May 12, 1970 HARUYUKI KUSAGAYA ET AL 3,511,996

X-RAY GENERATOR HAVING MEANS FOR PREVENTING D.C. MAGNETIZATION OF THE TRANSFORMER CORE

Filed Oct. 19, 1966

4 Sheets-Sheet 1

FIG. 1 PRIOR ART

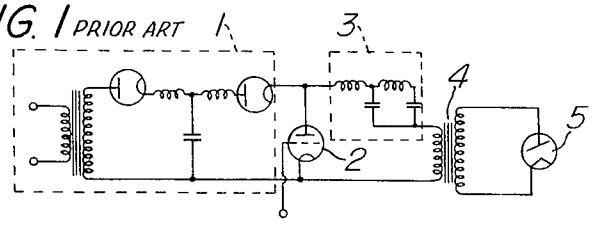


FIG. 2

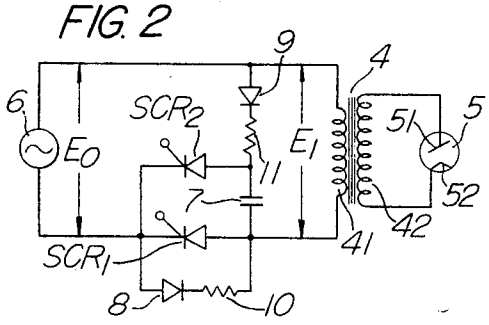


FIG. 5

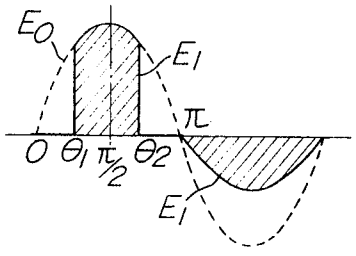


FIG. 3

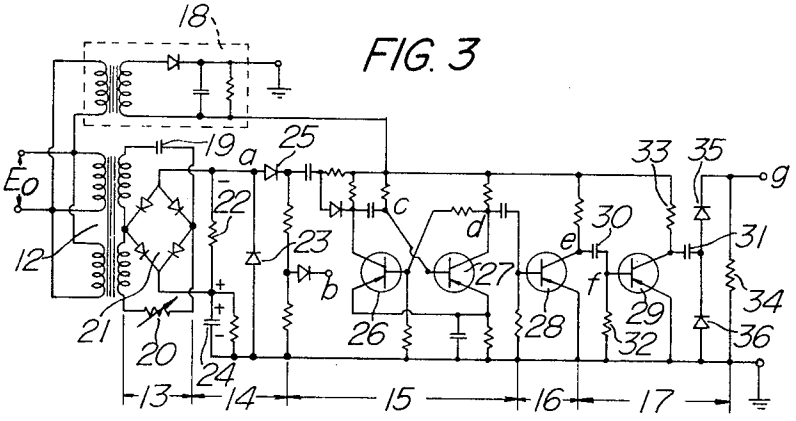


FIG. 6

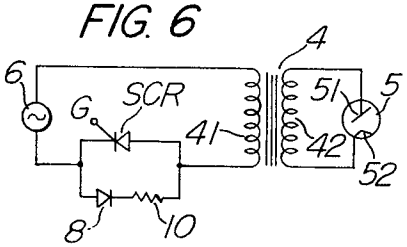
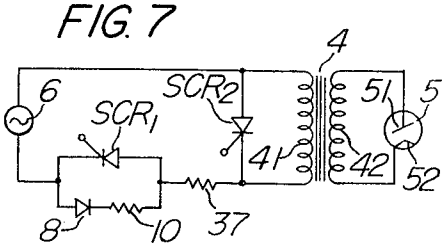


FIG. 7



INVENTORS

HARUYUKI KUSAGAYA

SHIGEHARU YAMADA

SHIGEO SATO

BY Paul M. Craig, Jr.

ATTORNEY

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FIG. 4

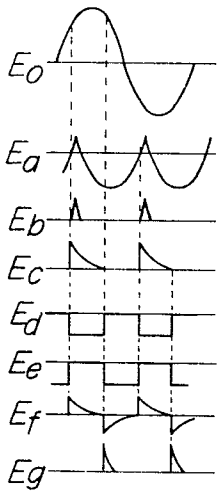


FIG. 8a

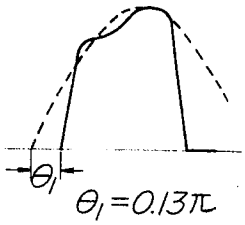


FIG. 8b

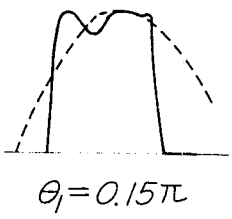


FIG. 8c

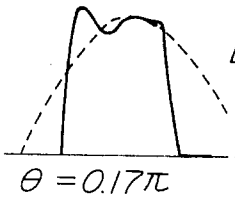


FIG. 8d

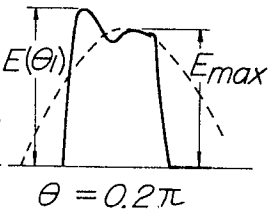


FIG. 9a

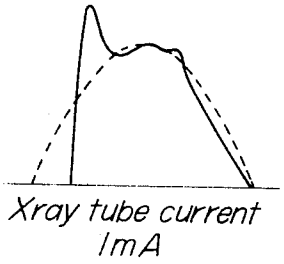


FIG. 9b

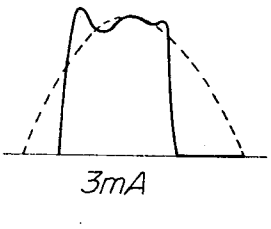


FIG. 9c

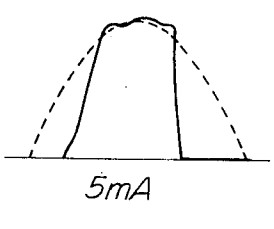
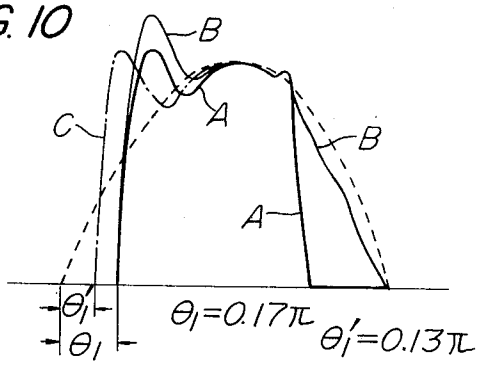


FIG. 10



INVENTORS
HARUYUKI KUSAGAYA
SHIGENOBU YANAI
SHIGEO SATO

BY Paul H. Craig, Jr.
ATTORNEY

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FIG. 11

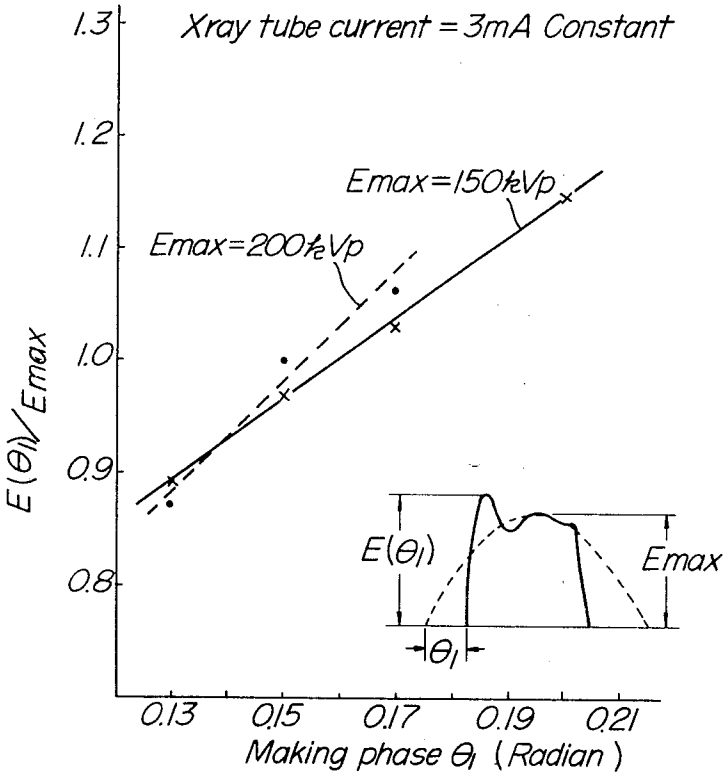
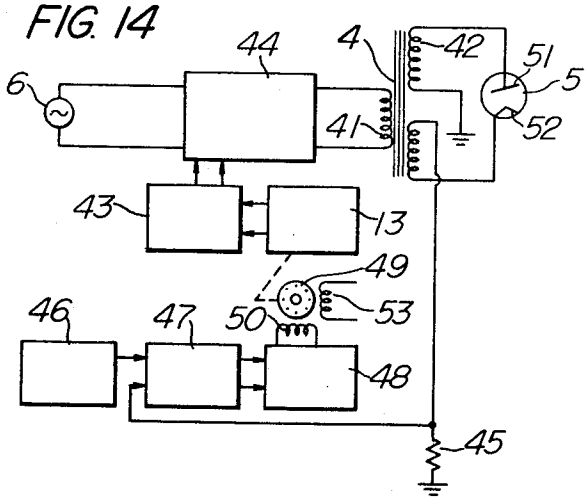


FIG. 14



INVENTORS
HARUYUKI KUSAGAYA
SHIGENOBU YANAKA
SHIGEO SATO

BY Paul M. Craig, Jr.
ATTORNEY

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FIG. 12

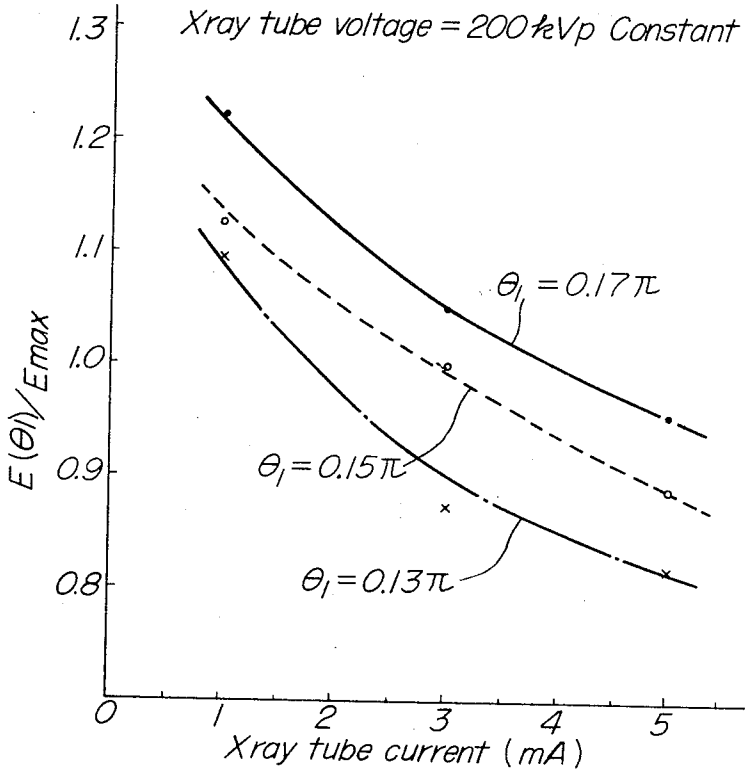
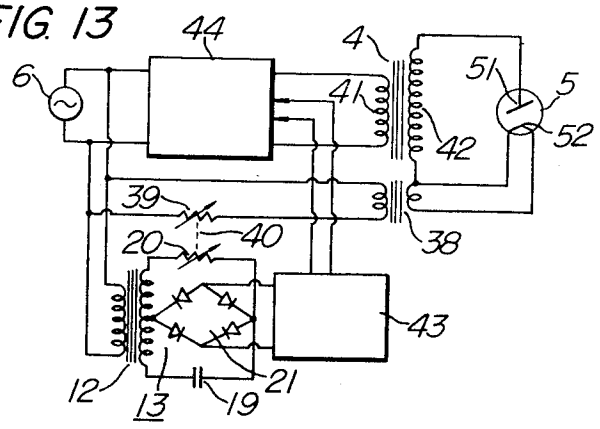


FIG. 13



INVENTORS
HARUYUKI KUSAGAYA
SHIGENOBU YANAKA
SHIGEO SATO

BY Paul M. Craig, Jr.
ATTORNEY

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3,511,996

X-RAY GENERATOR HAVING MEANS FOR PREVENTING D.C. MAGNETIZATION OF THE TRANSFORMER CORE

Haruyuki Kusagaya, Shigenobu Yanaka, and Shigeo Sato, Tokyo, Japan, assignors to Hitachi, Ltd., Tokyo, Japan, a Japanese corporation

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Int. Cl. H05g 1/14
U.S. Cl. 250—102
5 Claims

ABSTRACT OF THE DISCLOSURE

An X-ray generator is described wherein a controlled rectifier is used to preclude portions of a desired positive half-cycle of a sinusoidal supply voltage except for a chopped-out central portion. A resistor is connected in parallel with the controlled rectifier for exciting the transformer in a reverse direction during the undesired opposite half-cycle of the sinusoidal supply voltage. The parallel connected controlled rectifier and resistor are connected in series with the primary winding of a transformer whose secondary windings are connected to the anode and cathode of an X-ray tube. By this arrangement, D.C. magnetization of the core of the transformer and application of excessive reverse voltage to the X-ray tube is avoided, thereby enabling the X-ray generator to be made small in size and light in weight.

The present invention relates to an X-ray generator and more particularly to an industrial portable X-ray generator wherein an X-ray tube is adapted to be supplied with a pulse voltage so as to make the apparatus light and small.

In a portable X-ray generator for use in nondestructive testing of a metallic material, an X-ray tube and a high tension transformer for supplying power thereto are usually contained in the same casing and self-rectifying effect of the X-ray tube is utilized to apply thereto only the positive half-wave component of a sine-wave A.C. voltage fed from the high tension transformer to thereby generate X-rays. However, it is known that the hardness or the penetrability of X-rays generated by an X-ray tube generally changes according to the instantaneous value of a plate voltage applied to the X-ray tube and that hard X-rays capable of penetrating an iron plate or the like are only scarcely produced with a patential below 40 kv. Therefore, such a low voltage component as not contributing to the generation of X-rays having a desired penetrability is unnecessary for an industrial X-ray generator wherein only hard X-rays are required. It is already known that a high tension, pulse form voltage, having no low voltage component, should preferably be supplied to an X-ray tube for that purpose.

One of the advantages obtained by supplying an X-ray tube with a pulse voltage is that the electric power consumed by the X-ray tube may be reduced and that the temperature increase of the X-ray tube under operation may be correspondingly diminished. Also, since the magnetic flux through the iron core of a high tension transformer is proportional to the integrated value of an input voltage, it is possible to reduce the magnetic flux through the iron core relative to the case with a sine-wave input by using a pulse form input voltage and, in case where the magnetic fluxes are set equal, the cross section of the iron core may be reduced and windings may be made more compact. For the two reasons mentioned above, the size and weight of an X-ray generator may

be reduced when a pulsed voltage is employed as an input voltage.

Conventional X-ray generators using a pulse voltage include a type as shown in FIG. 1 in which a D.C. power supply, a switching tube and a pulse shaping circuit are combined to generate a pulse voltage and said voltage is boosted by a high tension transformer and fed to an X-ray tube. In this type of apparatus however, the high tension transformer is D.C. magnetized by the pulse input and so the cross-section of the core must be made relatively large to avoid polarential saturation of the core. Moreover, since a D.C. power supply for pulse generation is necessary, it is difficult to make the whole apparatus light and small.

Accordingly, it is a primary object of the present invention to provide an improved pulse-system X-ray generator which may be made much lighter and smaller than a conventional apparatus having a load capacitnce of the same order of magnitude.

Said object and a number of other objects, features and advantages of the present invention will become apparent from the following detailed description of some embodiments of the invention taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a circuit diagram showing a known pulse-system X-ray generator,

FIG. 2 is a circuit diagram showing an embodiment of the present invention,

FIG. 3 is a diagram illustrating in detail a trigger circuit used in the invention,

FIG. 4 shows a voltage waveform at each point of the trigger circuit shown in FIG. 3,

FIG. 5 is a sketch of a pulse waveform obtained with the apparatus shown in FIG. 2,

FIGS. 6 and 7 are circuit diagrams showing other embodiments of the invention,

FIGS. 8 (*a* to *d*), 9 (*a* to *c*), and 10 are diagrams showing measured waveforms of a voltage applied to an X-ray tube,

FIGS. 11 and 12 are diagrams showing relations of a peak value of an X-ray tube voltage at the beginning of a pulse to a pulse making phase and to an X-ray tube current, respectively, and

FIGS. 13 and 14 show further embodiments of the invention comprising pulse phase adjusting means for preventing an anomalous voltage at the beginning a pulse.

Referring to FIG. 1 showing a known apparatus, a pulse generating circuit is composed of a D.C. power supply **1**, a switching tube **2** and a waveform shaping circuit **3**, and a pulse generated therein is fed through a high tension transformer **4** and applied between the plate and the cathode of an X-ray tube **5**. In such a device, the iron core of the high tension transformer **4** is magnetically polarized by a D.C. component of an input pulse and the output is limited by the saturation of the core.

In order to eliminate the disadvantages of the known system, an X-ray generator according to the present invention comprises a high tension transformer having a primary winding and a secondary winding, the secondary winding, the secondary winding being connected at its ends with the plate and the cathode of an X-ray tube to supply a plate voltage to the X-ray tube. At least one controlled rectifier is connected between the primary winding of the transformer and an alternating current power supply for making and breaking the A.C. input to the transformer in response to means for controlling the conductive state of the controlled rectifier to supply the primary winding of the transformer with only a portion of each positive half wave of the alternating current input voltage lying in the vicinity of the peak thereof by eliminating from the positive half wave a low voltage component substantially incapable of contributing to the gen-

eration of X-rays, thereby providing a wave form to be applied to the X-ray tube which is substantially rectangular. A particularly advantageous feature of the present invention is the provision of a resistor connected in parallel with the controlled rectifier and having a value which allows a current to flow therethrough during the negative half wave of the alternating current input voltage sufficient to excite the transformer inversely to the extent necessary to prevent direct current magnetization of the core of the transformer.

Embodiments of the invention will now be described with reference to the drawings. In FIG. 2, a high tension transformer **4** includes a primary coil **41** and a secondary coil **42**, the ends of said secondary coil **42** being connected to a plate **51** and a cathode **52** of an X-ray tube **5**, respectively. There is connected between the primary coil **41** and the commercial A.C. power supply a pulse generating circuit composed of controlled rectifiers SCR_1 and SCR_2, a capacitor **7**, rectifiers **8, 9** and resistors **10, 11**.

An example of a trigger circuit supplying an ignition pulse to the controlled rectifiers SCR_1 and SCR_2 is shown in FIG. 3. This trigger circuit consists of a circuit **14** for generating an ignition pulse to be applied to SCR_1 whose input is fed through a transformer **12** and a phase-shifting and rectifying device **13**, a delay circuit **15**, a phase-inverting circuit **16**, and an ignition pulse generator circuit **17** for SCR_2. Reference numeral **18** denotes a negative power supply for said trigger circuit. In FIG. 3, after the secondary voltage of the transformer **12** is phase shifted with a phase-shifting circuit comprising a capacitor **19** and a resistor **20**, it is full-wave rectified with a rectifier **21** and applied as a negative potential between the terminals of a resistor **22**. Since at the same time a capacitor **24** is charged through a rectifier **23**, the potential at a point *a* is increased to the amount of the charging voltage across the capacitor **24** to become as shown in FIG. 4 (E*a*). Only the positive component of said voltage appears at the output terminal of a rectifier **25** and is then fed from the terminal *b* to SCR_1 as an ignition pulse. The delay circuit **15** is composed of a known one shot multivibrator employing transistors **26, 27** and it sends out from a terminal *d* a rectangular wave output having a waveform as shown in FIG. 4 (E*d*) every time a positive pulse is applied thereto through the rectifier **25**. The phase of said rectangular wave is inverted with a transistor **28**. Then the waveform is transformed by use of the ignition pulse generating circuit **17** composed of a transistor **29**, capacitors **30, 31**, resistors **32, 33, 34**, and rectifiers **35, 36** and the pulse is applied from a terminal *g* to SCR_2 as an ignition pulse delayed by a definite time interval as shown in FIG. 4 (E*g*).

Now, the operation of the X-ray generator shown in FIG. 2 which is controlled by said trigger circuit will be described hereinbelow in conjunction with voltage waveforms shown in FIG. 5. With an ignition pulse from the output terminal *b* of the trigger circuit, SCR_1 is turned on at a certain phase θ_1 (this phase will be referred to as a pulse phase) lying in the first half of the positive half wave of the sinewave input voltage E_0 shown in FIG. 5. While SCR_1 is on, the capacitor **7** is charged through the rectifier **9** and the resistor **11** and SCR_2 is turned on by an ignition pulse sent thereto from the output terminal *g* of the trigger circuit at a certain phase θ_2 (this phase is referred to as a pulse breaking phase) lying in the latter half of said positive half wave. Then the charging voltage of the capacitor **7** is applied to SCR_1 as an inverse bias and so SCR_1 is turned off. Through the period from θ_1 to θ_2, the load is applied with a positive potential by way of SCR_1. When the positive half wave of the input voltage disappears, SCR_2 turns off and while the following negative half wave is present, both SCR_1 and SCR_2 are kept off and the load is supplied with an inverse voltage through the rectifier **8** and the resistor **10**. Thus, by suitably selecting the

phase of the ignition pulses applied to SCR_1 and SCR_2, the waveform of the input voltage applied to the high tension transformer **4** is made as shown in FIG. 5 E_1 and that part of the positive half wave of the sine-wave voltage which forms a pulse ranging from θ_1 to θ_2 is boosted by the transformer **4** and applied between the plate and the cathode of the X-ray tube **5** in a forward direction to produce X-rays having a desired penetrability. While the negative half wave of the input voltage is present, the transformer is inversely excited by a current running through the resistor **10** and thus D.C. magnetization of the core is prevented. The resistor **10** is connected across the controlled rectifier SCR_1 so that said resistor may pass only the negative half wave of the input voltage, and the passing of a positive half wave is inhibited by the rectifier **8**. The value of the resistor **10** is chosen so that the area of the part of the positive half wave indicated by oblique lines in FIG. 5 may be equal to the area of the part of the negative half wave indicated by oblique lines and thus the D.C. component of the input voltage may vanish. As is evident from FIG. 5, the input voltage applied to the transformer in the period of a negative half wave is lower than the input voltage applied to the transformer in the period of a positive half wave due to the potential drop in the resistor **10** caused by a current of an inverse direction. Accordingly, the resistor **10** also serves as an inverse current reducing means for insuring that an excessive voltage of a reverse direction, which is a menace to the insulation of the apparatus, may not be applied to the X-ray tube in the half cycle when the tube is not conductive.

Other embodiments of a high tension pulse generator are shown in FIGS. 6 and 7. The embodiment shown in FIG. 6 is a pulse generator comprising a controlled rectifier SCR being a single unit to be turned on and off by a positive or negative gate pulse which is described, for instance, in an American journal "Electro-technology" for October 1963, pp. 62–72, said controlled rectifier SCR and one terminal of a series circuit consisting of a rectifier **8** and a resistor **10** provided across said controlled rectifier being connected to a commercial A.C. power supply **6** and the other terminal of said series circuit being connected to a primary coil **41** of a high tension transformer, wherein SCR is turned on by a positive pulse applied to a gate terminal G at phase θ_1, lying in the first half of the positive half wave of the sine-wave input voltage E_0 shown in FIG. 5 and then SCR is turned off by a negative pulse applied to the gate terminal G at phase θ_2 lying in the latter half of a positive half wave. Thus, only the part of the sine-wave around the peak ranging from θ_1 to θ_2 is applied as a pulse voltage to the primary terminals of the high tension transformer and in the period of a negative wave of the input voltage when SCR is off, the transformer **4** is excited inversely by a current through the resistor **10**.

The embodiment shown in FIG. 7 uses two ordinary controlled rectifiers, one of which denoted by SCR_1 is connected in series to a primary coil **41** of a high tension transformer and the other controlled rectifier SCR_2 is connected in parallel to the primary coil **41** of the high tension transformer. The primary coil **41** of the high tension transformer is first applied with a potential by turning SCR_1 on at phase θ_1 lying in the first half of a positive half wave of a sine-wave input voltage coming from a commercial A.C. power supply **6**, and then the primary coil **41** of the high tension transformer is short-circuited to remove the potential by turning SCR_2 on at phase θ_2 lying in the latter half of said positive half wave. While a negative half wave of the input voltage is present, both SCR_1 and SCR_2 are kept off and an inverse exciting current flows through the primary coil **41** of the high tension transformer by way of a rectifier **8** and a resistor **10**. Thus, a pulse having a waveform as shown in FIG. 5 is obtained. In FIG. 7, reference

numeral 37 denotes a protective resistor for limiting a short-circuit current.

As is apparent from the foregoing detailed description of the embodiments of the invention, it is possible to reduce the electric power consumed by an X-ray tube and the heat generated by the tube compared to the case where a sine-wave is directly applied and hence to reduce the size of a high tension transformer contained in the same case with said X-ray tube since, according to the present invention, a low voltage component of an input voltage not contributing to the generation of X-rays is cut at the primary side of a high tension transformer and only the part of the sine-wave positioned around the peak is applied to the X-ray tube as a high tension pulse.

Also, since a D.C. power supply as used in an apparatus shown in FIG. 1 is not required, an input voltage may be derived directly from a commercial A.C. power supply and since D.C. magnetization of an iron core of a high tension transformer is prevented by exciting said transformer inversely with a negative half wave of the input voltage, it is possible to admit a large variation of a magnetic flux in the core without saturating said core and thereby to reduce the size of a high tension transformer further. Further, as has been described, since the peak value of the reverse voltage applied to the X-ray tube can be made smaller than the peak value of the forward voltage, it is possible to employ a small size X-ray tube with a low reverse breakdown voltage. In addition, the reduction of the reverse voltage makes the electrical insulation of the transformer and its adjacent parts easier and enables the whole tube head housing the X-ray tube and the transformer to be reduced in size to the greatest possible extent. Accordingly, there is provided, according to the invention, an improved industrial X-ray generator having a small size, a light weight and portability unattainable by the prior art.

Let us consider, for example, an industrial X-ray generator having a load capacitance 200 kvp., 4 ma. In an ordinary system wherein an alternate current is applied, the weight of a high tension generator including an X-ray tube and a high tension transformer is about 52 kg., the weight of controlling means is about 18 kg. and thus the total weight becomes of the order of 70 kg., whereas according to the present invention the weight of a high tension generator is about 38 kg., the weight of the controlling means including SCR and accessories is about 20 kg. and the total weight is about 58 kg. Thus the weight is reduced by about 20%. If the size and weight are of the same order of magnitude, only an output current of the order of 1 ma. may be run in a conventional apparatus shown in FIG. 1 due to saturation of a core, while it is possible to derive a large output current of the order of 4 ma. in an apparatus according to the invention.

FIGS. 8 and 9 show waveforms obtained by operating an X-ray tube having means shown in FIG. 2 and FIG 3, wherein FIGS. 8(a) through (d) show waveformers of an X-ray tube voltage obtained by setting a pulse making phase θ_1 to be 0.13π, 0.15π, 0.17π and 0.2π, respectively (where an X-ray tube current is maintained at a constant 3 ma.) and FIGS. 9(a) through (c) show waveforms of an X-ray tube voltage obtained when an X-ray tube current is set to be 1 ma., 3 ma., and 5 ma. (a pulse making phase $\theta_1=0.17\pi$ constant). In either case, the maximum tube voltage E_{max} is set equal to 200 kvp. and the frequency of the power supply set to be 50 c./s.

Though a rectangular wave is ideal for an X-ray tube voltage, it has turned out that, in practice, an anomalous voltage as shown in FIGS. 8 and 9 appears at the secondary side of a transformer due to leakage inductance and stray capacitance when SCR_1 of FIG. 2 is turned on and that the peak value $E(\theta_1)$ of said anomalous voltage depends on the making phase, the tube current and the value of E_{max}.

FIG. 11 shows the relation between the making phase θ_1 and $E(\theta_1)/E_{max}$ and FIG. 12 shows the relation between the tube current and $E(\theta_1)/E_{max}$. It is seen from these relations that the peak value $E(\theta_1)$ of the anomalous voltage increases as the making phase θ_1 approaches $\pi/2$ if the tube current is kept constant and that said peak value increases as the tube current decreases if the making phase is constant.

Therefore, it is easy to select a pulse making phase suitable for producing an optimum waveform as shown in FIG. 9(c) against a particular value of a tube current. However, if the making phase θ_1 is fixed constant, a phenomenon that an anomalous voltage at the beginning of a pulse increases as shown in FIG. 9(b) or (a) may take place when a tube current is changed artificially or when a tube current varies due to an unexpected accident such as the variation of a working voltage of a power supply. Such a phenomenon not only damages insulation of the apparatus, but also reduces the generation of X-rays through the increase of the distortion of a waveform and thus prevents obstacles against use of the device.

This problem may be solved by providing means for adjusting the ignition phase of the controlled rectifier connected between the primary coil of the high tension transformer and the commercial A.C. power supply so as to advance the pulse making phase, when a tube current decreases, in correspondence to the change of the selected tube current or the variation of the working tube current.

This effect will be described with reference to the waveform diagram of a tube voltage. In FIG. 10, A indicates a waveform of a tube when the tube current is 3 ma. and the making phase $\theta_1=0.17\pi$, B shows a waveform of a tube voltage when the tube current is 1 ma. and the making phase $\theta_1'=0.17\pi$ and C shows a waveform of a tube voltage when the tube current is 1 ma. and the making phase $\theta_1=0.13\pi$. As is seen from these figures, when the tube current decreases, the increase of an anomalous voltage at the beginning of the pulse and the increase of waveform distortion may be suppressed if the pulse making phase is shifted correspondingly from θ_1 to θ_1', for instance, and when the tube current increases, a tube voltage having a desired waveform close to a rectangular wave may be maintained by delaying the pulse making phase. Further, when changing the pulse making phase θ_1, it is desirable to keep the pulse width constant by simultaneously varing the breaking phase θ_2.

FIG. 13 shows a practical example of an apparatus for adjusting the pulse making phase in accordance with the variation of a selected value in the tube current. In this apparatus, interlocking means **40** is provided between a heat regulator **39** connected to the primary winding of an X-ray filament transformer **38** and a variable resistor **20** forming an arm of a reactance bridge of a phase-shifting circuit **13**, and the value of the resistor **20** is adjusted in correspondence to the value of the tube current selected by the heat regulator **39** to determine thereby the phase of an A.C. input supplied to a trigger circuit **43**. The phase-shifting circuit **13** shown in FIG. 13 corresponds to the phase-shifting and rectifying device **13** in FIG. 3 and the trigger circuit **43** corresponds to the trigger circuit comprising the ignition pulse generator circuit **14** for SCR_1, the delay circuit **15**, the phase inverted circuit **16** and the ignition pulse generator circuit **17** for SCR_2 in FIG. 3. As has been already described in the explanation of FIG. 3, the phase of an ignition pulse produced by the trigger circuit **43** is determined by the phase of the A.C. input and so the phase of the ignition pulses applied from the trigger circuit **43** to the controlled rectifiers SCR_1, SCR_2, which as shown in FIG. 2 comprise the high tension pulse generating circuit **44** shown in FIG. 13, varies in accordance with the value of the selected tube current. Thus, the turn-on

phase θ_1 and the turn-off phase θ_2 of SCR_1 are adjusted to optimum values corresponding to the tube current.

FIG. 14 shows a practical example of an apparatus for adjusting the pulse making phase in accordance with the variation of the working tube current. This apparatus is used to compare the voltage produced at a resistor **45** by an X-ray tube current with a standard voltage applied to a DC constant-voltage device **46**, to transform the deviation into an alternate current with a DC–AC converter **47** and to apply said alternate current to a control coil **50** of a balanced motor **49** through an amplifier **48**. If an exciting coil **53** of the balanced motor **49** is supplied with a constant voltage, the phase of the voltage applied to the control coil **50** is inverted according as the detected deviation voltage is positive or negative and the motor **49** rotates in a forward or reverse direction. Therefore, by operating a variable element of a phase-shifting circuit **13** with said balanced motor, it is possible to shift the phase of an ignition pulse supplied in the same way as with the example of FIG. 13 from the trigger circuit **43** to the controlled rectifier of the high tension pulse generator **44** and to adjust automatically the relation between the X-ray tube current and the pulse making phase.

It is to be noted that the present invention is not restricted to the embodiments described above and that the invention covers all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. An X-ray generator comprising: a high tension transformer having a primary winding and a secondary winding, said secondary winding being connected at its ends with a plate and a cathode of an X-ray tube to supply a plate voltage to said X-ray tube; at least one controlled rectifier connected between the primary winding of said transformer and an A.C. power supply for controlling energization of the primary winding; means for controlling the conductive state of said at least one controlled rectifier to supply said primary winding of said transformer with only a portion of a desired half wave of said A.C. input voltage lying in the vicinity of the peak thereof by entirely eliminating from said desired half wave low voltage components not contributing substantially to the generation of X-rays and thereby make the waveform of the voltage applied to said X-ray tube substantially rectangular; and a resistor connected in parallel circuit relationship with said at least one controlled rectifier and connected in series circuit relationship with a unidirectional conducting means for allowing current to flow through said resistor only during each remaining half wave of said A.C. input voltage said resistor having a value such that intermediate each conducting interval of said at least one controlled rectifier the current passing through said resistor excites said transformer inversely to the extent necessary to prevent D.C. magnetization of the core of said transformer.

2. An X-ray generator according to claim **1** further comprising means for adjusting the phase of turn-on and turn-off of said at least one controlled rectifier in dependence upon the variation in the amount of the current flowing through said X-ray tube during X-ray generation.

3. An X-ray generator according to claim **2** wherein said means for controlling the conductive state of said at least one controlled rectifier includes turn-on signal producing means for supplying to the control gate of the said at least one controlled rectifier a turn-on signal at a desired point in the phase of the A.C. power supply, and turn-off commutating circuit means for commutating off said at least one controlled rectifier at a desired point in the phase of the A.C. power supply.

4. An X-ray generator according to claim **3** wherein the commutating circuit means comprises at least one additional controlled rectifier and a commutating capacitor connected in circuit relationship with the said at least one controlled rectifier for reverse biasing the said at least one controlled rectifier at a desired point in the phase of the A.C. power supply and turning it off, and turn-off signal producing means coupled to the control gate of the additional controlled rectifier for controlling its turn-on at a desired point in the phase of the A.C. power supply.

5. An X-ray generator according to claim **3** wherein the at least one controlled rectifier comprises a gate turn-off controlled rectifier and the commutating circuit means comprises turn-off signal producing means coupled to the control gate of the gate turn-off controlled rectifier in common with the turn-on signal producing means for turning-on and turning-off the gate turn-off controlled rectifier at desired points in the phase of the A.C. power supply.

References Cited

UNITED STATES PATENTS

3,221,167	11/1965	Weisglass	250—100 X
2,878,393	3/1959	Graves	250—103
3,130,312	4/1964	Craig	250—95
3,277,302	10/1966	Weighart	250—102
3,322,949	5/1967	Smith	250—100

OTHER REFERENCES

"General Electric Controlled Rectifier Manual," 1960, pp. 72, 73.

RALPH G. NILSON, Primary Examiner

A. L. BIRCH, Assistant Examiner

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