-invasively inspect the contents of packages **146** for explosives, knives, guns, contraband, etc.

FIGS. **12** and **13** illustrate embodiments of the present invention that include a partial cross-sectional view of a base material **88** in bearing assembly **58** having a combination material **158** applied thereto. One skilled in the art would recognize that the base material **88** may pertain to a tool steel ball **76**, **78** a race **72**, **74**, **80**, and **82** or both. The base material **88** may include tool steels typically used for bearing materials in x-ray tubes, such as Rex® 20, T5, T15 tool steels, and the like.

In embodiments of the present invention, combination material **158** has a hard coating **160** that includes titanium carbide deposited by chemical vapor deposition (CVD) on the base material **88**. Titanium carbide has extreme surface hardness and fine single-phase microstructure. An advantage of the CVD process is that it can be integrated with the tool steel heat treatment cycle and then air quenched and tempered. Titanium carbide typically has a hardness of approximately three times that of a base material such as, for instance, Rex® 20, and the like. For instance, titanium carbide coatings typically have a hardness of 3500 Hv, have a very fine microstructure with a grain size of approximately 0.1 μm, and have a single phase with no binder. Rex® 20 typically has a hardness of 66-67 HRC or 900Hv. Balls coated with titanium carbide may be manufactured having a surface roughness Ra of the titanium carbide ranging between 0.007-0.009 μm and may be manufactured in lots exceeding a Grade 3 quality. As such, bearings fabricated having balls that exceed a Grade 3 quality result in a bearing having improved friction properties, thereby having a reduced internal heat generation, reduced vibration, and reduced noise levels. Accordingly, bearings fabricated according to an embodiment of the present invention have an improved useful lifetime of the lubricant and, therefore, of the bearings themselves over many known x-ray tube bearings.

FIG. **12** is a partial cross-sectional view of a base material **88** of one of bearing balls **76**, **78** and races **72**, **74**, **80**, and **82**, having a combination coating **158** that includes a layer of hard coating **160** and a layer of solid lubricant **162** deposited thereon according to one embodiment of the present invention. The layer of hard coating **160**, which includes titanium carbide, is deposited on the base material **88** resulting in an outer layer that is harder than base material **88**. The layer of hard coating **160** is preferably heat treated and lapped to a surface finish quality exceeding that of a Grade 3 specification. The layer of hard coating **160** improves a desired curvature of the base material **88** during the life of the bearing assembly **58** and improves wear resistance in the bearing assembly **58**. A solid lubricant layer **162** is deposited on the layer of hard coating **160** that includes silver, gold (Au), MoS2, and the like, or combinations thereof.

FIG. **13** shows an embodiment of FIG. **12** illustrating the combination coating **158** having an improved interlayer adhesion between the hard coating layer **160** and the solid lubricant layer **162**. An adhesion layer **108** of at least one of Ti metal, Ni, Nichrome, Mo, and Zr is deposited on the hard coating layer **160**, which has titanium carbide therein, as an adhesion promoting interlayer to a thickness of, for example, 10 to 100 nm. Silver, for solid lubricant layer **162**, is then deposited on the adhesion layer **108**. Ti metal **108** has solubility in both the titanium carbide and in the silver, thus providing a chemically enhanced adhesion therebetween.

According to one embodiment of the present invention, a bearing assembly for an x-ray tube is disclosed that includes a bearing race, a bearing ball positioned adjacent to the bearing race, and a combination coating deposited on one of the bearing race and the bearing ball. The combination coating includes titanium carbide and a solid lubricant.

According to another embodiment of the present invention discloses a method of manufacturing an x-ray tube bearing assembly. The method includes depositing titanium carbide on one of a bearing race and a bearing ball and depositing a solid lubricant on the titanium carbide.

According to yet another embodiment of the present invention, an imaging system is disclosed including an x-ray detector, an x-ray tube having a rotatable shaft, and a bearing assembly supporting the rotatable shaft. The bearing assembly includes a bearing race, a bearing ball positioned adjacent to the bearing race, and a combination coating deposited on one of the bearing race and the bearing ball. The combination coating includes titanium carbide and a lubricant.

The present invention has been described in terms of the preferred embodiment, and it is recognized that equivalents, alternatives, and modifications, aside from those expressly stated, are possible and within the scope of the appending claims.

What is claimed is:

1. A bearing assembly mounted in an x-ray tube, the bearing assembly comprising:

a bearing race;

a bearing ball positioned adjacent to the bearing race; and

a combination coating deposited on one of the bearing race and the bearing ball, the combination coating comprising:

a coating having a hardness greater than a hardness of the bearing race and the bearing ball;

a solid lubricant; and

an adhesion promoting interlayer positioned between the coating and the solid lubricant.

2. The bearing assembly of claim **1** wherein the coating has a hardness greater than a hardness of the bearing ball.

3. The bearing assembly of claim **1** wherein the solid lubricant comprises one of silver, Au, and MoS2.

4. The bearing assembly of claim **1** wherein the coating has a maximum surface roughness less than Grade 3 steel balls.

5. The bearing assembly of claim **1** wherein the coating maximum surface roughness is less than approximately 0.007 μm Ra.

6. The bearing assembly of claim **1** wherein the adhesion promoting interlayer comprises one of Ti, Ni, Nichrome, Mo, and Zr.

7. The bearing assembly of claim **1** wherein the coating comprises titanium carbide.

8. The bearing assembly of claim **1** wherein the solid lubricant comprises one of silver, Au, and MoS2.

9. A method of manufacturing an x-ray tube bearing assembly, the method comprising:

depositing titanium carbide on one of a bearing race and a bearing ball;

depositing a solid lubricant on the titanium carbide; and

depositing an intermediate layer between the titanium carbide and the lubricant.

10. The method of claim **9** wherein the intermediate layer comprises one of Ti, Ni, Nichrome, Mo, and Zr.

11. The method of claim **9** wherein the step of depositing titanium carbide further includes depositing the titanium carbide using a chemical vapor deposition process.

12. The method of claim **9** further comprising heat treating the one of a bearing race and a bearing ball coated with titanium carbide.

13. The method of claim **12** further comprising surface grinding the one of a bearing race and a bearing ball coated with titanium carbide after heat treating.

14. The method of claim **13** further comprising surface grinding to a surface roughness of a ball quality exceeding a Grade 3 specification.

15. The method of claim **13** further comprising surface grinding to a maximum surface roughness no greater than approximately 0.007 μm Ra.

16. The method of claim **9** wherein the step of depositing a solid lubricant further comprises depositing one of silver, gold, and MoS2.

17. An imaging system comprising:

an x-ray detector;

an x-ray tube having a rotatable shaft; and

a bearing assembly supporting the rotatable shaft, the bearing assembly comprising:

a bearing race;

a bearing ball positioned adjacent to the bearing race; and

a combination coating deposited on one of the bearing race and the bearing ball, the combination coating comprising:

titanium carbide;

a lubricant; and

one of elemental titanium, elemental nickel, Nichrome, elemental molybdenum, and elemental zirconium positioned between the titanium carbide and the lubricant.

18. The imaging system of claim **17** wherein the lubricant comprises one of silver, gold, and MoS2.

19. The imaging system of claim **17** wherein the titanium carbide has a maximum surface roughness less than Grade 3 steel balls.

20. The imaging system of claim **17** wherein a titanium carbide maximum surface roughness is less than approximately 0.007 μm Ra.

21. The imaging system of claim **17** wherein the imaging system includes one of a CT, x-ray, mammography, and RAD imaging system.

22. A bearing assembly mounted in an x-ray tube, the bearing assembly comprising:

a bearing race;

a bearing ball positioned adjacent to the bearing race; and

a combination coating deposited on one of the bearing race and the bearing ball, the combination coating comprising:

titanium carbide;

a solid lubricant comprising MoS2; and

one of Ti, Ni, Nichrome, Mo, and Zr positioned between the titanium carbide and the solid lubricant.

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