US007643614B2

(12) United States Patent
Hebert et al.

(10) Patent No.: US 7,643,614 B2
(45) Date of Patent: Jan. 5, 2010

(54) **METHOD AND APPARATUS FOR INCREASING HEAT RADIATION FROM AN X-RAY TUBE TARGET SHAFT**

(75) Inventors: **Michael Hebert**, Muskego, WI (US); **Gregory Alan Steinlage**, Hartland, WI (US); **Thomas C. Tiearney, Jr.**, Waukesha, WI (US)

(73) Assignee: **General Electric Company**, Schenectady, NY

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 33 days.

(21) Appl. No.: **11/860,657**

(22) Filed: **Sep. 25, 2007**

(65) **Prior Publication Data**

US 2009/0080615 A1 Mar. 26, 2009

(51) **Int. Cl.**
H01J 35/00 (2006.01)

(52) **U.S. Cl.** **378/129**; 378/144

(58) **Field of Classification Search** 378/129, 378/143, 144

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,870,672	A	9/1989	Lindberg	378/129
5,553,114	A	9/1996	Siemers et al.	378/129
6,144,720	A	11/2000	DeCou et al.	378/131
6,456,692	B1 *	9/2002	Smith	378/129
6,553,097	B2 *	4/2003	Hansen et al.	378/144
6,707,883	B1 *	3/2004	Tiearney et al.	378/144
2004/0032929	A1 *	2/2004	Andrews et al.	378/119

* cited by examiner

Primary Examiner—Courtney Thomas
(74) *Attorney, Agent, or Firm*—Ziolkowski Patent Solutions Group, SC

(57) **ABSTRACT**

A target for generating x-rays includes a target substrate, a target shaft attached to the target substrate, and a radiation emissive coating applied to at least one of the target substrate and the target shaft, wherein a center-of-gravity of the target is positioned between a front bearing assembly and a rear bearing assembly of an x-ray tube.

29 Claims, 3 Drawing Sheets

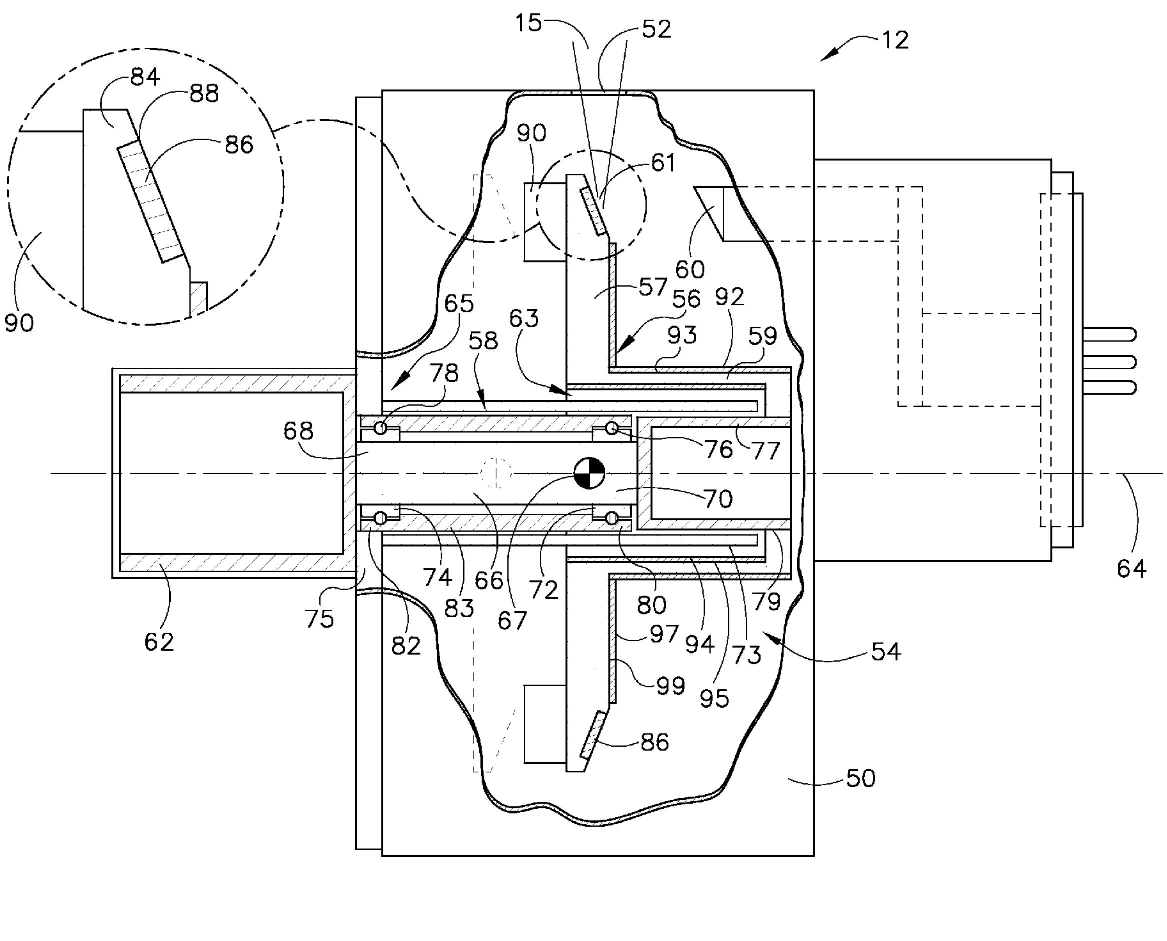
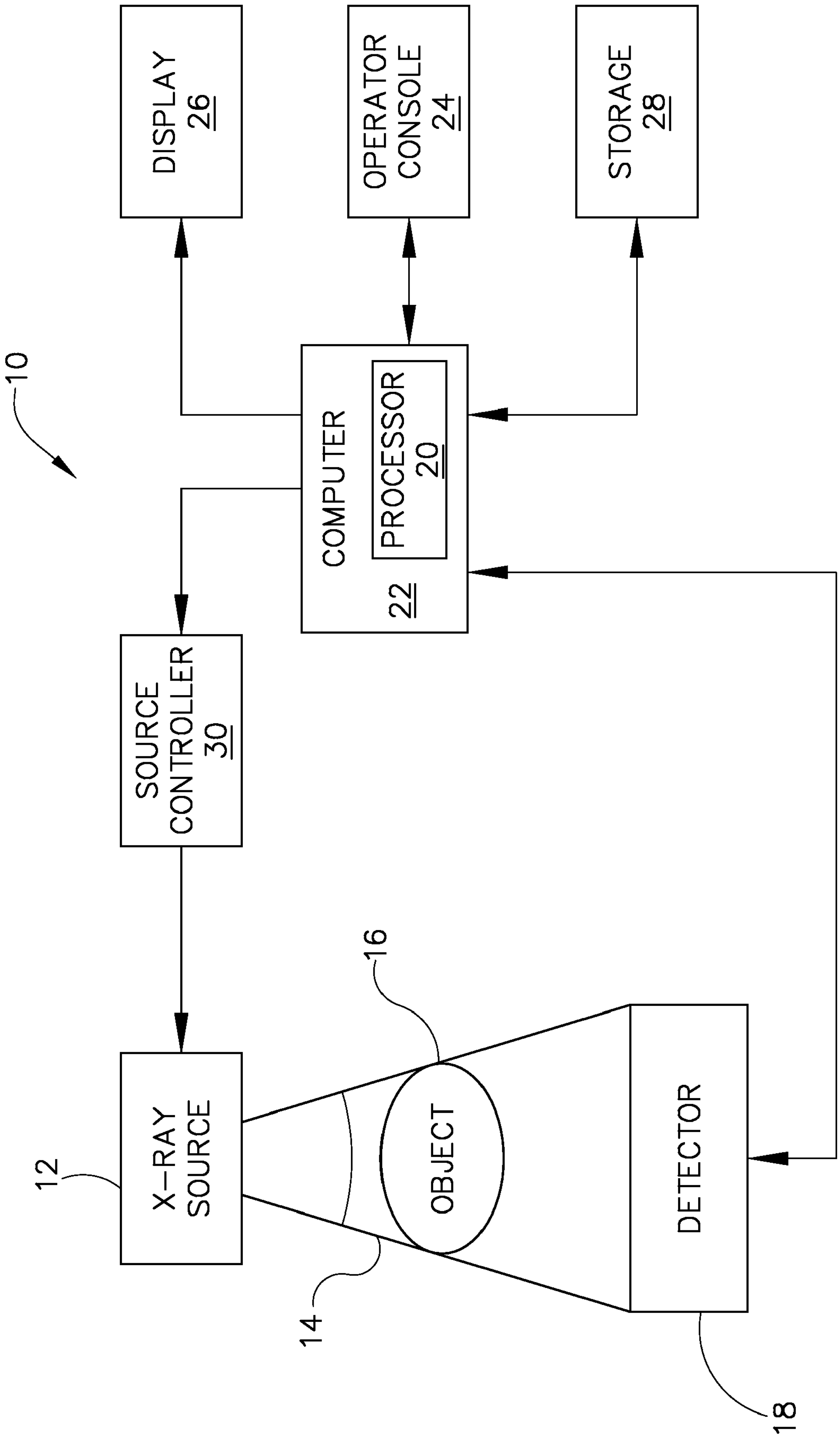


FIG. 1


10
DISPLAY 26
OPERATOR CONSOLE 24
STORAGE 28
COMPUTER
PROCESSOR 20
22
SOURCE CONTROLLER 30
X-RAY SOURCE
12
14
OBJECT
16
DETECTOR
18

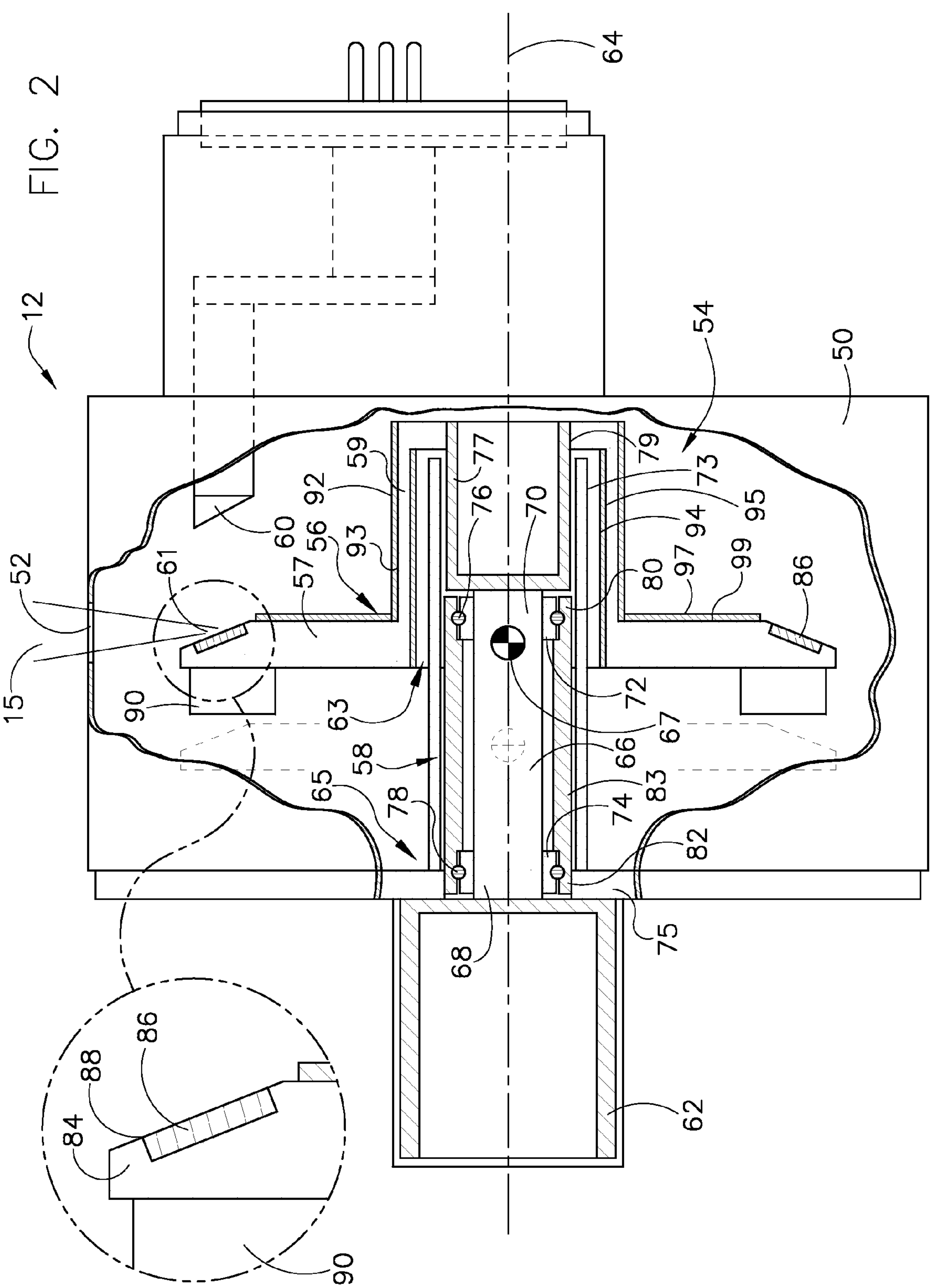

64
12
54
50
79
77
59
73
92
76
70
95
94
60
56
93
97
99
80
86
52
61
57
15
90
63
72
67
66
58
65
83
78
74
82
75
68
62
88
84

FIG. 2

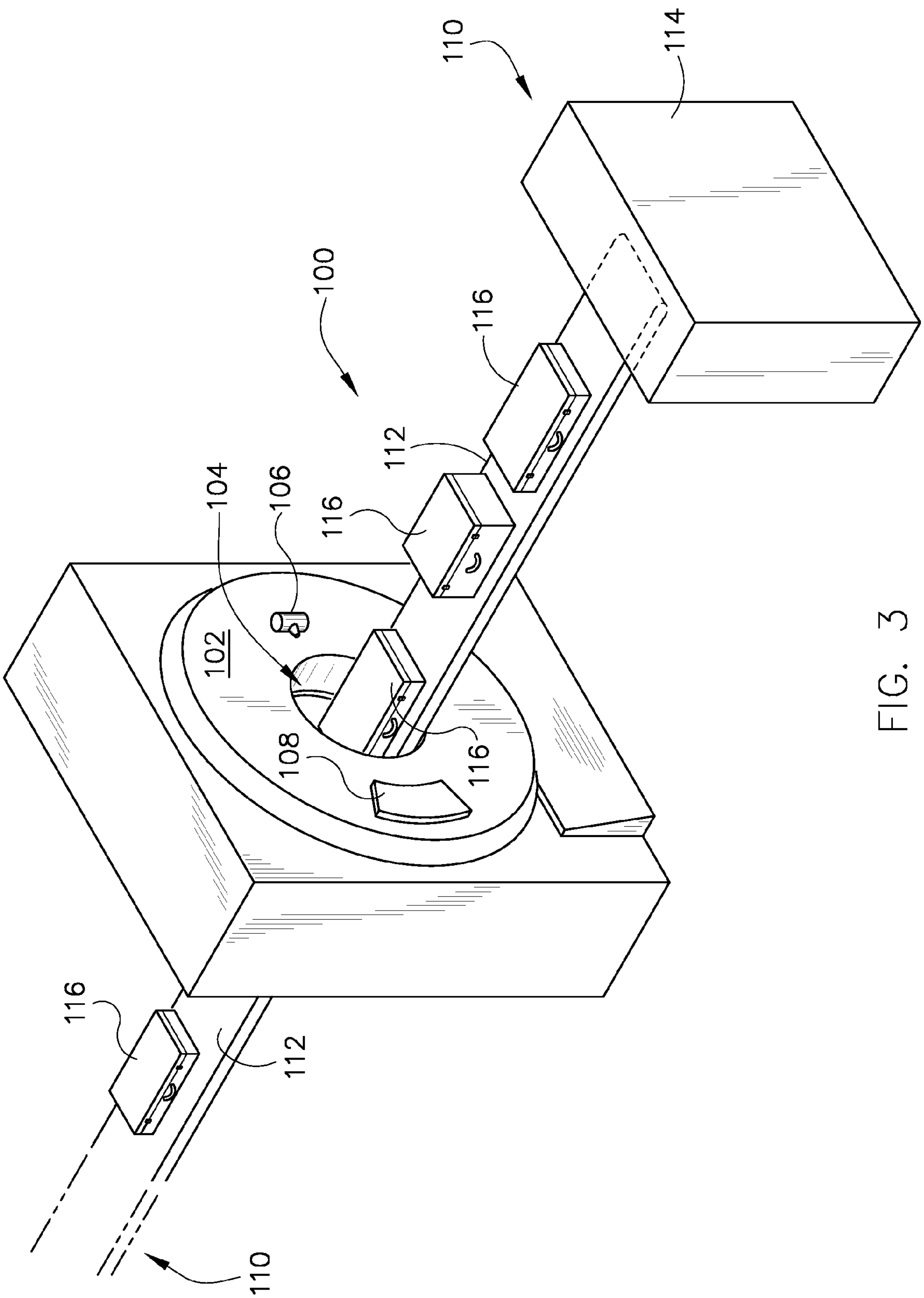


FIG. 3

METHOD AND APPARATUS FOR INCREASING HEAT RADIATION FROM AN X-RAY TUBE TARGET SHAFT

BACKGROUND OF THE INVENTION

The present invention relates generally to x-ray tubes and, more particularly, to a high emissive coating on a target shaft of an x-ray tube.

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 the 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.

Newer generation x-ray tubes have increasing demands for providing higher peak power, thus higher average power as well. Higher peak power, though, results in higher peak temperatures occurring in the target assembly, particularly at the target "track," or the point of impact on the target. Thus, for increased peak power applied, there are life and reliability issues with respect to the target. Such effects may be countered to an extent by, for instance, spinning the target faster. However, doing so has implications to reliability and performance of other components within the x-ray tube such as the target and the bearing assembly. And, although spinning the target faster may reduce the peak focal track temperature, there is limited enhancement or improvement in the overall average power capability of the x-ray tube. As such, spinning faster has minimal impact on decreasing the operating temperature of the bearing assembly for a given average power.

Therefore, it would be desirable to have a method and apparatus to improve thermal performance and reliability of an x-ray tube target and bearing.

BRIEF DESCRIPTION OF THE INVENTION

The present invention provides a high emissive coating on a target shaft of an x-ray tube anode.

According to one aspect of the present invention, a target for generating x-rays includes a target substrate, a target shaft attached to the target substrate, and a radiation emissive coating applied to at least one of the target substrate and the target shaft, wherein a center-of-gravity of the target is positioned between a front bearing assembly and a rear bearing assembly of an x-ray tube.

In accordance with another aspect of the invention, a method of fabricating an x-ray target assembly includes forming a substrate, and attaching a target shaft to the substrate. The method further includes forming a radiation emissive coating on at least one of the substrate and the target shaft and positioning a center-of-gravity of the substrate between a front bearing assembly and a rear bearing assembly of an x-ray tube.

Yet another aspect of the present invention includes an imaging system having an x-ray detector and an x-ray emission source. The x-ray emission source includes a cathode, a front bearing assembly, a rear bearing assembly, and an anode having a center-of-gravity between the front bearing assembly and the rear bearing assembly. The anode includes a target base material, a shaft attached to the target base material, and a radiation emissive coating attached to at least one of the target base material and the shaft.

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 block diagram of an imaging system that can benefit from incorporation of an embodiment of the present invention.

FIG. **2** is a cross-sectional view of an x-ray tube according to an embodiment of the present invention and useable with the system illustrated in FIG. **1**.

FIG. **3** is a pictorial view of a CT system for use with a non-invasive package inspection system that can benefit from incorporation of an embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. **1** is a block diagram of an embodiment of an imaging system **10** designed both to acquire original image data and to process the image data for display and/or analysis in accordance with the present invention. It will be appreciated by those skilled in the art that the present invention is applicable to numerous medical imaging systems implementing an x-ray tube, such as x-ray or mammography systems. Other imaging systems such as computed tomography systems and digital radiography systems, which acquire image three dimensional data for a volume, also benefit from the present invention. The following discussion of x-ray system **10** is merely an example of one such implementation and is not intended to be limiting in terms of modality.

As shown in FIG. **1**, x-ray system **10** includes an x-ray source **12** configured to project a beam of x-rays **14** through an object **16**. Object **16** may include a human subject, pieces of baggage, or other objects desired to be scanned. X-ray source **12** may be a conventional x-ray tube producing x-rays having a spectrum of energies that range, typically, from 30 keV to 200 keV. The x-rays **14** pass through object **16** and, after being attenuated by the object, impinge upon a detector **18**. Each detector in detector **18** produces an analog electrical signal that represents the intensity of an impinging x-ray beam, and hence the attenuated beam, as it passes through the object **16**. In one embodiment, detector **18** is a scintillation based detector, however, it is also envisioned that direct-conversion type detectors (e.g., CZT detectors, etc.) may also be implemented.

A processor **20** receives the analog electrical signals from the detector **18** and generates an image corresponding to the object **16** being scanned. A computer **22** communicates with processor **20** to enable an operator, using operator console **24**, to control the scanning parameters and to view the generated image. That is, operator console **24** includes some form of operator interface, such as a keyboard, mouse, voice activated controller, or any other suitable input apparatus that allows an operator to control the x-ray system **10** and view the reconstructed image or other data from computer **22** on a display unit **26**. Additionally, console **24** allows an operator to store the generated image in a storage device **28** which may include hard drives, floppy discs, compact discs, etc. The operator may also use console **24** to provide commands and instructions to computer **22** for controlling a source controller **30** that provides power and timing signals to x-ray source **12**.

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 target used for the production of x-rays wherein high peak temperatures are driven by peak power requirements.

FIG. **2** illustrates a cross-sectional view of an x-ray tube **12** incorporating an embodiment of the present invention. The x-ray tube **12** includes a frame, or casing **50** having a radiation emission passage **52** formed therein. The casing **50** encloses a vacuum **54** and houses an anode **56**, a bearing cartridge **58**, a cathode **60**, and a rotor **62**. The anode **56** includes a target **57** having a target shaft **59** attached thereto. X-rays **15** are produced when high-speed electrons are decelerated when directed from the cathode **60** to the target **57** via a potential difference therebetween of, for example, 60 thousand volts or more in the case of CT applications. The electrons impact a target track material **86** at focal point **61** and x-rays **15** emit therefrom. The x-rays **15** emit through the radiation emission passage **52** toward a detector array, such as detector **18** of FIG. **1**. To avoid overheating the target track material **86** from the electrons, the anode **56** is rotated at a high rate of speed about a centerline **64** at, for example, 90-250 Hz.

The bearing cartridge **58** includes a front bearing assembly **63** and a rear bearing assembly **65**. The bearing cartridge **58** further includes a center shaft **66** attached to the rotor **62** at a first end **68** of center shaft **66** and a bearing hub **77** attached at a second end **70** of center shaft **66**. The front bearing assembly **63** includes a front inner race **72**, a front outer race **80**, and a plurality of front balls **76** that rollingly engage the front races **72**, **80**. The rear bearing assembly **65** includes a rear inner race **74**, a rear outer race **82**, and a plurality of rear balls **78** that rollingly engage the rear races **74**, **82**. Bearing cartridge **58** includes a stem **83** which is supported by the x-ray tube **12**. A stator (not shown) is positioned radially external to and drives the rotor **62**, which rotationally drives anode **56**. The target shaft **59** is attached to the bearing hub **77** at joint **79**. One skilled in the art would recognize that target shaft **59** may be attached to the bearing hub **77** with other attachment means, such as a bolted joint, a braze joint, a weld joint, and the like. In one embodiment a receptor **73** is positioned to surround the stem **83** and is attached to the x-ray tube **12** at the back plate **75**. The receptor **73** extents into a gap formed between the target shaft **59** and the bearing hub **77**.

Referring still to FIG. **2**, the target **57** includes a target substrate **84**, having target track material **86** attached thereto. The target track material **86** typically includes tungsten or an alloy of tungsten, and the target substrate **84** typically includes molybdenum or an alloy of molybdenum. A heat storage medium **90**, such as graphite, may be used to sink and/or dissipate heat built-up near the focal point **61**. One skilled in the art will recognize that the target track material **86** and the target substrate **84** may comprise the same material, which is known in the art as an all metal target.

The anode **56** has a re-entrant target design that serves to position the mass or center-of-gravity **67**, of target **57** at a position between the front bearing assembly **63** and the rear bearing assembly **65** and substantially along centerline **64**, about which center shaft **66** rotates. Additionally, both target shaft **59** and bearing hub **77** serve to increase a conduction path length between target **57** and bearing cartridge **58** such that a reduction in the peak operating temperature of front inner race **72**, front balls **76**, and front outer race **80** may be realized as compared to a direct connection of target **57** to second end **70** of center shaft **66**. In one embodiment, as illustrated in phantom in FIG. **2**, the center-of-gravity **67** of the target **57** is positioned equidistant between the front bearing assembly **63** and the rear bearing assembly **65**. As such, the mechanical load of the target is positioned between the two bearing assemblies, thus causing the two bearing assemblies **63**, **65** to wear at approximately equal rates. One skilled in the art would recognize that the positioning of target **57** in a re-entrant target design as illustrated also results in a combined center-of-gravity of target **57**, target shaft **59**, bearing hub **77**, center shaft **66**, and rotor **62** positioned between the front bearing assembly **63** and the rear bearing assembly **65**. The distance of re-entrance of target **57** may be designed such that the combined center-of-gravity may be positioned equidistant between front bearing assembly **63** and rear bearing assembly **65** to cause two bearing assemblies **63**, **65** to wear at approximately equal rates.

In operation, as electrons impact focal point **61** and produce x-rays, heat generated therein causes the target **57** to increase in temperature, thus causing the heat to transfer via radiation heat transfer to surrounding components such as, and primarily, casing **50**. Heat generated in target **57** also transfers conductively through target shaft **59** and bearing hub **77** to bearing cartridge **58** as well, leading to an increase in temperature of bearing cartridge **58**. To reduce conductive heat transfer into bearing cartridge **58** and increase the amount of radiation heat transfer to the surrounding components, an emissive coating **92** may be applied to an outer diameter or surface **93** of target shaft **59**. Without an emissive coating, target shaft **59** may have an emissivity of 0.18. One skilled in the art would recognize that the emissive coating **92** may be applied by, for instance, plasma spray, chemical vapor deposition, electro-plating or physical vapor deposition, and the like, according to an embodiment of the present invention. In one embodiment the emissivity may be increased to, for instance, greater than 0.18. In one embodiment a coating having an emissivity of 0.75 is applied. An emissive coating **97**, furthermore, may be applied to a substrate, or surface **99** of the target **57** transverse to the axis of rotation **64**. One skilled in the art will recognize that an emissive coating may be applied to an outer circumference of the target **57**, or to a surface parallel to and opposite that of surface **99**. With the increase in radiative emissivity on outer surface **93** or surface **99**, an increase in heat transferred out of target shaft **59** via radiation will thus reduce heat transferred out of target shaft **59** via conduction, and, as a consequence, the operating temperature of the target shaft **59**, the bearing hub **77**, and the bearing cartridge **58** may be reduced.

In like fashion an emissive coating **94** may likewise be applied to an inner diameter or surface **95** of target shaft **59**. Accordingly, the operating temperature of the target shaft **59** may likewise be reduced in temperature as compared to a surface **95** without an emissive coating. And, although the inner surface **95** of the target shaft **59** views, in part, the bearing hub **77**, the target shaft **59** also views stem **83**. Thus, an increase in the emissivity of surface **95** will likewise increase the amount of radiation heat transfer to the stem **83**, thus avoiding some of the heat that would otherwise conduct down the bearing hub **77** to the front bearing assembly **63**. One skilled in the art will recognize that as for a longer target shaft **59** length, more of the surface **95** would likewise be exposed to the outer surface of stem **83**, thus increasing the rate of radiation heat transfer to the stem **83**, thereby avoiding some heat transfer via conduction directly into the front bearing assembly **63**. Furthermore, one skilled in the art would recognize that, in an embodiment that includes a receptor **73**, then heat transfer from the target shaft **59** to the receptor **73** will likewise be increased for increased emissivity of target shaft **59** at surface **95**.

FIG. **3** is a pictorial view of a CT system for use with a non-invasive package inspection system. Package/baggage inspection system **100** includes a rotatable gantry **102** having an opening **104** therein through which packages or pieces of baggage may pass. The rotatable gantry **102** houses a high frequency electromagnetic energy source **106** as well as a detector assembly **108** having scintillator arrays comprised of scintillator cells. A conveyor system **110** is also provided and includes a conveyor belt **112** supported by structure **114** to automatically and continuously pass packages or baggage pieces **116** through opening **104** to be scanned. Objects **116** are fed through opening **104** by conveyor belt **112**, imaging data is then acquired, and the conveyor belt **112** removes the packages **116** from opening **104** 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 **116** for explosives, knives, guns, contraband, etc.

According to one embodiment of the present invention, a target for generating x-rays includes a target substrate, a target shaft attached to the target substrate, and a radiation emissive coating applied to at least one of the target substrate and the target shaft, wherein a center-of-gravity of the target is positioned between a front bearing assembly and a rear bearing assembly of an x-ray tube.

In accordance with another embodiment of the invention, a method of fabricating an x-ray target assembly includes forming a substrate, and attaching a target shaft to the substrate. The method further includes forming a radiation emissive coating on at least one of the substrate and the target shaft and positioning a center-of-gravity of the substrate between a front bearing assembly and a rear bearing assembly of an x-ray tube.

Yet another embodiment of the present invention includes an imaging system having an x-ray detector and an x-ray emission source. The x-ray emission source includes a cathode, a front bearing assembly, a rear bearing assembly, and an anode having a center-of-gravity between the front bearing assembly and the rear bearing assembly. The anode includes a target base material, a shaft attached to the target base material, and a radiation emissive coating attached to at least one of the target base material and the shaft.

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. An apparatus for generating x-rays comprising:

a target substrate;

a re-entrant target shaft attached to the target substrate, the re-entrant target shaft having an inner surface and an outer surface, the inner surface positioned to face toward a center of rotation of the target;

an emissive coating applied to the target substrate and the inner surface of the target shaft; a bearing cartridge coupled to the re-entrant target shaft and configured to cause the re-entrant target shaft to rotate about the center of rotation, the bearing cartridge comprising:

a shaft;

a stem; and

a bearing assembly rotatably coupling the shaft to the stem; and

a receptor extending between the inner surface of the re-entrant target shaft and the stem such that a first gap is formed between the re-entrant target shaft and the receptor and such that a second gap is formed between the stem and the receptor, wherein the receptor is configured to receive a heat transfer from the inner surface of the target shaft.

2. The apparatus of claim **1** further comprising a track material attached to the target substrate.

3. The apparatus of claim **1** further comprising a heat storage medium attached to the target substrate.

4. The apparatus of claim **3** wherein the heat storage medium is graphite.

5. The apparatus of claim **1** wherein the emissive coating applied to the target substrate is applied to a face of the target substrate transverse to an axis of rotation of the target substrate.

6. The apparatus of claim **1** comprising an emissive coating applied to an outer surface of the re-entrant target shaft.

7. The apparatus of claim **1** wherein the emissive coating is one of a plasma spray coating, a chemical vapor deposition coating, an electroplate coating, and a physical vapor deposition coating.

8. The apparatus of claim **1** wherein a center of gravity of the target is positioned between a front bearing assembly and a rear bearing assembly.

9. The apparatus of claim **8** wherein the center-of-gravity of the target is positioned equidistant between the front bearing assembly and the rear bearing assembly.

10. The apparatus of claim **1** wherein the target material comprises one of molybdenum and an alloy of molybdenum.

11. The apparatus of claim **1** wherein the track material comprises one of tungsten and an alloy of tungsten.

12. The apparatus of claim **1** wherein the target is positioned within an x-ray tube and the x-ray tube is positioned within a system that comprises one of an x-ray system, a digital radiography system, a computed tomography system, and a mammography system.

13. The apparatus of claim **1** wherein the re-entrant target shaft comprises the target substrate axially positioned between a front bearing and a rear bearing, the re-entrant target shaft forming a radial gap between the re-entrant target shaft and a bearing hub.

14. An apparatus for generating x-rays comprising:

a target substrate having a face thereof transverse to an axis of rotation of the target substrate;

a target shaft attached to the target substrate, the target shaft having an outer surface and an inner surface;

an emissive coating applied to the face of the target substrate and to the inner surface of the target shaft;

a bearing cartridge coupled to the target shaft and configured to cause the target shaft to rotate about the axis of rotation, the bearing cartridge comprising:

a center shaft;

a stem; and

a pair of bearing assemblies rotatably coupling the center shaft to the stem; and

a receptor extending between the target shaft and the stem such that a first gap is formed between the stem and the receptor, wherein the receptor is configured to receive a transfer of heat from the inner surface of the target shaft.

15. A method of fabricating an x-ray tube target assembly comprising:

forming a substrate;

attaching a target shaft to the substrate;

positioning the substrate equidistant between a front bearing and a rear bearing; and

forming an emissive coating on the substrate and the target shaft.

16. The method of claim **15** further comprising forming a track material on the substrate.

17. The method of claim **15** wherein the emissive coating is formed by one of plasma spray, chemical vapor deposition, and physical vapor deposition.

18. The method of claim **15** wherein the emissive coating is formed on a face of the substrate transverse to an axis of rotation of the substrate.

19. The method of claim **15** wherein the emissive coating is formed on an outer surface of the target shaft and on an inner surface of the target shaft.

20. The method of claim **15** further comprising attaching the target shaft to a hub of a bearing shaft, wherein the bearing shaft passes through at least one of a front bearing assembly and a rear bearing assembly.

21. An imaging system comprising:

an x-ray detector; and

an x-ray emission source having:

a bearing cartridge comprising:

a center shaft;

a stem; and

a bearing assembly rotatably coupling the shaft to the stem;

a cathode;

an anode, the anode comprising:

a target base material;

a shaft attached to the target base material, the shaft having an inner surface and an outer surface; and

an emissive coating attached to the target base material and both the inner surface of the shaft and the outer surface of the shaft; and

a receptor positioned between the stem of the bearing cartridge and the inner surface of the shaft such that a space is formed between the receptor and the stem.

22. The method of claim **20** further comprising positioning a receptor between the target shaft and a stem of the bearing shaft such that a first gap is formed between the stem and the receptor.

23. The system of claim **21** further comprising a track material attached to the target base material.

24. The system of claim **21** further comprising a hub attached to the center shaft of the bearing cartridge and to the shaft attached to the target base material, wherein the receptor extends between the hub and the shaft attached to the target base material.

25. The system of claim **21** wherein the system comprises one of an x-ray system, a digital radiography system, a computed tomography system, and a mammography system.

26. The system of claim **21** wherein the emissive coating is attached to an outer surface of the target base material.

27. The system of claim **21** wherein the emissive coating is attached to an outer surface of the shaft.

28. The system of claim **21** wherein the emissive coating is attached to an inner surface of the shaft.

29. The system of claim **21** wherein the emissive coating is attached to an outer surface of the shaft and an inner surface of the shaft.

* * * * *