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(54) **CONTROL MEANS FOR HEAT LOAD IN X-RAY SCANNING APPARATUS**

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(76) Inventors: **Edward James Morton**, Guildford (GB); **Russell David Luggar**, Dorking (GB); **Paul De Antonis**, Horsham (GB)

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Correspondence Address:  
**PATENTMETRIX**  
14252 CULVER DR. BOX 914  
IRVINE, CA 92604 (US)

(57) **ABSTRACT**

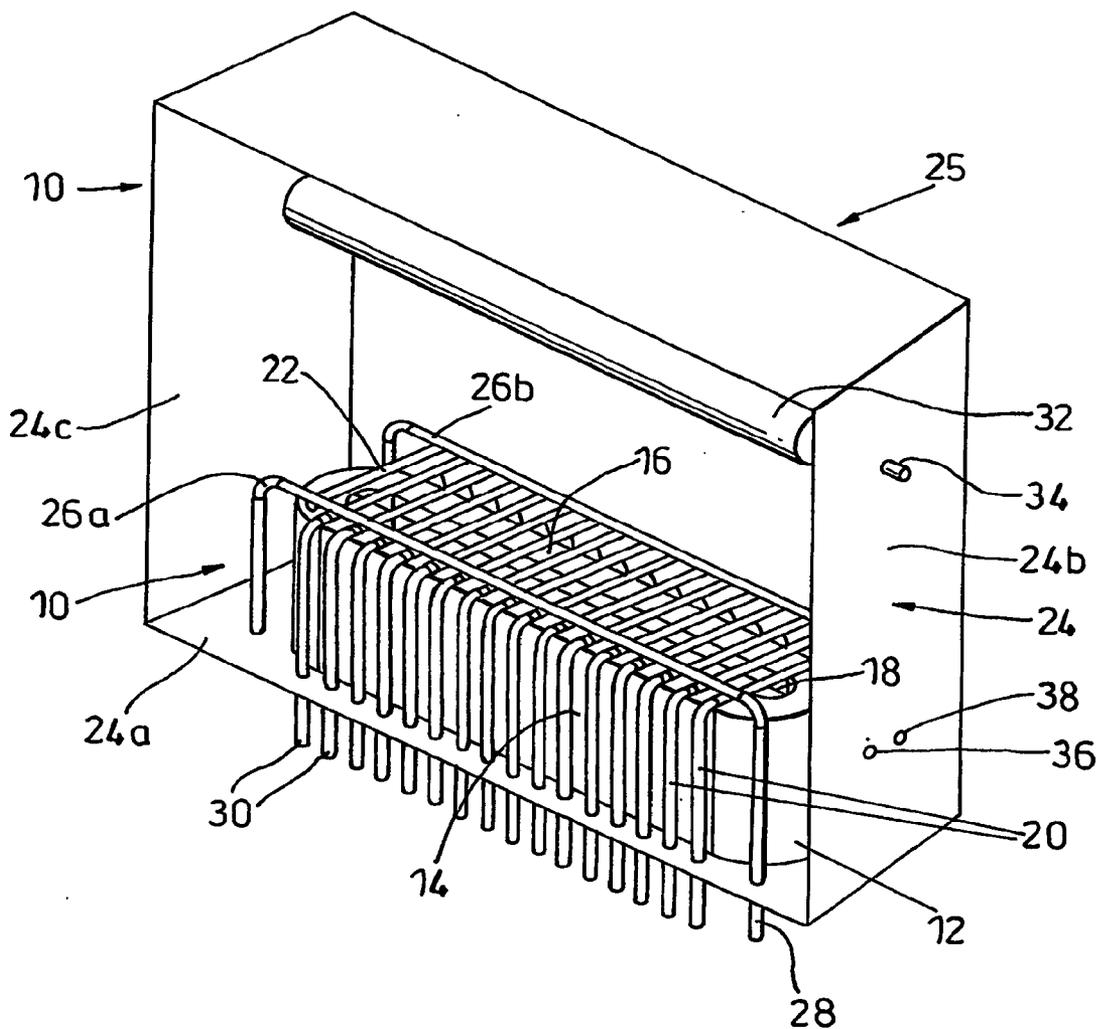
The present invention is an X-ray scanning system having at least one multi-focus X-ray tubes spaced around an axis and arranged to emit X-rays through an object on the axis. The emitted X-rays are detected by sensors. Each multi-focus X-ray tube can emit X-rays from a plurality of source positions. In an exemplary scanning cycle, each of the source positions in each X-ray tube is used at least once and ordered to minimize the thermal load on the tubes.

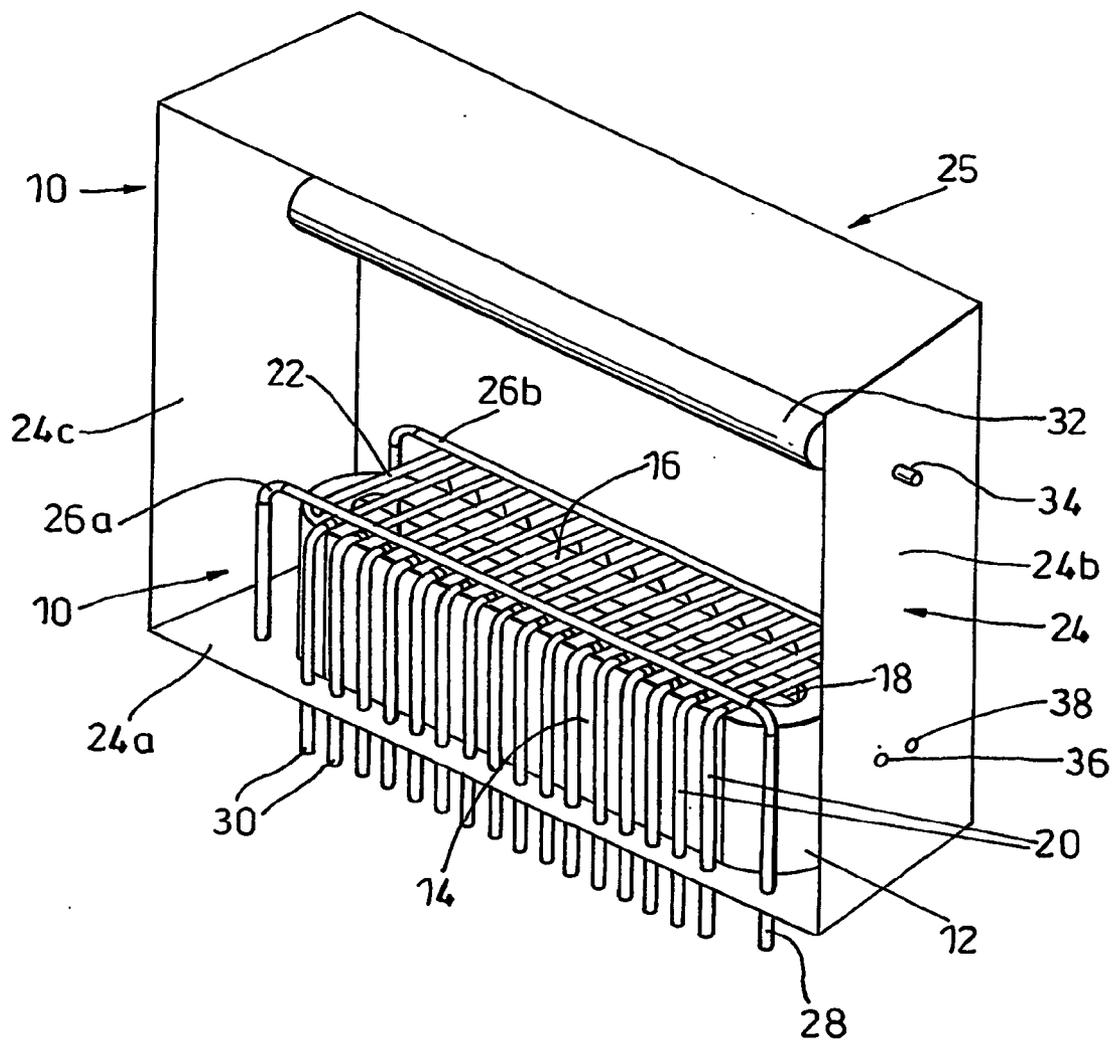
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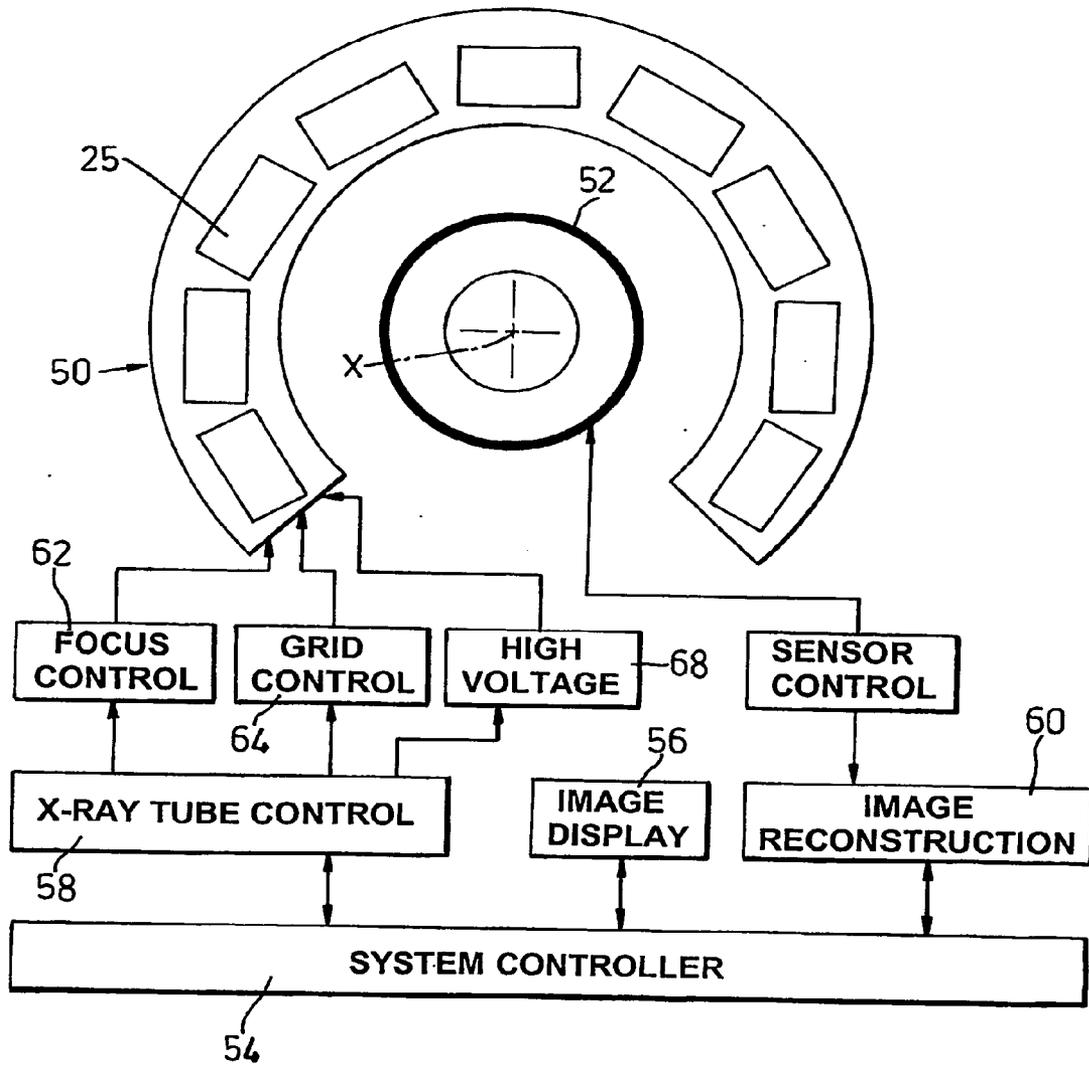
**Related U.S. Application Data**

(63) Continuation of application No. 10/554,656, filed on Mar. 29, 2007, now Pat. No. 7,564,939, filed as application No. PCT/GB04/01729 on Apr. 23, 2004.

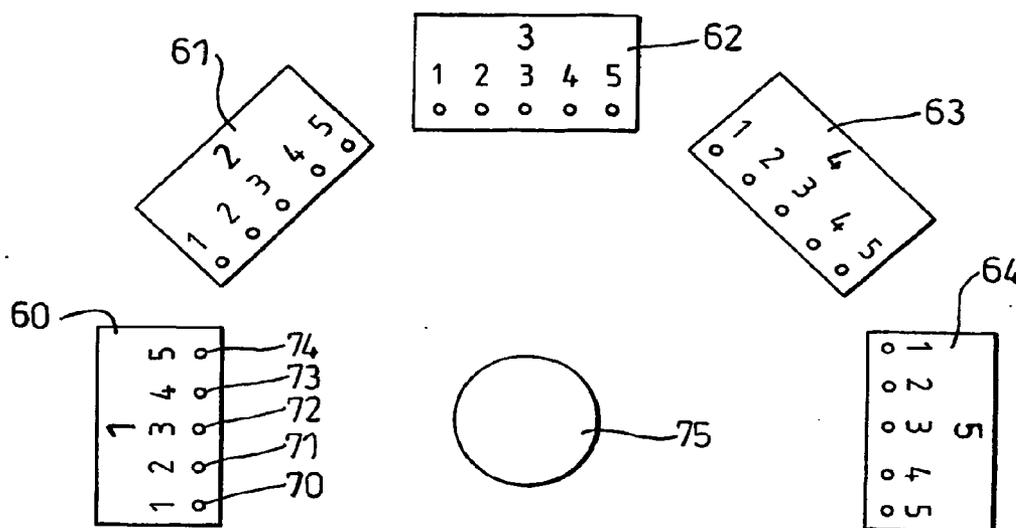




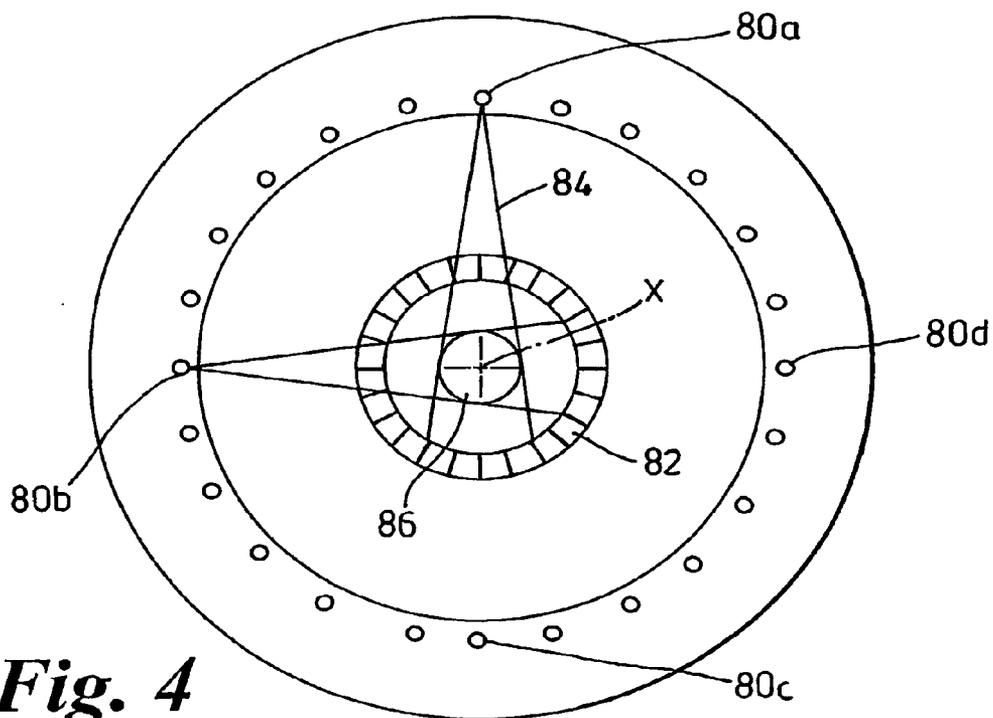
**Fig. 1**



*Fig. 2*



**Fig. 3**



**Fig. 4**

## CONTROL MEANS FOR HEAT LOAD IN X-RAY SCANNING APPARATUS

### CROSS-REFERENCE TO PRIOR APPLICATIONS

[0001] This application is a continuation of U.S. patent application Ser. No. 10/554,656 filed on Oct. 25, 2005 which is a 371 national stage application of PCT/GB04/01729 which was filed on and relies on for priority UK Patent Application No. 0309387, filed on Apr. 25, 2003.

[0002] The present invention relates to X-ray scanning in which X-rays are directed through an object from a number of positions around the object and the X-rays transmitted through the object are detected and used to build up an image of the object. This type of scanning is referred to as computed tomography (CT) scanning.

[0003] One method of CT scanning involves rotating an X-ray source around the object so that it directs X-rays through the object in different directions. Another method, for example as disclosed in U.S. Pat. No. 4,274,005, involves positioning a number of X-ray sources around the object and then operating the sources in turn so that the active source position scans round the object.

[0004] As the use of X-ray scanners, for example in security applications, increases, there is an increasing demand for scanners which operate quickly and which have a long lifetime.

[0005] Accordingly the present invention provides an X-ray imaging apparatus comprising X-ray production means arranged to produce X-rays from a plurality of source positions spaced around an object location and spaced from each other by a source spacing, a plurality of X-ray sensors arranged to be spaced around the object position so as to detect X-rays emitted from the source positions and passing through the object position, and control means arranged to control the order in which the source positions are active such that the average smallest displacement between an active source position in one emission period and an active source position in the subsequent period is greater than the source spacing.

[0006] This increase in average spacing between successively active source positions helps to spread the thermal load in the X-ray source.

[0007] Preferably said average smallest displacement is at least twice the source spacing. This can most easily be achieved by ensuring that the control means is arranged such that no active source position in any one emission period is adjacent a source position active in the next emission period.

[0008] The control means may be arranged so that in each emission period only one source position is active.

[0009] Alternatively the control means may be arranged such that in each emission period a plurality of source positions are active simultaneously. This can reduce the scanning time and increase the scanning rate.

[0010] Where the source positions are each arranged to produce X-rays which will be detected by a corresponding group of sensors, the control means is preferably arranged such that in each emission period, there is no overlap between the groups of sensors for said plurality of source positions. This ensures that the detected X-rays from each of the simultaneously active sources can be distinguished.

[0011] Preferably in each emission period at least half of the sensors are arranged to receive X-rays from the active source positions. More preferably in each emission period

substantially all of the sensors are arranged to receive X-rays from the active source positions.

[0012] Preferably the apparatus comprises a plurality of X-ray tubes each providing a plurality of said source positions.

[0013] In this case the control means is preferably arranged such that in each emission period the active source position is in a different tube from the active source position in the previous emission period.

[0014] Conveniently only one source position is active in each emission period and the active source positions are provided in each of the tubes in turn.

[0015] Preferably, within each tube, the order in which the source positions are active is arranged such that in each emission period the active source position is non-adjacent to the source position active in the previous emission period.

[0016] Preferred embodiments of the present invention will now be described by way of example only with reference to the accompanying drawings in which:

[0017] FIG. 1 shows an X-ray emitter suitable for use with the invention,

[0018] FIG. 2 is a diagram of an X-ray imaging system according to the invention including a number of emitter units as shown in FIG. 1;

[0019] FIG. 3 is a diagram of the layout of an X-ray imaging system according to a second embodiment of the invention; and

[0020] FIG. 4 is a diagram of the layout of an X-ray imaging system according to a third embodiment of the invention.

[0021] Referring to FIG. 1, a multi-focus X-ray tube 10 comprises a ceramic former 12 and an emitter element 18 extending along between the sides 14, 16 of the former. A number of grid elements in the form of grid wires 20 are supported on the former 12 and extend over the gap between its two sides 14, 16 perpendicular to the emitter element 18, but in a plane which is parallel to it. A number of focusing elements in the form of focusing wires 22 are supported in another plane on the opposite side of the grid wires to the emitter element. The focusing wires 22 are parallel to the grid wires 20 and spaced apart from each other with the same spacing as the grid wires, each focusing wire 22 being aligned with a respective one of the grid wires 20.

[0022] The source 10 is enclosed in a housing 24 of an emitter unit 25 with the former 12 being supported on the base 24a of the housing. The focusing wires 22 are supported on two support rails 26a, 26b which extend parallel to the emitter element 18, and are spaced from the former 12, the support rails being mounted on the base 24a of the housing. The support rails 26a, 26b are electrically conducting so that all of the focusing wires 22 are electrically connected together. One of the support rails 26a is connected to a connector 28 which projects through the base 24a of the housing to provide an electrical connection for the focusing wires 22. Each of the grid wires 20 extends down one side 16 of the former and is connected to a respective electrical connector 30 which provide separate electrical connections for each of the grid wires 20.

[0023] An anode 32 is supported between the side walls 24b, 24c of the housing. The anode extends parallel to the emitter element 18. The grid and focusing wires 20, 22 therefore extend between the emitter element 18 and the anode 32. An electrical connector 34 to the anode extends through the side wall 24b of the housing.

[0024] The emitter element 18 is supported in the ends of the former and is heated by means of an electric current supplied to it via further connectors 36, 38 in the housing.

[0025] In order to produce a beam of electrons from one position, a pair of adjacent grid wires 20 can be connected to an extracting potential which is positive with respect to the element 18 while the remaining grid wires are connected to a blocking potential which is negative with respect to the element 18. By selecting which pair of wires 20 is used to extract electrons, the position of the beam of electrons can be chosen. As the X-rays will be emitted from the anode 32 at a point where the electrons strike it, the position of the X-ray source can also be chosen by choosing the extracting pair of grid wires. The focusing elements 22 are all kept at a positive potential with respect to the grid wires 20 so that electrons extracted between any pair of the grid wires will also pass between, and be focussed by, a corresponding pair of focusing elements 22.

[0026] Referring to FIG. 2, an X-ray scanner 50 is set up in a conventional geometry and comprises an array of emitter units 25 arranged in an arc around a central scanner axis X, and orientated so as to emit X-rays towards the scanner axis X. A ring of sensors 52 is placed inside the emitters, directed inwards towards the scanner axis. The sensors 52 and emitter units 25 are offset from each other along the axis X so that X-rays emitted from the emitter units pass by the sensors nearest to them, through the object, and are detected by a number of sensors furthest from them. The number of sensors 52 that will detect X-rays from each source depends on the width of the fan of X-rays that is emitted from each source position in the tubes 25. The scanner is controlled by a control system which operates a number of functions represented by functional blocks in FIG. 5. A system control block 54 controls, and receives data from, an image display unit 56, an X-ray tube control block 58 and an image reconstruction block 60. The X-ray tube control block 58 controls a focus control block 62 which controls the potentials of the focus wires 22 in each of the emitter units 25, a grid control block 64 which controls the potential of the individual grid wires 20 in each emitter unit 25, and a high voltage supply 68 which provides the power to the anode 32 of each of the emitter blocks and the power to the emitter elements 18. The image reconstruction block 60 controls and receives data from a sensor control block 70 which in turn controls and receives data from the sensors 52.

[0027] In operation, an object to be scanned is passed along the axis X, and X-ray beams are directed through the object from the X-ray tubes 25. In each scanning cycle each source position in each tube 25 is used once, the scanning cycle being repeated as the object moves along the axis X. Each source position produces a fan of X-rays which after passing through the object are detected by a number of the sensors 52. However, the order in which the tubes and the positions within the tubes are used is controlled as will now be described.

[0028] The order of X-ray emission from the source positions in the tubes 25 is chosen so as to minimize the thermal load on the X-ray tube. This is achieved by ordering the emissions so that each source position is non-adjacent to, and therefore spaced from, the previous one and the subsequent one. This ordering applies both to the source positions within each tube 25, and also to the tubes themselves. Therefore each source position is in a different tube to the previous one and the next one. In fact the best distribution of thermal load is achieved if the source position cycles through all of the tubes,

using one position from each tube, and then cycles through the tubes again using a different source position within each tube. The cycling is then repeated until all of the source positions in all of the tubes have been used once. This completes one scanning cycle which can then be repeated.

[0029] Within each tube the source positions are taken in an order which spreads the thermal load within the tube. This is achieved by ordering the source positions so that the distance between each source position and the next one in that tube, and the previous one in that tube, are both maximized. Firstly, therefore, if the number of source positions per tube allows it, each source position in the tube should be non-adjacent to the next and previous ones in that tube. Then, depending on the number of source positions, the ordering is chosen so as to distribute the thermal load as much as possible.

[0030] For example, if as in a second embodiment of the invention shown in FIG. 3, there are five X-ray tubes 60, 61, 62, 63, 64 numbered in the order in which they are positioned 1, 2, 3, 4 and 5, and each one can produce X-rays from 5 source positions 70, 71, 72, 73, also numbered in order along the tube 60 as 1, 2, 3, 4 and 5, then best ordering for the source positions within each tube is 1, 3, 5, 2, 4. The same sequence is also used for ordering the tubes so as to maximize the angular separation between successive emissions. This produces an emission ordering as follows, where the source positions are numbered in order round the object 75 starting at the left hand end of the tube 60 at the left end of the row and counting to the right hand end of the tube 64 at the right end of the row.

Tube	Source Position in Tube	Overall Source position
1	1	1
3	1	11
5	1	21
2	1	6
4	1	16
1	3	3
3	3	13
5	3	23
2	3	8
4	3	18
1	5	5
3	5	15
5	5	25
2	5	10
4	5	20
1	2	2
3	2	12
5	2	22
2	2	7
4	2	17
1	4	4
3	4	14
5	4	24
2	4	9
4	4	19

[0031] The same ordering could also be used with, for example, 25 source positions in a single tube which is shaped around the object 75.

[0032] It will be appreciated that, for X-ray tubes with less than 5 source positions it is not possible to avoid using adjacent positions in subsequent emissions. However, for tubes with 5 or more source positions, this can be avoided.

[0033] Referring to FIG. 4, in a third embodiment of the invention a plurality of X-ray sources 80 are spaced around an

axis X, with a plurality of sensors 82 axially offset from the sources 80 as in the first embodiment. When one of the sources 80a emits an X-ray beam 84 this diverges, passes through the object 86 and reaches a number of the sensors 82. The number of sensors 82 which will detect X-rays from each of the sources depends on the width of the beam of X-rays, which is a known quantity for any give system, and can be quantified in terms of a half-angle. This is the angle between the centre of the beam and the edge of the beam.

[0034] When the sensors 82 which are needed to detect X-rays from each of the source positions 80 are known, source positions can be selected which can emit simultaneously, provided that they do not require any common detectors. For example if there are 24 source positions 80 and 24 sensors 82 and each source position requires 5 sensors, then four of the sensors 80a, 80b, 80c, 80d, spaced around the object at 90° intervals can be used simultaneously.

[0035] In practice the number of source positions and sensors is likely to be higher than this. To satisfy the Nyquist sampling theorem, it is necessary to match the number of source positions  $N_\phi$  to the number of sensors  $N_s$  of width d that are required to cover the linear dimension of the object  $N_s d$ . This leads to the result

$$N_\phi = \pi N_s / 2.$$

[0036] For example an image where  $N_s=64$  will require  $N_\phi=100$  sampling points to satisfy the Nyquist sampling criterion.

[0037] It will be appreciated that the ordering of the emission positions can be varied in a large number of ways for any given number of emission positions, and that the optimum ordering will also vary depending on the number of emission positions and the number of X-ray tubes.

1-13. (canceled)

14. An X-ray imaging apparatus comprising:

at least one X-ray tube comprising a first X-ray source and a second X-ray source, wherein each of said first and second X-ray sources produce X-rays and wherein the first X-ray source and the second X-ray source are adjacent each other and spaced from each other by a first spacing;

at least one X-ray sensor to detect X-rays emitted from the at least one X-ray tube; and

a controller for activating said first X-ray source when said second X-ray source is inactive and for activating said second X-ray source when said first X-ray source is inactive.

15. The X-ray imaging apparatus of claim 1 wherein said X-ray tube comprises a third X-ray source and wherein said third X-ray source is spaced from said first X-ray source by a second spacing.

16. The X-ray imaging apparatus of claim 15 wherein said second spacing is greater than said first spacing.

17. The X-ray imaging apparatus of claim 16 wherein said controller first activates said first X-ray source while keeping inactive the second X-ray source and the third X-ray source.

18. The X-ray imaging apparatus of claim 17 wherein said controller activates said third X-ray source, while keeping

inactive the first and second X-ray sources, immediately after inactivating said first X-ray source.

19. The X-ray imaging apparatus of claim 14 further comprising a second X-ray tube comprising a first X-ray source and a second X-ray source, wherein each of said first and second X-ray sources produce X-rays and wherein the first X-ray source and the second X-ray source are adjacent each other and spaced from each other by a spacing;

20. The X-ray imaging apparatus of claim 19 wherein the controller immediately activates the first X-ray source in the second X-ray tube after inactivating the first X-ray source in the at least one X-ray tube and before activating the second X-ray source in the at least one X-ray tube.

21. An X-ray imaging apparatus comprising

a first X-ray tube comprising a first plurality of source positions, including a first source position and a second source position, wherein the first source position and the second source position are adjacent each other and spaced from each other by a first source spacing;

a second X-ray tube comprising a second plurality of source positions, including a third source position and a fourth source position, wherein the third source position and the fourth source position are adjacent each other and spaced from each other by a second source spacing;

at least one X-ray sensor to detect X-rays emitted from the first or second X-ray tubes; and

a controller for controlling an order in which the first, second, third, and fourth source positions are active such that a displacement between an active source position in one emission period and an active source position in a period immediately after the emission period is greater than an amount related to said first and second source spacing.

22. The imaging apparatus of claim 21 wherein said displacement is at least twice the first source spacing.

23. The imaging apparatus of claim 21 wherein said displacement is at least twice the second source spacing.

24. The imaging apparatus of claim 21 wherein an active source position in the emission period is not adjacent a source position that is active in the period immediately after the emission period.

25. The imaging apparatus of claim 21 wherein only one of the first, second, third or fourth source position in an X-ray tube is active in each emission period.

26. The imaging apparatus of claim 21 wherein one source in said first X-ray tube and one source in said second X-ray tube are active simultaneously in each emission period.

27. The imaging apparatus of claim 21 wherein, in each emission period, more than one source position is active and each of said active source positions is located in a different X-ray tube.

28. The imaging apparatus of claim 21 wherein only one source position in each X-ray tube is active in each emission period and each X-ray tube is active in a sequential order.

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