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(54) **EMISSION CURRENT CONTROL FOR HV-GENERATORS**

(57) The present invention relates to emission current control for kVp-switching high-voltage generators. An apparatus (20) is provided for determining a reference emission current of an X-ray source for a peak-kilovoltage, kVp, switching spectral scan. The apparatus comprises an input (22), a processor (24), and an output (26). The input is configured to receive a measurement of a tube voltage of the X-ray source. The tube voltage has a peak voltage switching between a first voltage and a second voltage, the first voltage being higher than the second voltage. The processor is configured to analyze the received measurement of the tube voltage to determine a time constant of a falling voltage transition slope during a kVp-switching cycle, and to determine the reference emission current of the X-ray source based on the determined time constant of the falling voltage transition slope. The output is configured to provide the determined reference emission current of the X-ray source, which is usable for controlling an emission current of the X-ray source.

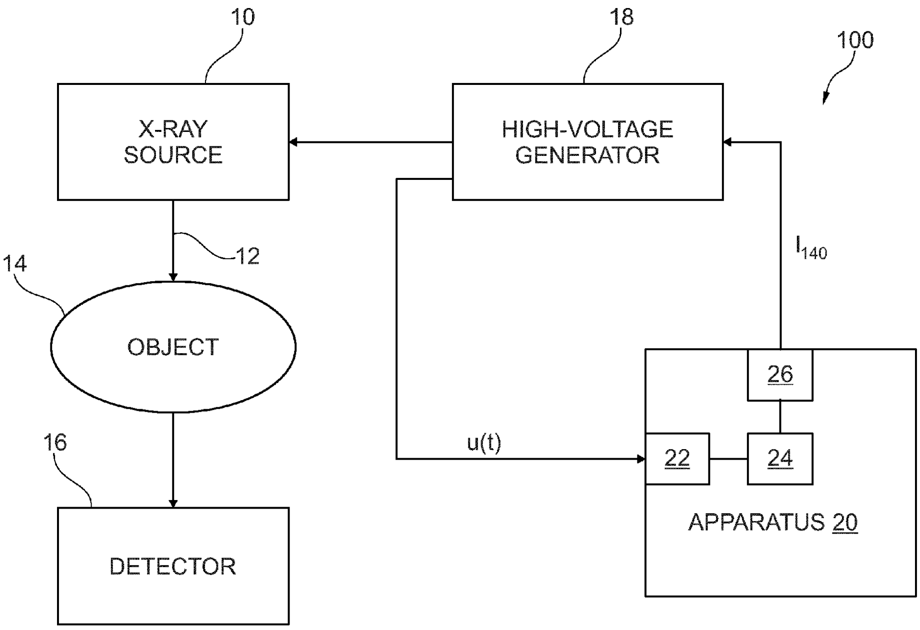

Fig. 1

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Description

FIELD OF THE INVENTION

[0001] The present invention relates to an apparatus and a method for determining a reference emission current of an X-ray source for a peak-kilovoltage (kVp) switching spectral scan, to a system that comprises the apparatus, to a method for controlling an emission current of an X-ray source, to a computer program product, and to a computer-readable medium.

BACKGROUND OF THE INVENTION

[0002] The operation of an X-ray tube is governed by the high voltage applied between an anode and a cathode of this tube, as well as by the electric heating current with which a filament of the cathode is taken to high temperature. The high voltage is typically supplied by a high-voltage generator. According to the principle of X-ray emission, the electrons are extracted from the cathode and projected at high speed into the anode. The anode target, which is struck by these electrons, then emits X-rays, which can be used to produce X-ray exposures, or more generally X-ray images. The high voltage applied is directly related to the energy of the X-photons emitted.

[0003] The high-voltage generator also controls the emission current of the X-ray tube. This means that mainly the temperature of the cathode defines the emission current. Currently the high-voltage generator measures the emission current and adapts the filament heating to reach the emission current target.

[0004] This simple control method may be challenged for kVp-switching. Rapid kVp-switching (kVp-S) is a spectral imaging technique that switches the voltage (kVp) rapidly between successive measurement intervals to obtain spectral information. A theoretically optimal kVp-switching generator should switch infinitely fast and should have small waveform ripple. The fast change of the emission current makes the measurement and the entire control difficult.

SUMMARY OF THE INVENTION

[0005] There is a need to improve the emission current control for an X-ray tube.

[0006] The invention is defined by the independent claims, wherein further embodiments are defined by the dependent claims.

[0007] According to a first aspect of the present invention, there is provided an apparatus for determining a reference emission current of an X-ray source for a kVp-switching spectral scan. The apparatus comprises an input, a processor, and an output. The input is configured to receive a measurement of a tube voltage of the X-ray source. The tube voltage has a peak voltage switching between a first voltage and a second voltage. The first voltage is higher than the second voltage. The processor is configured to analyze the received measurement of the tube voltage to determine a time constant of a falling voltage transition slope during a kVp-switching cycle, and to determine the reference emission current of the X-ray source based on the determined time constant of the falling voltage transition slope. The output is configured to provide the determined reference emission current of the X-ray source, which is usable for controlling an emission current of the X-ray source.

[0008] The apparatus as disclosed herein measures the time constant of the falling voltage transition to estimate a reference emission current, which is usable for controlling the emission current for fast kVp-switching. The method as disclosed herein may allow to control the emission current for fast kVp-switching that does not suffer or suffer less from variation of the emission current during the fast-switching cycles.

[0009] This will be explained in detail hereinafter and in particular with respect to the exemplary apparatus shown in FIG. 1 and with respect to the exemplary waveform of the tube voltage shown in FIGS. 2 and 3.

[0010] According to an embodiment of the present invention, the reference emission current is an emission current at a reference tube voltage.

[0011] The rapid change of the emission current within the switching cycles may require a new definition of a reference value. One can use the mean current over the cycle. However, for spectral imaging it may be better to define the current for a reference tube voltage e.g., 140 kVp. In the following, we refer to this definition and call the reference current I140 by way of example. However, it will be appreciated that the reference current may be defined for a reference tube voltage 80 kVp, 100 kVp, or any other tube voltage.

[0012] According to an embodiment of the present invention, a voltage range is defined between a third voltage and a fourth voltage that is lower than the third voltage, the third voltage being equal to or lower than the first voltage and the fourth voltage being equal to or greater than the second voltage. The processor is configured to determine the reference emission current of the X-ray source based on a time constant of a falling voltage transition from the third voltage to the fourth voltage.

[0013] This will be explained in detail hereinafter and in particular with respect to the example shown in FIG. 3.

[0014] According to a second aspect of the present invention, there is provided a system. The system comprises an X-ray source, a voltage generator configured to supply a voltage for operating the X-ray source, and an apparatus according to the first aspect and any associated example. The X-ray source is configured to generate X-rays. The apparatus is configured to determine a reference emission current of the X-ray source. The voltage generator is configured to control a filament heating of the X-ray source to keep the reference emission current stable over time.

[0015] This will be explained in detail hereinafter and in particular with respect to the exemplary X-ray system shown in FIG. 1.

[0016] According to a third aspect of the present invention, there is provided a method for determining a reference emission current of an X-ray source for a kVp-switching spectral scan. The method comprises:

- receiving a measurement of a tube voltage of the X-ray source, wherein the tube voltage has a peak voltage switching between a first voltage and a second voltage, the first voltage being higher than the second voltage;
- analyzing the received measurement of the tube voltage to determine a time constant of a falling voltage transition slope during a kVp-switching cycle;
- determining the reference emission current of the X-ray source based on the determined time constant of the falling voltage transition slope; and
- providing the determined reference emission current of the X-ray source.

The method will be explained in detail hereinafter and in particular with respect to the examples shown in FIG. 5.

[0017] According to an embodiment of the present invention, the reference emission current is an emission current at a reference tube voltage.

[0018] According to an embodiment of the present invention, a voltage range is defined between a third voltage and a fourth voltage lower than the third voltage, the third voltage being equal to or lower than the first voltage and the fourth voltage being equal to or greater than the second voltage. The reference emission current of the X-ray source is determined based on a time constant of a voltage transition from the third voltage to the fourth voltage.

[0019] This will be explained hereinafter and in particular with respect to the example shown in FIG. 4.

[0020] According to a fourth aspect of the present invention, there is provided a method for controlling an emission current of an X-ray source. The method comprises:

- receiving, by a voltage generator, a reference emission current generated according to the method of the third aspect and any associated example; and
- controlling, by the voltage generator, a filament heating of the X-ray source to keep the reference emission current stable over time.

[0021] This will be explained hereinafter and in particular with respect to the example shown in FIG. 5.

[0022] According to a further aspect of the present invention, there is provided a computer program product comprising instructions which, when executed by a processor, cause the processor to carry out the steps of the method of the third aspect and any associated example or the method of the fourth aspect and any associated example.

[0023] According to another aspect of the present invention, there is provided a computer-readable medium having stored thereon the computer program product.

[0024] It should be appreciated that all combinations of the foregoing concepts and additional concepts discussed in greater detail below (provided such concepts are not mutually inconsistent) are contemplated as being part of the inventive subject matter disclosed herein. In particular, all combinations of claimed subject matter appearing at the end of this disclosure are contemplated as being part of the inventive subject matter disclosed herein.

[0025] These and other aspects of the invention will be apparent from and elucidated with reference to the embodiment(s) described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] In the drawings, like reference characters generally refer to the same parts throughout the different views. Also, the drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention.

FIG. 1 schematically shows an exemplary X-ray system.
FIG. 2 shows an exemplary waveform of the tube voltage.
FIG. 3 shows a zoom into one of the smooth falling transition slopes shown in FIG. 2.
FIG. 4 shows a flowchart describing an exemplary method for determining a reference emission current of an X-ray source for a kVp-switching spectral scan.
FIG. 5 shows a flowchart describing a method for controlling an emission current of an X-ray source.

DETAILED DESCRIPTION OF EMBODIMENTS

[0027] FIG. 1 schematically shows an exemplary X-ray system 100 according to some embodiments of the present disclosure. Examples of the X-ray system may include, but are not limited to, a C-arm system, a computed tomography (CT) system, a digital X-ray radiography (DXR) system, and an image-guided therapy (IGT) system. The following discussion of the X-ray system 100 is merely an example of such implementation and is not intended to be limiting in terms of modality.

[0028] As shown in FIG. 1, the X-ray system 100 comprises an X-ray source 10 configured to project a beam of X-rays 12 through an object 14. Examples of the object 14 may include, but are not limited to, a human subject, pieces of baggage, or other objects desired to be scanned. The X-ray source 10 may be an X-ray tube producing X-rays having a spectrum of energies that range e.g., from 30 keV to 200 keV. The X-rays 14, after being attenuated by the object 14, impinges upon a radiation detector 16. The radiation detector 16 produces an electrical signal that represents the intensity of an impinging X-ray beam 12. The radiation detector 16 may be e.g., a scintillation-based detector or a direct-conversion type detector.

[0029] Typically, the X-ray source 10 is an X-ray tube connected to a high-voltage generator, such as the high-voltage generator 18 illustrated in FIG. 1. The high-voltage generator 18 supplies the high-voltage for operating the X-ray tube. In some examples, the X-ray tube may include one or more filaments positioned within a cathode that emit electrons towards an anode when the high voltage is applied thereto, when a current is driven through the one or more filaments.

[0030] As described above, the high-voltage generator 18 typically controls the emission current of the X-ray tube. Most X-segments have heat limited emission. This means that mainly the temperature of the cathode defines the emission current. In the prior art, the high-voltage generator measures the emission current and adapts the heating to reach the emission current target. The temperature change may be a relatively slow process, e.g., hundreds of milliseconds because heating and cooling are slow processes.

[0031] This simple emission control method may be challenged for kVp-switching. If the tube voltage (kVp) is rapidly switched, fast electrical field effects impact the emission current. For example, if the tube voltage is changed from 80 kVp to 140 kVp, the emission current may change by 20%-30% although the filament temperature stays constant. In addition, it may be necessary to adjust the focal spot (FS) to maintain the same size for 80 kVp and 140 kVp. If the FS is controlled by electrodes, a change of the steering voltages may change the emission current as well (e.g., 20%-30%). These two effects will impact the emission current rapidly within the switching cycles.

[0032] The fast change of the emission current makes the measurement and the entire control difficult. The problem may be further increased for time-based dose modulation. The dose of a kVp-S acquisition can be changed dynamically during the scan by changing the duty cycle of the kVp-waveform.

[0033] In order to address one or more of the above-identified technical problems, the present disclosure proposes a novel method to control the emission current for fast kVP-switching that does not suffer or suffer less from variation of the emission current during the switching cycles.

[0034] In particular, as shown in FIG. 1, an apparatus 20 is provided for determining a reference emission current of an X-ray source for a kVp switching spectral scan. The apparatus 20 comprises an input 22, a processor 24, and an output 26.

[0035] In general, the apparatus 20 may comprise various physical and/or logical components for communicating and manipulating information, which may be implemented as hardware components (e.g., computing devices, processors, logic devices), executable computer program instructions (e.g., firmware, software) to be executed by various hardware components, or any combination thereof, as desired for a given set of design parameters or performance constraints. Although Fig. 1 may show a limited number of components of the apparatus 20 by way of example, it can be appreciated that a greater or a fewer number of components may be employed for a given implementation.

[0036] In some implementations, the apparatus 20 may be embodied as, or in, a device or apparatus, such as a server, workstation, or mobile device. The processor 24 may comprise one or more microprocessors, which execute appropriate software. The software may have been downloaded and/or stored in a corresponding memory, e.g., a volatile memory such as RAM or a non-volatile memory such as flash. The software may comprise instructions configuring the one or more processors to perform the functions as described herein.

[0037] It is noted that the processor may be implemented as dedicated hardware to perform some functions and/or a programmable device (e.g., one or more programmed microprocessors and associated circuitry) to perform other functions. For example, the functional units of the apparatus 20, e.g., the input 22, the one or more processors 24, and the output 26 may be implemented in the device or apparatus in the form of programmable logic, e.g., as a Field-Programmable Gate Array (FPGA), or as an application-specific integrated circuits (ASIC). In general, each functional unit of the apparatus may be implemented in the form of a circuit.

[0038] In some implementations, the apparatus 20 may reside in a system console (not shown), e.g., running as a software.

[0039] The input 22 is configured to receive a measurement of a tube voltage u(t) of the X-ray source. The tube voltage u(t) has a peak voltage switching between a first voltage and a second voltage. The first voltage is higher than the second voltage.

[0040] The tube voltage may be acquired during regular operation, e.g. by measuring the voltage at the output of the high-voltage generator 18. FIG. 2 shows an exemplary waveform of a tube voltage that was measured at the output of the high-voltage generator 18. In this example, the tube voltage u(t) has a peak voltage switching between a first voltage 140 kVp and a second voltage 80 kVp. The exemplary waveform shown in FIG. 2 also demonstrates a duty cycle change for time-based dose modulation. After the fourth cycle, the kVp high time is increased.

[0041] Many high-voltage generators for the X-ray source use a high-voltage cascade in the backend electronics. The last stage may comprise a diode and a capacitor. For high to low voltage transitions, the voltage before the diode will be lowered and the diode decouples the capacitor and the tube. Consequently, the emission current of the tube will discharge the capacitor. As shown in FIG. 2, the falling voltage transition slopes of the waveform show no ripple because the high-voltage generator is decoupled from the output and the output voltage just shows the "smooth" discharge of the capacitor by the "smooth" transition current. FIG. 3 shows a zoom into one of the smooth falling transition slopes, i.e., falling transmission slope 28, shown in FIG. 2.

[0042] If the capacitance (including e.g., parasitic capacitors of the cable, tube etc.) is known, the voltage transition of the output can be measured and used to estimate the emission current. This will be explained in detailed hereinafter.

[0043] For the voltage transition, we assume the filament temperature and the steering voltage to form the focal spot to be constant. The emission current that discharges the output capacitor depends on the reference current 1140 times a tube voltage dependent function f(u), which is typically a simple linear function. Although we refer to this definition and call the reference current I140 by way of example, it will be appreciated that the reference current may be defined for a reference tube voltage 80 kVp, 100 kVp, or any other reference tube voltage.

[0044] By definition f(140kV)=1 with an output capacitance of C, the tube voltage will follow the equation (1):

$$\partial u/\partial t=(I\_140\ f(u))/C \quad (1)$$

[0045] The function f(u) may either be modeled or derived from a calibration. If f(u) is given with a closed formula, the equation may be solved to a form I_140=K(u(t), C). If u(t) is measured for a time period, the desired entity I140 can be estimated. Another way is to define a voltage range, e.g., u1 and u2 shown in FIG. 3, and to measure the time it takes u(t) to transit from u1 to u2. The voltage u1 may also be referred to as a third voltage, and the voltage u2 may also be referred to as a fourth voltage. For example, as shown in FIG. 3, u1 is defined as 120 kVp and u2 is defined as 100 kVp. The time it takes to transit from u1 to u2 is Δt. This time Δt is proportional to I140 and a constant that can be identified in a calibration.

[0046] Turning back to FIG. 1, the processor 24 is configured to analyze the received measurement of the tube voltage u(t) to determine a time constant of a falling voltage transition slope, e.g., Δt, during a kVp-switching cycle, and to determine the reference emission current, e.g., I140, of the X-ray source based on the determined time constant of the falling voltage transition slope e.g., based on the above-described approach.

[0047] The apparatus 20 then provides the reference emission current, e.g., I140, via the output 26, to the high-voltage generator 18.

[0048] Knowing the reference emission current, e.g., I140, the high-voltage generator 18 is configured to control the filament heating to keep the reference emission current e.g., I140, stable over time.

[0049] FIG. 4 shows a flowchart describing an exemplary method 200 for determining a reference emission current of an X-ray source for a kVp-switching spectral scan.

[0050] The method 200 may be implemented as a device, module or related component in a set of logic instructions stored in a non-transitory machine- or computer-readable storage medium such as random access memory (RAM), read only memory (ROM), programmable ROM (PROM), firmware, flash memory, etc., in configurable logic such as, for example, programmable logic arrays (PLAs), field programmable gate arrays (FPGAs), complex programmable logic devices (CPLDs), in fixed-functionality hardware logic using circuit technology such as, for example, application specific integrated circuit (ASIC), complementary metal oxide semiconductor (CMOS) or transistor-transistor logic (TTL) technology, or any combination thereof. For example, computer program code to carry out operations shown in the method 200 may be written in any combination of one or more programming languages, including an object-oriented programming language such as JAVA, SMALLTALK, C++, Python, or the like and conventional procedural programming languages, such as the "C" programming language or similar programming languages. For example, the exemplary method may be implemented as the apparatus 20 shown in FIG. 1.

[0051] In step 210, the method 200 comprises a step of receiving a measurement of a tube voltage of the X-ray source. The tube voltage has a peak voltage switching between a first voltage and a second voltage. The first voltage is higher than the second voltage.
For example, as shown in FIG. 1, the apparatus 20 receives a measurement of a tube voltage of the X-ray source. The tube voltage may be acquired during regular operation, e.g. by measuring the voltage at the output of the high-voltage generator 18.

[0052] An exemplary waveform of the tube voltage is shown in FIG. 2. The tube voltage u(t) shown in FIG. 2 has a peak voltage switching between a first voltage 140 kVp and a second voltage 80 kVp.

[0053] In step 220, the method 200 further comprises a step of analyzing the received measurement of the tube voltage to determine a time constant of a falling voltage transition slope during a kVp-switching cycle.

[0054] For example, as shown in FIG. 3, the apparatus 20 may determine the time constant Δt of the exemplary falling voltage transition slope 28 during a kVp-switching cycle.

[0055] In step 230, the method 200 further comprises the step of determining the reference emission current of the X-ray source based on the determined time constant of the falling voltage transition slope.

[0056] For example, the apparatus 20 shown in FIG. 1 may determine the reference emission current, e.g., a reference emission current at 140 kVp, according to the above-described equation (1).

[0057] In step 240, the method 200 further comprises the step of providing the determined reference emission current of the X-ray source.

[0058] For example, as shown in FIG. 1, the apparatus 20 provides the determined reference emission current I140 to the high-voltage generator 18.

[0059] FIG. 5 shows a flowchart describing a method 300 for controlling an emission current of an X-ray source. For example, the exemplary method 300 may be implemented by the high-voltage generator 18 shown in FIG. 1.

[0060] In step 310, the high-voltage generator 18 receives a reference emission current I140 provided by the apparatus 20 shown in FIG. 1. The reference emission current I140 may be determined according to the method 200 shown in FIG. 4.

[0061] In step 320, the high-voltage generator 18 controls a filament heating of the X-ray source to keep the reference emission current stable over time.

[0062] In another exemplary embodiment of the present invention, a computer program or a computer program element is provided that is characterized by being adapted to execute the method steps of the method according to one of the preceding aspects, on an appropriate system.

[0063] The computer program element might therefore be stored on a processor, which might also be part of an embodiment of the present invention. This processor may be adapted to perform or induce a performing of the steps of the method described above. Moreover, it may be adapted to operate the components of the above-described apparatus. The processor can be adapted to operate automatically and/or to execute the orders of a user. A computer program may be loaded into a working memory of a data processor. The data processor may thus be equipped to carry out the method of the invention.

[0064] This exemplary embodiment of the invention covers both, a computer program that right from the beginning uses the invention and a computer program that by means of an up-date turns an existing program into a program that uses the invention.

[0065] Further on, the computer program element might be able to provide all necessary steps to fulfil the procedure of an exemplary embodiment of the method as described above.

[0066] According to a further exemplary embodiment of the present invention, a computer readable medium, such as a CD-ROM, is presented wherein the computer readable medium has a computer program element stored on it, which computer program element is described by the preceding section.

[0067] A computer program may be stored and/or distributed on a suitable medium, such as an optical storage medium or a solid-state medium supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the internet or other wired or wireless telecommunication systems.

[0068] However, the computer program may also be presented over a network like the World Wide Web and can be downloaded into the working memory of a data processor from such a network. According to a further exemplary embodiment of the present invention, a medium for making a computer program element available for downloading is provided, which computer program element is arranged to perform a method according to one of the previously described embodiments of the invention.

[0069] It has to be noted that embodiments of the invention are described with reference to different subject matters. In particular, some embodiments are described with reference to method type claims whereas other embodiments are described with reference to the device type claims. However, a person skilled in the art will gather from the above and the following description that, unless otherwise notified, in addition to any combination of features belonging to one type of subject matter also any combination between features relating to different subject matters is considered to be disclosed with this application. However, all features can be combined providing synergetic effects that are more than the simple summation of the features.

[0070] While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive. The invention is not limited to the disclosed embodiments. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing a claimed invention, from a study of the drawings, the disclosure, and the dependent claims.

[0071] In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single processor or other unit may fulfil the functions of several items re-cited in the claims. Measures re-cited in mutually different dependent claims may advantageously be combined. Any reference signs in the claims should not be construed as limiting the scope.

Claims

1. An apparatus (20) for determining a reference emission current of an X-ray source for a peak-kilovoltage, kVp, switching spectral scan, the apparatus comprising:

- an input (22) configured to receive a measurement of a tube voltage of the X-ray source, wherein the tube voltage has a peak voltage switching between a first voltage and a second voltage, the first voltage being higher than the second voltage;
- a processor (24) configured to analyze the received measurement of the tube voltage to determine a time constant of a falling voltage transition slope during a kVp-switching cycle, and to determine the reference emission current of the X-ray source based on the determined time constant of the falling voltage transition slope; and
- an output (26) configured to provide the determined reference emission current of the X-ray

source, which is usable for controlling an emission current of the X-ray source.

2. The apparatus according to claim 1, wherein the reference emission current is an emission current at a reference tube voltage.

3. The apparatus according to claim 1 or 2,

wherein a voltage range is defined between a third voltage and a fourth voltage that is lower than the third voltage, the third voltage being equal to or lower than the first voltage and the fourth voltage being equal to or greater than the second voltage; and
wherein the processor is configured to determine the reference emission current of the X-ray source based on a time constant of a falling voltage transition from the third voltage to the fourth voltage.

4. A system, comprising:

an X-ray source configured to generate X-rays;
a voltage generator configured to supply a voltage for operating the X-ray source and to control a filament heating of the X-ray source to keep the reference emission current stable over time; and
an apparatus according to any one of the preceding claims, wherein the apparatus is configured to determine a reference emission current of the X-ray source.

5. A method (200) for determining a reference emission current of an X-ray source for a peak-kilovoltage, kVp, switching spectral scan, the method comprising:

- receiving (210) a measurement of a tube voltage of the X-ray source, wherein the tube voltage has a peak voltage switching between a first voltage and a second voltage, the first voltage being higher than the second voltage;
- analyzing (220) the received measurement of the tube voltage to determine a time constant of a falling voltage transition slope during a kVp-switching cycle;
- determining (230) the reference emission current of the X-ray source based on the determined time constant of the falling voltage transition slope; and
- providing (240) the determined reference emission current of the X-ray source.

6. The method according to claim 5, wherein the reference emission current is an emission current at a reference tube voltage.

7. The method according to claim 5 or 6,

wherein a voltage range is defined between a third voltage and a fourth voltage lower than the third voltage, the third voltage being equal to or lower than the first voltage and the fourth voltage being equal to or greater than the second voltage; and
wherein the reference emission current of the X-ray source is determined based on a time constant of a voltage transition from the third voltage to the fourth voltage.

8. A method (300) for controlling an emission current of an X-ray source, the method comprising:

- receiving (310), by a voltage generator, a reference emission current generated according to any one of claims 5 to 7; and
- controlling (320), by the voltage generator, a filament heating of the X-ray source to keep the reference emission current stable over time.

9. A computer program product comprising instructions which, when executed by a processor, cause the processor to carry out the steps of the method of claims 5 to 7 or claim 8.

10. A computer-readable medium having stored thereon the computer program product of claim 9.

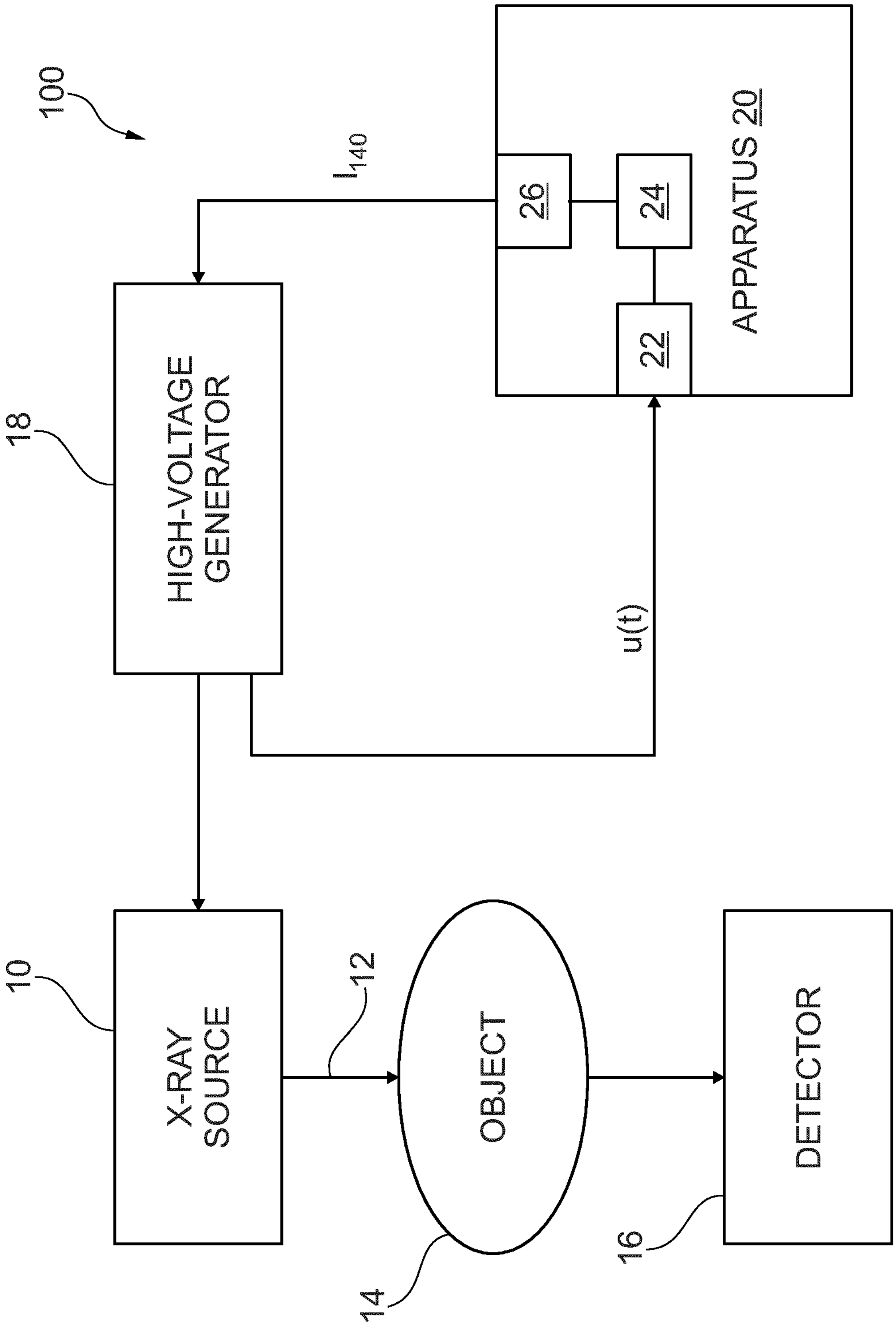
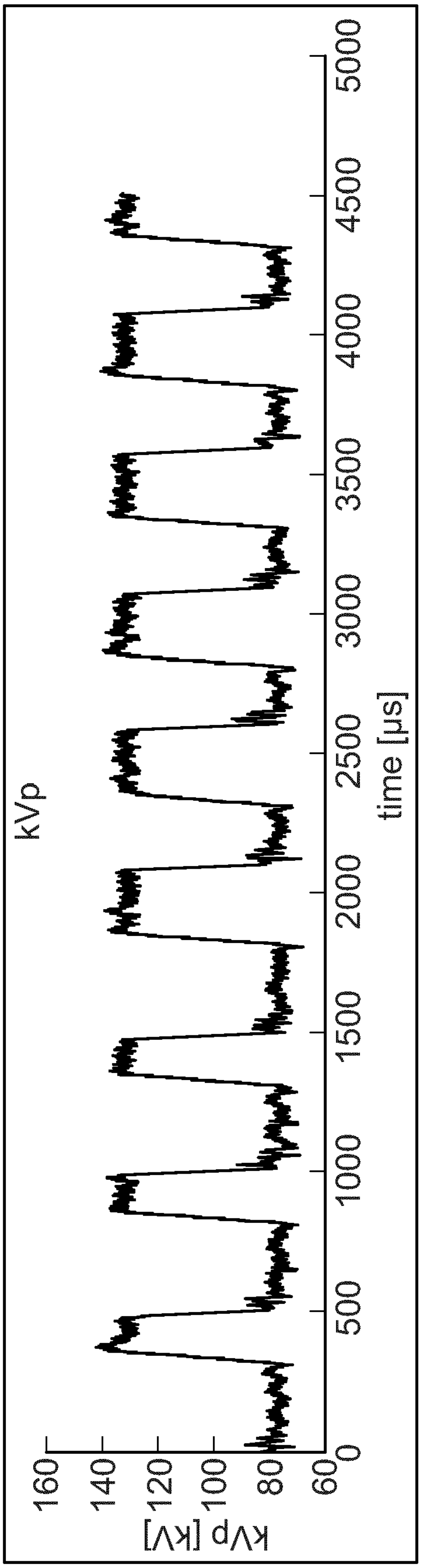

100
I140
APPARATUS 20
26
24
22
18
HIGH-VOLTAGE GENERATOR
u(t)
10
X-RAY SOURCE
12
OBJECT
DETECTOR
14
16

Fig. 1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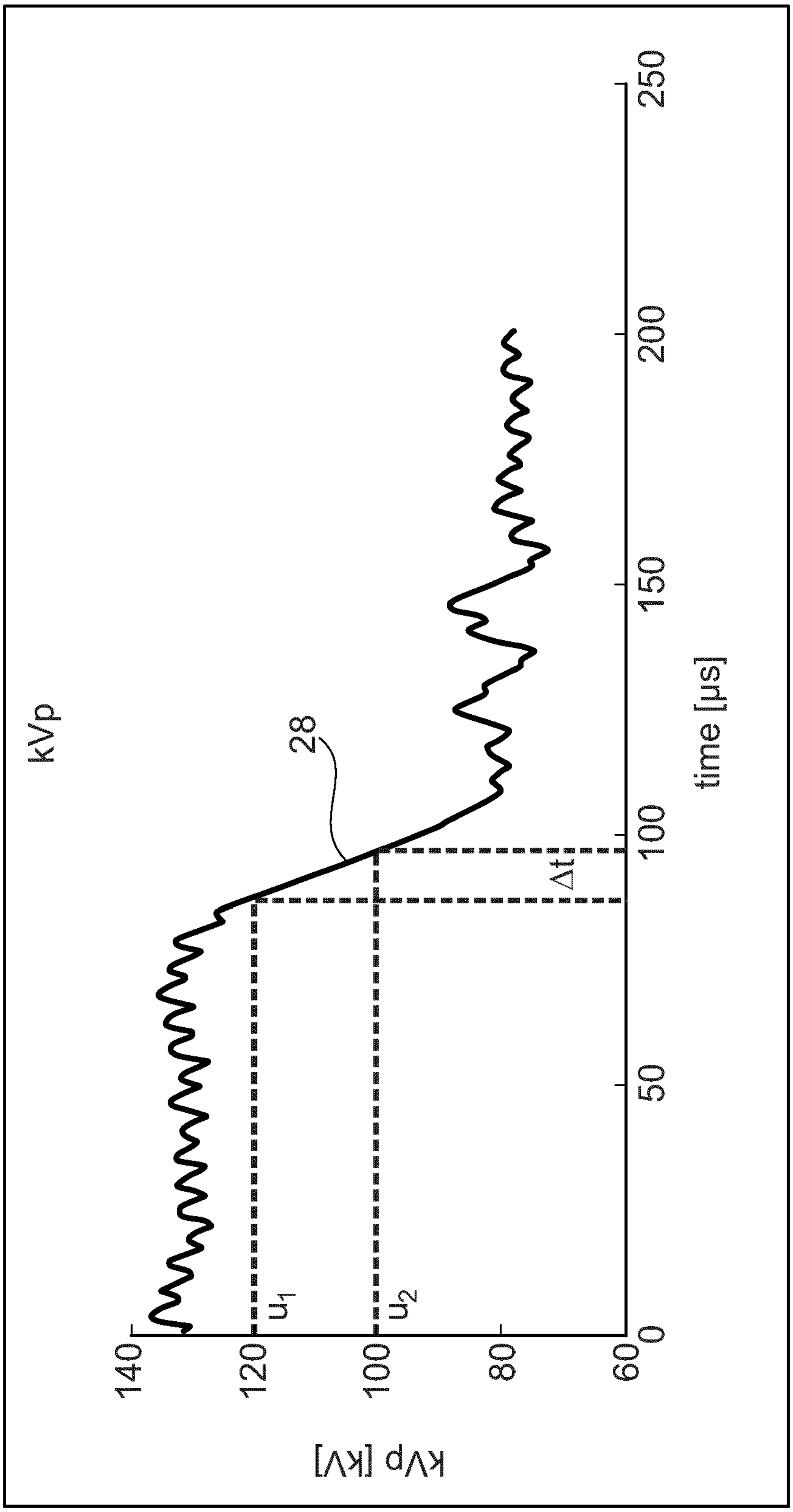
time [µs]

Fig. 2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120
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0
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100
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u_1
u_2
Δt
28

Fig. 3

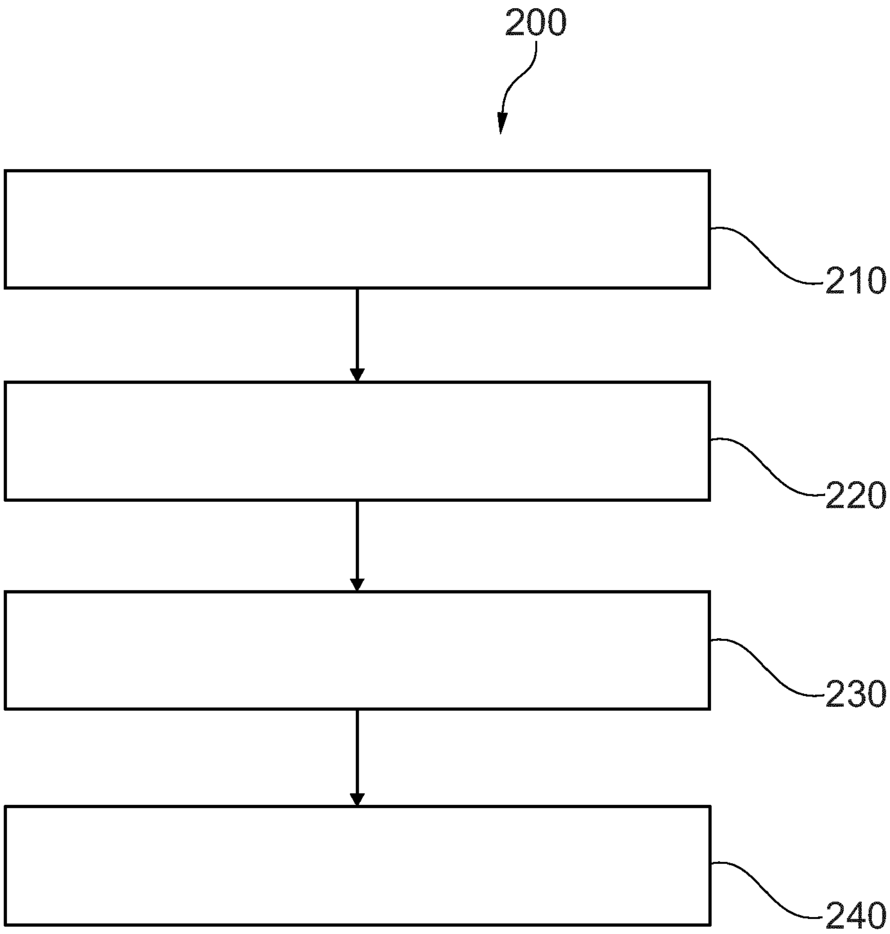

Fig. 4

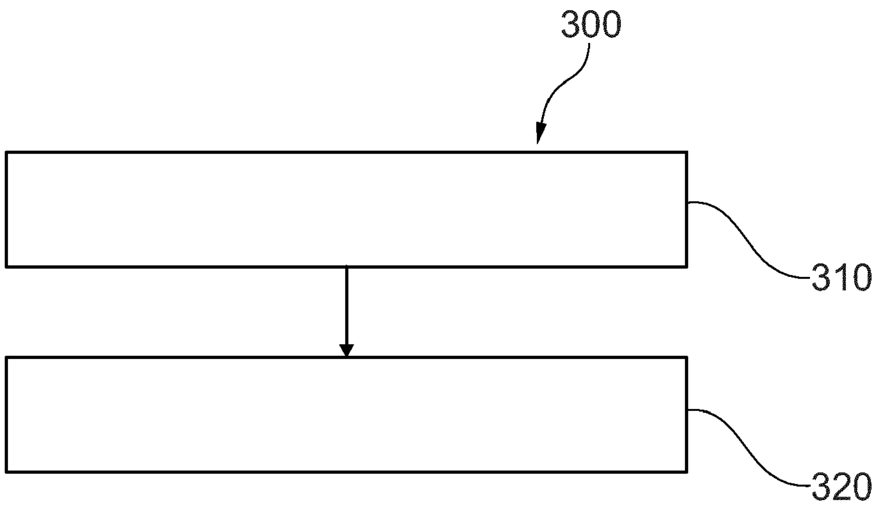

Fig. 5

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EUROPEAN SEARCH REPORT

Application Number
EP 22 21 4527

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 5 629 844 A (KRICHTAFOVITCH IGOR A [US] ET AL) 13 May 1997 (1997-05-13) * figures 1-4 * * column 2, line 31 - column 3, lines 24, 43-54 * * column 4, line 26 - column 9, line 33 * * column 16, lines 18-31 * -----	1-10	INV. H05G1/34 H05G1/26
A	JP 2013 192801 A (TOSHIBA CORP; TOSHIBA MEDICAL SYS CORP) 30 September 2013 (2013-09-30) * figures 1,2,4,10 * * paragraphs [0011], [0015], [0024] - [0028], [0053], [0054], [0057], [0058] * * paragraphs [0064], [0065], [0068], [0073], [0079], [0080], [0085] - [0089], [0092] * -----	1-10	
A	US 2020/413525 A1 (ZHU GUOPING [CN] ET AL) 31 December 2020 (2020-12-31) * figures 7,8 * * paragraphs [0005], [0076] - [0081] * -----	1-10	TECHNICAL FIELDS SEARCHED (IPC) H05G
X	US 9 992 855 B2 (GEN ELECTRIC [US]) 5 June 2018 (2018-06-05) * figures 4,5 * * column 1, lines 50-66 * * column 2, lines 14-44 * -----	1-10	

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
Munich	25 May 2023	Giovanardi, Chiara

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
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T : theory or principle underlying the invention
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D : document cited in the application
L : document cited for other reasons
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 22 21 4527

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82