the power density of x-rays at the point of impact with a part usually corresponds with an increase in potentially undesirable effects, such as an increase in heat generation, energy consumption, weight, and component and operating costs, among others.

SUMMARY

The subject matter of the present application has been developed in response to the present state of the art, and in particular, in response to the shortcomings of traditional x-ray backscatter devices, that have not yet been fully solved by currently available techniques. Accordingly, the subject matter of the present application has been developed to provide a backscatter device, and associated apparatuses, systems, and methods, with a zone plate, that overcomes at least some of the above-discussed shortcomings of prior art techniques.

Disclosed herein is an x-ray backscatter apparatus for non-destructive inspection of a part. The apparatus includes an x-ray emitter, an inspection filter, and a zone plate. The x-ray emitter includes an x-ray shield, a vacuum tube, a cathode, and an anode. The x-ray shield has an emission aperture. The vacuum tube is within the x-ray shield. The cathode is enclosed within the vacuum tube and is selectively operable to generate an electron emission. The anode is enclosed within the vacuum tube and located relative to the cathode to receive the electron emission and convert the electron emission from the cathode to a hard x-ray emission, or referred to as a hard x-ray stream. In one embodiment, an x-ray stream is defined as a hard x-ray stream if the x-rays of the stream have an energy level greater than 5-10keV. In another embodiment, the x-ray stream is a hard x-ray stream if it has an energy level above 50keV. In a further embodiment, the x-ray stream is a hard x-ray stream if the x-rays of the stream have an energy level between approximately 60keV and approximately 80keV. In other embodiments, the hard x-ray stream includes x-rays having an energy level greater than 80keV. The anode is located relative to the emission aperture to direct at least a portion of the hard x-ray stream through the emission aperture. The inspection filter is separate from the x-ray emitter.

The zone plate is external to the x-ray shield and located relative to the emission aperture. The zone plate receives the portion of the hard x-ray stream from the emission aperture of the x-ray shield and focuses the portion of the hard x-ray stream received from the emission aperture into a focused hard x-ray stream. The zone plate is fixed relative to the x-ray emitter and is positioned between the x-ray emitter and the inspection filter to direct the focused hard x-ray emission to the inspection filter. The inspection filter is rotatable relative to the zone plate to pass a portion of the focused hard x-ray emission based on a rotational position of the inspection filter relative to the zone plate. The preceding subject matter of this paragraph characterizes example 1 of the present disclosure.

The zone plate includes a plurality of Fresnel zones. The preceding subject matter of this paragraph characterizes example 2 of the present disclosure, wherein example 2 also includes the subject matter according to example 1, above.

At least one of the plurality of Fresnel zones of the zone plate has at least one radius corresponding to a focal length of the zone plate. The preceding subject matter of this paragraph characterizes example 3 of the present disclosure, wherein example 3 also includes the subject matter according to any one of examples 1 or 2, above.

The zone plate is made, at least partially, of carbon nanotubes. The preceding subject matter of this paragraph characterizes example 4 of the present disclosure, wherein example 4 also includes the subject matter according to any one of examples 1-3, above.

The zone plate is made, at least partially, of lead. The preceding subject matter of this paragraph characterizes example 5 of the present disclosure, wherein example 5 also includes the subject matter according to any one of examples 1-4, above.

The zone plate comprises a surface plating. The preceding subject matter of this paragraph characterizes example 6 of the present disclosure, wherein example 6 also includes the subject matter according to any one of examples 1-5, above.

The surface plating is gold. The preceding subject matter of this paragraph characterizes example 7 of the present disclosure, wherein example 7 also includes the subject matter according to any one of examples 1-6, above.

The hard x-ray stream has an energy level between approximately 60keV and approximately 80keV. The preceding subject matter of this paragraph characterizes example 8 of the present disclosure, wherein example 8 also includes the subject matter according to any one of examples 1-7, above.

Also disclosed herein is an x-ray backscatter system for non-destructive inspection of a part. The system includes a base, an x-ray emitter, an inspection filter, and a zone plate. The x-ray emitter is coupled to the base. The inspection filter is movable coupled to the base and rotatably positionable to receive a hard x-ray emission from the x-ray emitter and pass at least a portion of the hard x-ray emission through a filter aperture in the inspection filter to a selectable location on the part based on a rotational position of the inspection filter relative to the x-ray emitter. The zone plate is interposed between the x-ray emitter and the inspection filter. The zone plate receives the hard x-ray emission from the x-ray emitter, modifies a beam pattern of the hard x-ray emission received from the x-ray emitter into a modified beam pattern, and pass the modified beam pattern of the hard x-ray emission to the inspection filter. The preceding subject matter of this paragraph characterizes example 9 of the present disclosure.The system further includes a detector coupled to the base and selectively operable to detect hard x-rays backscattered from the part. The preceding subject matter of this paragraph characterizes example 10 of the present disclosure, wherein example 10 also includes the subject matter according to example 9, above.

The zone plate is moveable relative to the x-ray emitter to further modify the beam pattern of the hard x-ray emission received from the x-ray emitter. The preceding subject matter of this paragraph characterizes example 11 of the present disclosure,

wherein example 11 also includes the subject matter according to any one of examples 9 or 10, above.

The x-ray emitter and the zone plate are adjustable relative to the base to modify an emission direction relative to the base. The preceding subject matter of this paragraph characterizes example 12 of the present disclosure, wherein example 12 also includes the subject matter according to any one of examples 9-11, above.

The base includes a mobility system operable to move the base relative to the part. The preceding subject matter of this paragraph characterizes example 13 of the present disclosure, wherein example 13 also includes the subject matter according to any one of examples 9-12, above.

The mobility system includes at least one of a wheel, a tread, a skid, a track, a roller, a cable, a pulley, a motor, a slide, and a beating. The preceding subject matter of this paragraph characterizes example 14 of the present disclosure, wherein example 14 also includes the subject matter according to any one of examples 9-13, above.

The system further includes a control unit to control a position of the zone plate relative to the x-ray emitter or relative to the inspection filter. The preceding subject matter of this paragraph characterizes example 15 of the present disclosure, wherein example 15 also includes the subject matter according to any one of examples 9-14, above.

The inspection filter includes a rotatable ring with a plurality of apertures. At least one of the plurality of apertures is different from another of the plurality of apertures. The preceding subject matter of this paragraph characterizes example 16 of the present disclosure, wherein example 16 also includes the subject matter according to any one of examples 9-15, above.

Also disclosed herein is a method of non-destructive inspection of a part by x-ray backscatter. The method includes receiving a hard x-ray emission from an x-ray emitter at a zone plate. The method also includes focusing the hard x-ray emission into a focused

hard x-ray stream with the zone plate. The method also includes directing at least a portion of the focused hard x-ray stream with the zone plate through a first filter aperture of an inspection filter and onto a first portion of the part corresponding to a rotational position of the inspection filter relative to the zone plate, wherein the zone plate is positioned between the x-ray emitter and the inspection filter. The preceding subject matter of this paragraph characterizes example 17 of the present disclosure.

The method further includes adjust an orientation of the inspection filter relative to the zone plate such that the focused hard x-ray stream is directed through a second filter aperture of the inspection filter and onto a second portion of the part. The second filter aperture is different from the first filter aperture. The preceding subject matter of this paragraph characterizes example 18 of the present disclosure, wherein example 18 also includes the subject matter according to example 17, above.

improved image resolution, an improved image sharpness, a reduced number of required transverse scans, a dynamic and instantaneous field of view, a reduced image distortion, a reduced pin-cushion effect at imaging corners, a reduced power supply requirement, a reduced cooling requirement, a reduced system weight, a reduced system size, an improved portability, an improved viability for a broader range of testing situations, and an improved component life compared with the x-ray backscatter apparatus 10.

As used herein, the focused x-ray emission 104 may include any x-ray emission or stream in which at least a portion of the x-rays of the focused x-ray emission 104 are modified by the zone plate 102 to be less divergent than the x-rays of the incident x-ray emission 14 from the x-ray emitter 12. The focused x-ray emission 104 may also include any x-ray stream in which a portion of the x-rays of the focused x-ray emission 104 are modified to a convergent mode from a divergent mode by the zone plate 102. The zone plate 102 may also modify the received x-rays from a divergent mode to a collimated mode. In some examples, the zone plate 102 may receive the incident x-ray emission 14 in a mode that is at least partially convergent and further focus the x-rays to greater convergence. Alternatively, the zone plate 102 may receive the incident x-ray emission 14 in a divergent mode and focus the incident x-ray emission 14 into a less divergent state.

In some examples, the zone plate 102 may provide between approximately 20% and approximately 40% focus of the received x-rays. More specifically, the zone plate 102 may provide approximately 30% focus. Other embodiments of the zone plate 102 may focus more or less than the examples given above. In some embodiments, the zone plate 102 may focus the incident x-ray emission 14 sufficient to pass between approximately 60% and approximately 70% of the incident x-ray emission 14 through the filter aperture 18 as the filtered x-ray emission 20.

In some implementations, the zone plate 102 may be made wholly or partially of lead. In some embodiments, the density of the lead allows for a greater effect of the zone

What is claimed is:

1. An x-ray backscatter apparatus for non-destructive inspection of a part, the apparatus comprising:

an x-ray emitter, comprising:

an x-ray shield, comprising an emission aperture;

a vacuum tube within the x-ray shield;

a cathode enclosed within the vacuum tube and selectively operable to generate an electron emission; and

an anode, enclosed within the vacuum tube and located relative to the cathode, to receive the electron emission and convert the electron emission from the cathode to a hard x-ray emission, and located relative to the emission aperture to direct at least a portion of the hard x-ray emission through the emission aperture;

an inspection filter, separate from the x-ray emitter; and

a zone plate, external to the x-ray shield and located relative to the emission aperture, to receive the portion of the hard x-ray emission from the emission aperture of the x-ray shield and to focus the portion of the hard x-ray emission received from the emission aperture into a focused hard x-ray emission, wherein the zone plate is fixed relative to the x-ray emitter and is positioned between the x-ray emitter and the inspection filter to direct the focused hard x-ray emission to the inspection filter, the inspection filter being rotatable relative to the zone plate to pass a portion of the focused hard x-ray emission based on a rotational position of the inspection filter relative to the zone plate.

2. The apparatus according to claim 1, wherein the zone plate comprises a plurality of Fresnel zones.

3. The apparatus according to claim 2, wherein at least one of the plurality of Fresnel zones of the zone plate has at least one radius corresponding to a focal length of the zone plate.

4. The apparatus according to any of claims 1 to 3, wherein the zone plate is made, at least partially, of carbon nanotubes.

5. The apparatus according to any of claims 1 to 4, wherein the zone plate is made, at least partially, of lead.

6. The apparatus according to any of claims 1 to 5, wherein the zone plate comprises a surface treatment.

7. The apparatus according to claim 6, wherein the surface treatment is a gold plating.

8. The apparatus according to any of claims 1 to 6, wherein the hard x-ray emission has an energy level between 60keV and 80keV.

9. An x-ray backscatter system for non-destructive inspection of a part, the system comprising:

a base;

an x-ray emitter coupled to the base;

an inspection filter movably coupled to the base and rotatably positionable to receive a hard x-ray emission from the x-ray emitter and pass at least a portion of the hard x-ray emission through a filter aperture in the inspection filter to a

selectable location on the part based on a rotational position of the inspection filter relative to the x-ray emitter; and

a zone plate, interposed between the x-ray emitter and the inspection filter, to receive the hard x-ray emission from the x-ray emitter, modify a beam pattern of the hard x-ray emission received from the x-ray emitter into a modified beam pattern, and pass the modified beam pattern of the hard x-ray emission to the inspection filter.

10. The system according to claim 9, further comprising a detector coupled to the base and selectively operable to detect hard x-rays backscattered from the part.

11. The system according to any of claim 9 to 10, wherein the zone plate is moveable relative to the x-ray emitter to further modify the beam pattern of the hard x-ray emission received from the x-ray emitter.

12. The system according to any of claim 9 to 11, wherein the x-ray emitter and the zone plate are adjustable relative to the base to modify an emission direction relative to the base.

13. The system according to any of claims 9 to 12, wherein the base comprises a mobility system operable to move the base relative to the part.

14. The system according to claim 13, wherein the mobility system comprises at least one of a group, the group consisting of a wheel, a tread, a skid, a track, a roller, a cable, a pulley, a magnet, a motor, a slide, and a bearing.

15. The system according to any of claims 9 to 14, further comprising a control unit to control a position of the zone plate relative to the x-ray emitter or relative to the inspection filter.

16. The system according to any of claim 9 to 15, wherein the inspection filter comprises a rotatable ring with a plurality of apertures, wherein at least one of the plurality of apertures is different from another of the plurality of apertures.

17. A method of non-destructive inspection of a part by x-ray backscatter, the method comprising:

receiving a hard x-ray emission from an x-ray emitter at a zone plate;

focusing the hard x-ray emission into a focused hard x-ray emission with the zone plate; and

directing at least a portion of the focused hard x-ray emission with the zone plate through a first filter aperture of an inspection filter and onto a first portion of the part corresponding to a rotational position of the inspection filter relative to the zone plate, wherein the zone plate is positioned between the x-ray emitter and the inspection filter.

18. The method according to claim 17, further comprising adjusting an orientation of the inspection filter relative to the zone plate such that the focused hard x-ray emission is directed through a second filter aperture of the inspection filter and onto a second portion of the part, wherein the second filter aperture is different from the first filter aperture.

19. The method according to any of claims 17 to 18, wherein focusing the hard x-ray emission comprises focusing the hard x-ray emission by between 30% and 40%.

20. The method according to any of claims 17 to 19, wherein the portion of the focused hard x-ray emission directed through the first filter aperture constitutes between 60% and 70% of the hard x-ray emission from the x-ray emitter.