Oct. 4, 1966 F. G. WEIGHART 3,277,302

X-RAY APPARATUS HAVING MEANS FOR SUPPLYING AN ALTERNATING SQUARE WAVE VOLTAGE TO THE X-RAY TUBE

Original Filed May 10, 1963 2 Sheets-Sheet 1

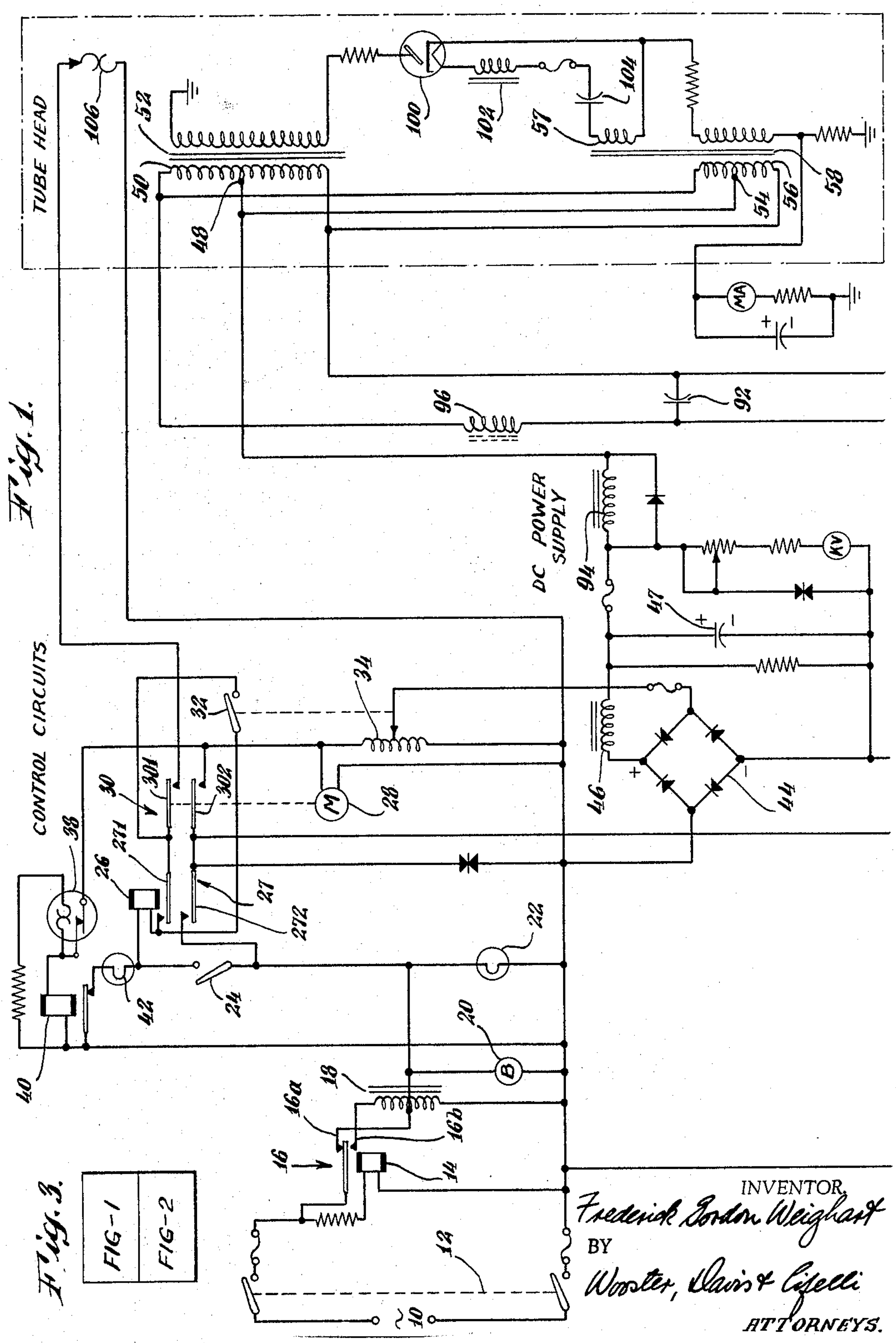

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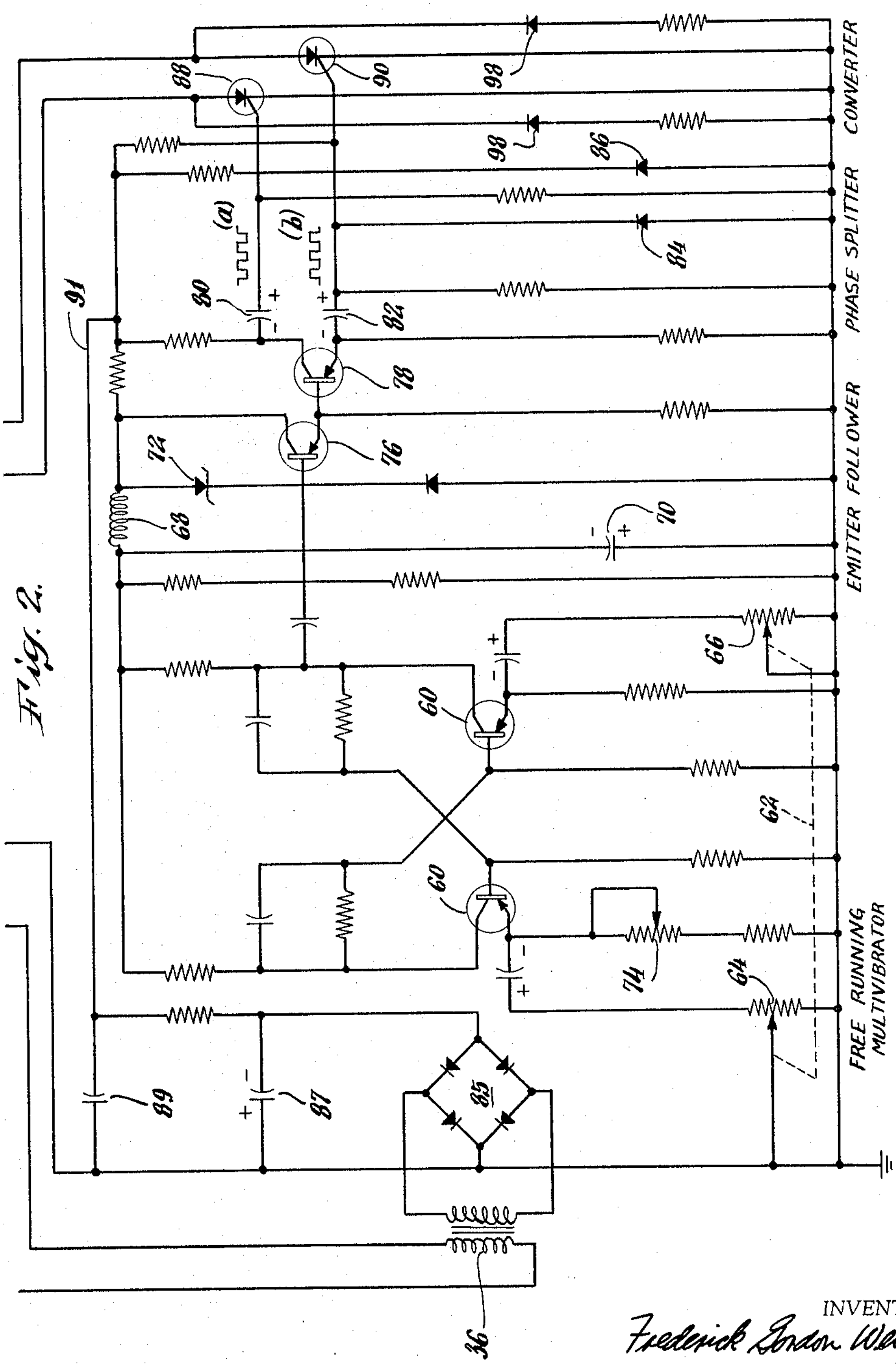
Fig. 2.



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X-RAY APPARATUS HAVING MEANS FOR SUPPLYING AN ALTERNATING SQUARE WAVE VOLTAGE TO THE X-RAY TUBE

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Continuation of application Ser. No. 279,362, May 10, 1963. This application Feb. 25, 1965, Ser. No. 435,150
12 Claims. (Cl. 250—102)

The present invention relates to an X-ray apparatus and, more particularly, to X-ray apparatus which is lightweight, compact, portable and permits accurate control of the wave length of its generated radiation.

This application is a continuation of co-pending application Serial Number 279,362, X-Ray Apparatus, filed May 10, 1963, in the name of Frederick G. Weighart and assigned of record to Automation Industries, Inc., now abandoned.

X-ray devices for inspecting industrial products and machine parts are commonly used in the nondestructive testing industry. In recent years, the requirements for X-ray apparatus have become stricter. It has also become desirable for the X-ray equipment to be of the so-called "portable" variety whereby it can be easily moved from one location to another. This has become very important for field testing purposes. However, portable X-ray equipment available heretofore has left much to be desired.

As is well known, an X-ray tube requires the application of high voltage between the cathode and the anode in order to generate X-rays. This voltage very frequently exceeds 100,000 volts. The components required to develop and handle voltages of such a magnitude must be relatively large, well shielded and well insulated. For maximum portability, the X-ray apparatus should be capable of operating from a standard sixty-cycle power source. Step-up transformers capable of operating at sixty-cycles and developing voltages in excess of 100,000 volts are very large and heavy, and have greatly reduced the portability of prior X-ray apparatus.

The penetrating power of X-rays is inversely proportional to their wave length, and the wave lengths in turn are inversely proportional to the anode voltage applied to the X-ray tube. Thus, when a sine wave is applied between the anode and cathode of an X-ray tube, the wave length of the radiated emission will vary widely as the amplitude of the anode voltage varies throughout the cycle. The "hardest" X-rays, i.e., those having the shortest wave lengths, are produced at the peak of the sine wave and have the maximum penetrating power. During the portions of the cycles when the anode voltage is less than its peak value, the X-rays are "softer" and have considerably less penetrating power. As a result in alternating X-ray systems available heretofore, there has been no control over the spectral output of the X-ray tube and it has been impossible or extremely difficult to achieve maximum penetration efficiency.

It is one of the primary objects of this invention to provide X-ray apparatus of improved portability.

It is a further object of this invention to provide an X-ray device which can be operated from standard sixty-cycle power sources but is lightweight and easily transported from one location to another.

It is a further object of this invention to provide such a device wherein the wave length of the output radiation is controllable.

The manner in which the above objects are achieved will be more apparent from the following description, the appended claims and the figures of the attached drawings, wherein:

FIGURES 1 and 2 are schematic diagrams of an X-ray of a circuit apparatus embodying one form of this invention; and

FIGURE 3 illustrates the relationship between FIGURES 1 and 2.

Before proceeding to a detailed description of the circuit of this invention, its general operation may be briefly described as follows:

The circuit is energized from a sixty-cycle power source which may be either 115 or 230 volts. This is applied to an input transformer whose output controls the operation of the X-ray circuitry and also provides safety features and operator indications. The primary input to the transformer is also applied to a D.C. power supply which, in the embodiment to be described, comprises a full wave rectifier. One side of the relatively low voltage D.C. source is applied to the center tap of the primary of the anode transformer. By means of the novel circuitry to be described below, the ends of the transformer primary are alternately grounded to provide a square wave output from the secondary side at a frequency determined by the frequency of the alternate grounding.

The specific construction of the circuit of the invention will now be described by reference to the drawing. Primary 60 cycle power input is applied to the circuit at terminals **10** and is controlled by means of the double pole single throw switch **12** and the relay **14**. The relay **14** operates only upon the application of 230 volts A.C. to automatically double the turns of the primary winding of auto-transformer **18**.

Transformer **18** can receive either a 115 or a 230 volt input without switching or internal wiring changes. The contacts **16** are illustrated in their "normal" position with contact **16*a*** closed. Upon the application of 230 volts to relay coil **14**, **16*a*** opens and **16*b*** closes, applying the input voltage to the entire primary winding of transformer **18**.

Energization of the transformer **18** also energizes a cooling blower **20** and an indicating lamp **22** which provides a standby indication. For further operation of the X-ray circuitry, a keyed switch **24** is provided for purposes of safety. Closing of the switch **24** applies power directly to one side of the actuating coil of relay **26**.

An electrically operated timer motor **28** operates switches **30** and, when the timer is turned off zero, the contacts **301**, **302** close. Switch **32** then closes when transformer **34** is adjusted to minimum output. This completes the circuit to the coil of relay **26** so that contacts **271** and **272** close.

Contact **271** serves as a holding contact to keep the relay **26** energized when the kv. control transformer **34** is adjusted to operating voltage and switch **32** opens. Contact **272** applies power to the primary of transformer **36** and to kv. control transformer **34**. When voltage is applied to transformer **34**, it is also applied to the normally closed contact of a flasher **38** which intermittently operates the relay **40**, causing the warning lamp **42** to flash.

The output voltage from kv. control transformer **34** is applied to a full wave rectifier circuit **44**. The pulsating D.C. output is filtered by an inductor **46**, smoothed by shunt-connected capacitor **47**, and is applied to the center tap **48** of the primary **50** of transformer **52** and to the center tap **54** of primary **56** of transformer **58**.

The low voltage D.C. which is thus applied to the primaries of transformers **52** and **58** is converted to A.C. by alternately grounding the opposite ends of each of the primary windings. This is accomplished by means of the trigger circuits to be described below. The frequency of the switching is the frequency of the induced alternating E.M.F. applied to the X-ray tube.

The trigger circuits used in this invention comprise a multivibrator, an emitter follower, a phase splitter and a converter. The multivibrator of this invention is of a standard design and includes a pair of transistors **60**. Its frequency is controlled within the range of 500 to 650 cycles per second by means of a milliampere control **62** comprising ganged potentiometers **64, 66**.

The supply voltage for the multivibrator is decoupled by inductor **68** and capacitor **70**. The collector voltage is maintained at a preset value by means of a suitable Zener diode **72**. The width of each half cycle of the square wave output of the multivibrator is controlled by the duty cycle adjustment control potentiometer **74**. This control establishes the conduction time of transistor **60** and thereby controls the pulse duration of each transistor.

The square wave output from the multivibrator is applied by means of the emitter follower **76** to a phase splitter transistor **78**. The outputs from the phase splitter taken over coupling capacitors **80, 82** from the collector and emitter circuit, respectively, comprise two trains (*a*) and (*b*) of square wave pulses which are 180 degrees out of phase. Pulses (*a*) and (*b*) are each prevented from going negative by means of the clipping diodes **84, 86**.

The "base-line" of each train is adjusted by the A.C. voltage level from rectifier **85** as smoother by capacitors **87, 89** and received over conductor **91**. Pulse train (*a*) is applied to the gate of a silicon-controlled rectifier **88** and pulse train (*b*) is applied to the gate of silicon-controlled rectifier **90**.

As the pulse trains (*a*) and (*b*) are 180 degrees out of phase, the silicon-controlled rectifiers **88, 90** are alternately caused to conduct. As the rectifiers **88** and **90** alternately conduct, they connect the opposite ends of the primary **50** of transformer **52** and the opposite ends of primary **56** of transformer **58** to ground, thereby providing an alternating input at the switching frequency.

A commutating capacitor **92** is connected across the primaries **50** and **56** of the transformers **52, 58**. The slight delay introduced by the charging time of capacitor **92** permits each of silicon-controlled rectifiers **88, 90** to return to the blocking state.

Too rapid charging of the capacitor **92** is prevented by choke **94** at the outlet of the D.C. power supply. Choke **96** limits transient peaks during switching and diodes **98** prevent negative peaks and oscillation.

The operating voltages for the X-ray tube **100** are supplied through the anode transformer **52** and the cathode filament transformer **58**. The A.C. voltage which is induced in each transformer secondary is variable in amplitude by variation of the input voltage controlled by variable auto-transformer **34**.

In one embodiment of the invention, the actual D.C. voltage from rectifier **44** is variable between 15 and 60 volts and results in induced secondary voltages variable between 17.5 and 70 kvp. making the total voltage applied between anode and cathode during the "on" period of the tube equal to 35–140 kvp. Furthermore, it will be recognized that the voltage which is supplied between the anode and cathode of the X-ray tube has a square wave form. Accordingly, the radiation emitted by the tube is of a fixed wave length and thus has a constant penetrating power throughout each portion of its on cycle.

The anode current of the X-ray tube **100** is dependent upon cathode emission which, in turn, is dependent upon filament temperature. The filament temperature is controlled by the series circuit of inductance **102** and capacitance **104** which form a resonant circuit responsive to the frequency of the secondary voltage induced in a separate filament winding **57** of transformer **58**.

In the described embodiment the LC circuit is resonant at 650 cycles and at that frequency permits maximum current flow and maximum filament temperature. However, as the frequency is decreased, the LC circuit offers a higher impedance, thereby directly reducing the current flow and indirectly reducing the anode current. The operation of this filament control is disclosed and claimed in co-pending patent application, Serial No. 263,043, for Voltage Control, filed March 5, 1963, by James F. McNulty, and assigned to the same assignee as the present application, now abandoned.

A thermal cutout switch **106** is included in that portion of the apparatus housing the X-ray tube **100** for turning off all voltages when the temperature of this portion of the apparatus exceeds a preselected amount. When the thermal cutout **106** opens, the relay **26** is de-energized, opening switches **271, 272** and returning the unit to its standby condition.

It will be understood by those skilled in the art that a number of important advantages are achieved by the apparatus of this invention.

First, the apparatus is energized from a standard 60 cycle power source but utilizes internal high frequency, produced by solid state circuitry, to reduce component sizes.

Second, the output spectrum from the X-ray tube is controlled by shaping the high voltage wave form applied to the tube. In the illustrated embodiment, this applied voltage is in the form of a square wave to produce maximum penetrating power. However, other wave shapes can also be employed, for example—a sawtooth wave would provide a linear frequency change in the output radiation.

Third, the high voltage control is achieved solely in the low voltage circuits. A novel approach is employed utilizing a controllable low voltage A.C. which is rectified to D.C. The D.C. is then applied alternately between the center tap and each end of the primary winding of the anode transformer.

In addition to the foregoing, many other advantages of the invention as well as many modifications and variations not departing from its spirit and scope, will be apparent to those skilled in the art.

It may be seen that the frequency at which the multivibrator runs may be considerably higher than the standard 60 c.p.s. power supply. This, in turn, will greatly reduce the amount of material required for the cores of the transformers and the conductors forming the various windings. Since the multivibrator and related equipment are all of the solid state variety they are of a very small and lightweight variety. As a consequence, the overall weight and size of the X-ray apparatus is greatly reduced so that a high performance X-ray apparatus can be built in a sufficiently small size to be portable.

Accordingly, the foregoing disclosure and description thereof are for illustrative purposes only, and do not in any way limit the invention which is defined only by the claims which follow.

What is claimed is:

1. X-ray apparatus of the class described including the combination of

input means adapted to be interconnected with a source of power,

square wave generator means coupled to the input means for producing a low voltage train of square waves,

a step-up transformer having a primary winding and a secondary winding, said windings having a turns-ratio which will provide a high tension voltage in the secondary winding,

said primary winding being coupled to said square wave generator means whereby the low voltage train of square waves circulates in said primary winding and produces a high tension train of alternating square wave in the secondary winding,

an X-ray tube having an anode and cathode, and

means coupling said secondary winding to the said tube for coupling the high tension train of square waves to the anode, said high tension square waves being effective to maintain the anode at a substantially constant voltage when the anode is radiating X-rays.

2. X-ray apparatus of the class described including the combination of

input means adapted to be interconnected with a source of power for receiving power therefrom,

pulse generator means interconnected with the input means for producing a series of low voltage pulses of square wave shapes,

a step-up transformer having a primary winding and a secondary winding, said windings having a turns-ratio which will provide a high tension voltage in the secondary winding,

said primary winding being coupled to said pulse generator means whereby the series of low voltage pulses circulate through the primary and produce a train of high tension pulses in the secondary winding having alternating polarities,

an X-ray tube having an anode and cathode,

means coupling said secondary winding to the tube for coupling the train of high tension pulses to the anode, and

means in said pulse generator means to vary time durations of the pulses of opposite polarity applied to the anode.

3. X-ray apparatus of the class described for inspecting a particular portion of a test piece, said apparatus including the combination of

a high tension power supply for producing a high voltage,

pulse generating means in said power supply for producing alternating high voltage pulses having alternately opposed polarities and square wave shapes, and

an X-ray tube having a cathode and anode, said tube being coupled to said high tension power supply to form a self-rectifying circuit, said anode being effective to radiate X-rays in response to the high voltage pulses, the amplitude of said voltage pulses producing X-rays having a wave length which will penetrate the portion of said test piece being inspected.

4. X-ray apparatus of the class described including the combination of

input means adapted to be interconnected with a source of power for receiving power therefrom,

pulse generator means coupled to the input means for producing a low voltage train of pulses having predetermined wave shapes,

a step-up transformer having a primary winding and a secondary winding, said primary winding being coupled to said pulse generator whereby said low voltage pulses circulate in said primary winding,

said secondary winding being coupled to said primary winding and having a step-up turns-ratio whereby the low voltage pulse train in the primary produces a high tension voltage pulse train of alternating polarity in the secondary winding having wave forms corresponding to the pulses in said low voltage train,

an X-ray tube having an anode and cathode, and

means coupling the anode and cathode to said secondary winding for coupling the high tension voltage to the anode whereby said anode is energized corresponding to the pulses in the high tension voltage.

5. X-ray apparatus of the class described including the combination of

converter means adapted to the interconnected with a source of alternating power having a first frequency, said converter means being effective to produce a square wave having a frequency that is greater than the frequency of said source,

a step-up transformer having a primary winding and a secondary winding, said windings having a turns-ratio which will provide a high tension voltage in the second winding,

said primary winding being coupled to the converter means for receiving the higher frequency square wave and producing a higher frequency, high tension alternating square wave in the secondary,

an X-ray tube having an anode and cathode, and

means coupling said secondary winding to said tube for coupling the high frequency, high tension square wave to the anode.

6. X-ray apparatus of the class described including the combination of

rectifying means adapted to be interconnected with an alternating power source, said rectifying means being effective to rectify said power and provide a direct voltage between the opposite sides thereof,

a step-up transformer having a primary winding and a secondary winding, said primary winding having the center thereof coupled to one side of the rectifying means,

converter means interconnected with said rectifying means and the opposite ends of the primary winding, said converter means being effective to alternately interconnect the opposite ends of the primary winding with the opposite sides of the rectifying means at a frequency that is higher than the frequency of said source to thereby produce a higher frequency, high tension voltage in the secondary winding,

an X-ray tube having a cathode for generating free electrons and an anode for radiating X-rays, and

said means coupling the secondary winding to the anode to apply the higher frequency, high tension voltage to said anode to accelerate the free electrons whereby the tube radiates X-rays.

7. X-ray apparatus of the class described including the combination of

power supply means adapted to be interconnected with a power source, said power supply means being effective to provide direct power,

frequency converter means interconnected with said power supply means to convert said direct power into a high frequency alternating power,

a step-up transformer having a primary winding and a secondary winding coupled to the primary winding, said primary winding being interconnected with the frequency converter for receiving the high frequency power,

an X-ray tube having an anode and cathode, and means directly connecting the anode and cathode to the secondary winding to form a self-rectifying circuit that includes the anode and cathode.

8. X-ray apparatus including the combination of

rectifier means arranged to be energized from an A.C. power source at a first frequency to form D.C. power supply means,

transformer means having a primary winding with a center tap between its ends and a secondary winding coupled to the primary winding,

switching means having a first solid state controlled rectifier connected between one end of said primary winding and ground, and having a second solid state controlled rectifier connected between the other end of said primary winding and ground to alternately pass the D.C. output of said power supply means through said primary winding in opposite directions to produce an A.C. output at a second frequency in the secondary winding,

triggering circuit means having multivibrator means arranged to produce a square wave output, phase splitter means activated by said square wave output to produce first and second out-of-phase triggering signals together with means for applying the first triggering signal to the gate of said first rectifier and the second triggering signal to the gate of said second rectifier to alternately activate the gates of said first and second solid state controlled rectifiers at a frequency substantially higher than said first frequency but less than radio frequency, and

X-ray tube means connected to receive said A.C. output across its anode cathode circuit.

9. X-ray apparatus including the combination of

rectifier means arranged to be energized from an alternating power source at a first voltage and first frequency to produce a D.C. output signal,

relay means having a first position and a second position to connect said rectifier means for energization from a supply voltage, said relay means being responsive to the magnitude of said voltage to move to one position when the voltage is at a first level and a second position when the voltage is at a second level,

transformer means having a primary winding and a secondary winding, said primary winding including a tap positioned between its ends,

means for applying one side of said D.C. output to said tap and the other side to ground,

a first solid state controlled rectifier connected between a first end of said primary winding and ground,

a second solid state controlled rectifier connected between a second end of said primary winding and ground,

multivibrator means arranged to produce a square wave output at a second frequency,

phase splitter means activated by said square wave output to produce first and second out-of-phase triggering signals,

means for applying the first triggering signal to the gate of said first controlled rectifier,

means for applying the second triggering signal to the gate of said second controlled rectifier, and

X-ray tube means connected to receive said X-ray output across its anode cathode circuit.

10. X-ray apparatus of the class described including the combination of

input means adapted to be coupled to a source of alternating power having a standard frequency,

rectifying means coupled to the input means for receiving the alternating power of standard frequency, said rectifying means being effective to rectify said alternating power and provide direct power having a unipolar voltage,

converter means interconnected with said rectifying means to intermittently invert the voltage of the direct power and form a bipolar second alternating power,

timing means coupled to the converter means to trigger the converter at a frequency which is higher than the standard frequency of said source whereby the second alternating power will have said higher frequency,

a primary winding in a step-up transformer coupled to the converter means for receiving the high frequency power,

a secondary winding in said transformer coupled to the primary winding to produce a high voltage having said high frequency,

an X-ray tube having an anode and cathode, and

a self-rectifying circuit coupling the secondary winding to the anode and cathode.

11. X-ray apparatus of the class described including the combination of

frequency converter means adapted to be interconnected with a low frequency power source, said converter means being effective to provide alternating power having a frequency which is higher than the low frequency of said source,

frequency control means coupled to the frequency converter means for varying the frequency of the higher frequency power,

a step-up transformer having a primary winding and a pair of secondary windings, said primary winding being coupled to the frequency converter for receiving the higher frequency power and producing a high tension voltage in the first secondary winding,

an X-ray tube having a cathode for producing free electrons and an anode for radiating X-rays,

coupling means coupling the second secondary winding to the cathode for energizing said cathode to produce the free electrons,

coupling means coupling the anode to the first secondary windings to apply the high tension voltage to said anode and accelerate the free electrons to the anode whereby the tube radiates X-rays,

at least one of said coupling means including a frequency responsive impedance to vary the voltage thereacross as the high frequency varies.

12. X-ray apparatus of the class described including the combination of

frequency converter means adapted to be interconnected with a power source having a standard low frequency, said converter means being effective to provide alternating power having a frequency which is higher than the standard frequency of said source,

control means coupled to the frequency converter means for varying the voltage of the higher frequency power,

a step-up transformer having a primary winding and a secondary winding, said primary winding being coupled to the frequency converter for receiving the high frequency power having a controlled voltage and producing a controlled high tension voltage in the secondary,

an X-ray tube having a cathode for producing free electrons and an anode for radiating X-rays, and

means coupling the secondary winding to the anode to apply the controlled high tension voltage to the anode to accelerate the free electrons to the anode whereby the tube radiates X-rays.

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