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HIGH VOLTAGE POWER SUPPLY

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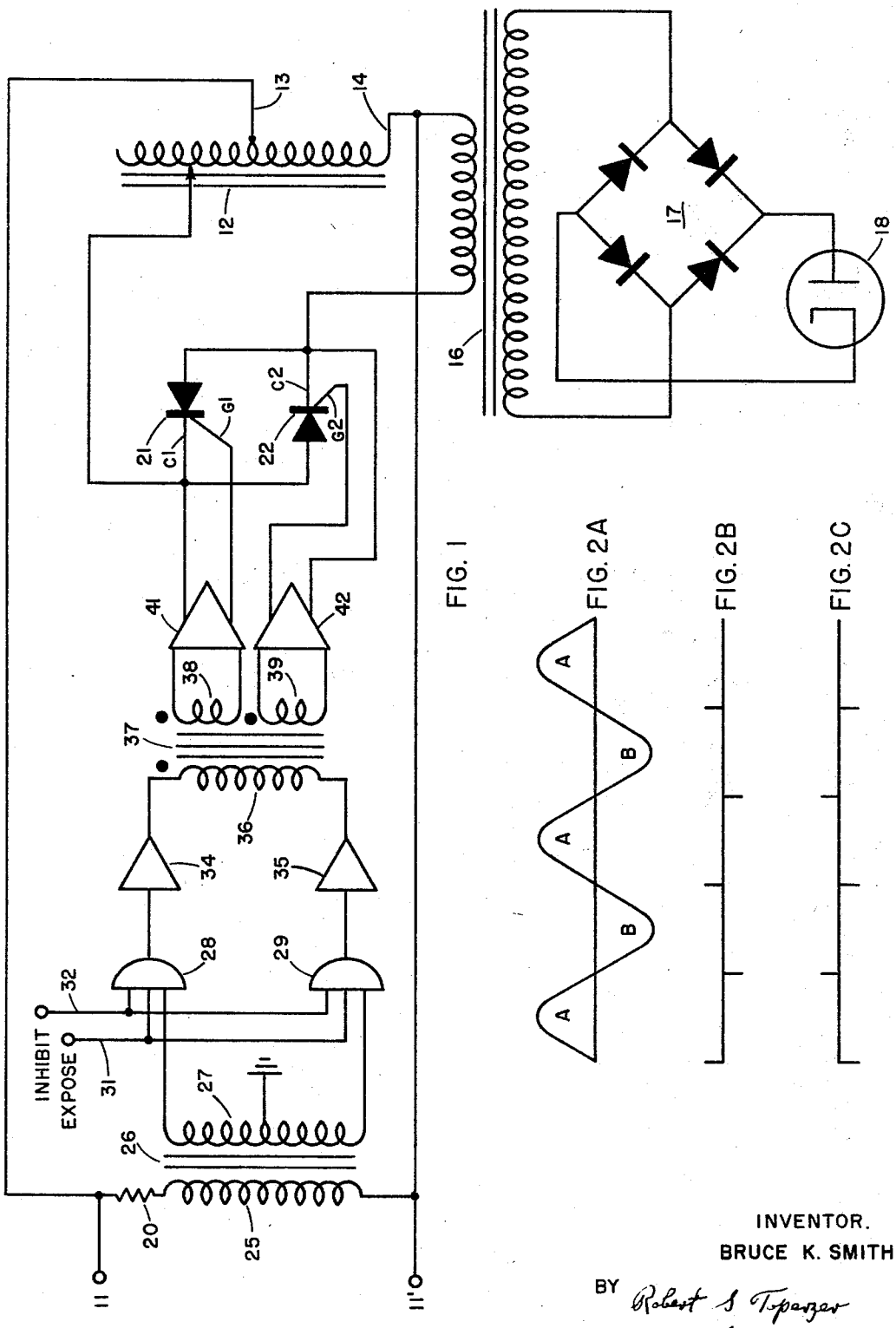


FIG. 1

FIG. 2A

FIG. 2B

FIG. 2C

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HIGH VOLTAGE POWER SUPPLY

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This invention relates generally to high voltage power supply apparatus and especially to apparatus of the type used in connection with X-ray generating equipment.

As is well known to those skilled in the art, conventional X-ray generating equipment for clinical use includes one or more high voltage transformers for supplying power to the X-ray tube. Such tubes commonly require anywhere from 30 to 150 kilovolts at 500 milliamperes, which means that the transformer must be a fairly heavy one, in the order of 500 lbs. and 15 cubic feet. This is the major reason for the large bulk of such equipment.

To keep the size of these transformer units to a minimum, special provisions are usually made to ensure that the high voltage transformer or transformers are not subject to large transient currents such as would otherwise occur when the sense of the residual flux, which remains after an exposure has been completed, is the same as that which is produced when the transformer is first energized for another exposure. In the past, a phase sensitive relay has been used for this purpose, the contacts of the relay operating in synchronism with the alternations of the current supplied to the transformer and evidencing by their condition, the sense of the last half cycle of current supplied during each exposure. Connected in circuit with the relay is a thyratron control which enables a contactor in circuit with the transformer to initiate the next exposure in precise time relation to a zero axis crossing of the current waveform which introduces the currect direction of the excursion of the curent waveform, that is the proper half cycle. It follows that not only must the contactor be a heavy one to carry the required amount of current to the transformer, but also it must be fast acting and precise in its response upon closure. As a result, considerable difficulty has been encountered in maintaining such contactors in adjustment since as costly as these units are, there are many factors affecting their adjustment, such as contact wear and spring fatigue which cannot be entirely avoided. Then, too, the relay itself is subject to malfunction for much the same reasons and at best its operational life is strictly limited.

In accordance with the present invention these difficulties are overcome through the use of silicon controlled rectifiers in combination with a novel control circuit for the rectifiers which performs this phase memory function. In brief, the control circuit includes means to provide pulses of alternating polarity in synchronism with the current supplied to the high voltage transformer, and means to control the duration of the pulses as a function of the exposure time. The pulses are applied to the primary of a saturable transformer which in turn supplies control pulses for alternately enabling a pair of silicon controlled rectifiers. The rectifiers are disposed in parallel but with their polarity reversed with respect to one another so that during an exposure operation, alternating current is permitted to flow to the high voltage primary first through one and then the other of the rectifiers in a continuing sequence. Upon completion of the exposure, the sense of the residual flux remaining in the saturable transformer is adapated to represent the residual flux state of the high voltage transformer. Accordingly, when a new exposure is initiated, the sense of the first control pulse produced by the saturable transformer will be predetermined so that the first one of the rectifiers to be enabled conducts current to the high voltage transformer in the proper direction to avoid transient overloading.

An object of the present invention therefore is to provide an improved high voltage power supply for X-ray applications.

A more specific object is to provide a novel form of phase memory circuit for use in this type of power supply.

Still another object is to provide more compact and reliable apparatus of the above-mentioned character.

The novel features of the invention together with further objects and advantages will become more readily apparent from the following detailed description of a preferred embodiment and from the accompanying drawing to which the description refers. In the drawing:

FIG. 1 is a schematic diagram of the power supply apparatus in accordance with the present invention, and

FIGS. 2A through 2C are timing diagrams of certain of the waveforms and pulses that are present in the apparatus.

With reference now to the drawing, it will be observed that the numerals **11**, and **11'** have been used to designate a source of alternating current such as 110 or 220 volts and that the input circuit of an adjustable auto transformer **12** is connected across these therminals. As shown, the input circuit of this transformer is characterized by a tap **13** and one end of the transformer winding **14**. Coupled to the output circuit of the transformer **12** is a high voltage transformer **16** having its secondary winding connected to a full wave bridge rectifier circuit **17**. High voltage for powering a device such as an X-ray tube **18** is derived from the bridge circuit.

To control the high voltage in accordance with the invention there are provided in circuit between the auto transformer **12** and the high voltage transformer **16** a pair of silicon controlled rectifiers **21** and **22**. Rectifiers **21** and **22** are arranged in parallel with their polarities reversed with respect to one another, and are alternately enabled to conduct by means of control pulses, which are derived in the following manner. There is coupled to a source of alternating current such as that provided at terminals **11**, **11'**, the primary **25** of a pulse transformer **26** which has its secondary **27** connected to a pair of logical AND circuits **28** and **29**. A current limiting resistor **20** is included in circuit with the primary **25**. In addition to the signal inputs from transformer **26**, each AND circuit is responsive to an expose signal on a line **31** and inhibit signal on a line **32**. The latter signal determines the duration of the high voltage applied to X-ray tube **18**. In this regard it will be understood, of course, that such timing information can be furnished by means of a signal on but one line, although for convenience it is preferred to employ both an expose and inhibit signal input to control the AND circuits.

Coupled to the output of the respective AND circuits through driver amplifiers **34** and **35** is the primary winding **36** of a saturable transformer **37**. Saturable transformer **37** has a pair of secondary windings **38** and **39** which are connected through individual driver amplifiers **41** and **42** to the gate circuit of the silicon controlled rectifiers **21** and **22**. As shown, gate electrodes *g*1 and *g*2, and cathodes *c*1 and *c*2 comprise these respective gate circuits.

In operation, it will be assumed for purposes of explanation that the AND circuits respond to signals of positive polarity only, and that line **32** is provided with a positive level whenever the X-ray apparatus with which X-ray tube **18** is associated, is conditioned for an exposure. Accordingly, when an expose signal is produced on line **31** to make the exposure, it follows than AND circuits **28** and **29** will be conditioned to respond to positive pulses from pulse transformer **26**.

The mode of response of the AND circuits will be readily understood by reference to FIGS. 2A through

2C. FIG. 2A illustrates the sinusoidal waveform of the alternating current delivered to the primary of pulse transformer **26** by way of terminals **11** and **11'**. The positive half cycles are designated by the letter "A" and the negative half cycles are designated "B." FIGS. 2B and 2C illustrate the relative polarities of the pulses from the pulse transformer **26** as they appear at the inputs to the respective AND circuits. Also illustrated is the time relation of the pulses to the current waveform of FIG. 2A namely, the time corresponding approximately to the zero axis crossings of the waveform by virtue of the fact that the pulse transformer is adapted to saturate at but a small fraction of the peak value of the current. It is evident from FIGS. 2A through 2C, therefore, that AND circuits **28** and **29** are sensed alternately by the pulses from transformer **26** and that as a result, pulses of alternating polarity are passed to the primary of transformer **37** by way of amplifiers **34** and **35**.

If it is assumed that the first pulse to be passed to the primary of saturable transformer **37** induces a current which flows away from the dot end of the winding, then the current induced in secondary winding **38** likewise flows away from the dot end of the winding as does the current induced in secondary winding **39**. Assuming also that no phase reversal takes place in amplifiers **41** and **42**, this means that gate electrode *g*1 of rectifier **21** is maintained positive so that the rectifier is enabled to conduct, while the opposite is true for rectifier **22**. The senses of the winding of auto transformer **12** and pulse transformer **26** are arranged so that at the same time rectifier **21** is enabled, its anode swings positive with respect to its cathode so that current is permitted to flow from the auto transformer to the primary of the high voltage transformer. This condition obtains until the next half cycle designated B in FIG. 2A, notwithstanding the fact that the control pulse applied to the gate electrode of rectifier **21** is only momentary, because it is characteristic of the rectifier that once it has been enabled, it continues to conduct in the easy direction. With the advent of the next half cycle B, a pulse of opposite polarity from the first pulse is passed to the primary of the saturable transformer which in turn induces a pulse in secondary winding **38** that enables rectifier **22**. Current now flows in the opposite direction from the auto transformer to the high voltage transformer by way of rectifier **22**. No current flows through rectifier **21** since it is substantially nonconductive to current flowing in this direction and so it becomes disabled. In this way, the rectifiers continue to be alternately enabled and disabled permitting alternating current to flow from the auto transformer to the primary of the high voltage transformer until an inhibit signal is produced on line **32**. When the inhibit signal occurs, that is when the positive level on line **32** is removed, then both AND circuits **28** and **29** are disabled from supplying further pulses to the saturable transformer **37**. Rectifiers **21** and **22** then cease conducting upon completion of the half cycle occurring contemporaneously with the inhibit signal, and no further current flows from the auto transformer to the primary of the high voltage transformer.

Thus far in the discussion of the operation of the apparatus, the residual flux state of the saturable transformer has been disregarded. But now let it be assumed that the last pulse to be passed to the primary of the saturable transformer was a positive one, and that another positive pulse is produced when the sequence of operations just described is reinitiated. This of course will be the case when an exposed signal is applied to AND circuits **28** and **29**, during one of the positive half cycles A, the probability of course being that this will occur 50% of the time. Under these conditions no control pulse is produced by saturable transformer **37** in response

to this first positive current pulse inasmuch as the transformer has been saturated by the positive pulse occurring at the end of the last exposure. Hence, no current is permitted to flow to the high voltage transformer during this first half cycle. Instead the high voltage transformer becomes energized during the next half cycle when the direction of current flow is opposite to that which it was when the transformer became deenergized at the end of the previous exposure thereby avoiding the high transient current and resultant damage to the transformer which would otherwise occur.

Although the invention has been described in terms of a single idealized embodiment, those skilled in the art will recognize that this embodiment is susceptible of various modifications and refinements that are within the spirit and scope of the invention. For example, various pulse shaping techniques can be incorporated in the circuitry either to supplement the function of the pulse transformer or in lieu thereof. Also it will be apparent that the expose and inhibit functions can be carried out in various other ways. Therefore the invention should not be deemed to be limited to the details of what has been described herein by way of illustration but rather it should be deemed to be limited only by the scope of the appended claims. What is claimed is:

1. In an X-ray system, the combination comprising an X-ray tube, a high voltage transformer having a secondary winding coupled to said X-ray tube and a primary winding adapted to induce high voltage in said secondary winding, a pair of oppositely poled rectifiers, each having gate means to enable it to conduct current selectively in response to a control signal, said rectifiers being disposed in parallel between a source of alternating current and the primary winding of said high voltage transformer, means to produce synchronizing signals representative of the alternations of the current from said source, means to produce timing signals defining the beginning and the end of a time period of pre-determined duration corresponding to a desired X-ray exposure time, a saturable transformer having a primary winding and a secondary winding, means to produce current alternations in the primary winding of said saturable transformer in synchronism with said synchronizing signals for a period defined by said timing signals, and means to derive from said saturable transformer secondary, control signals for alternately enabling said rectifiers to conduct current from said source to said high voltage transformer primary.

2. The combination as claimed in claim **1** wherein said means for producing current alternations in the primary of said saturable transformer includes a switching circuit to signal the simultaneous occurrence of said synchronizing signals and said timing signals, and an amplifier circuit coupled between said switching circuit and said saturable transformer primary.

3. The combination as claimed in claim **2** wherein said means to generate synchronizing signals comprises a pulse transformer coupled to said source.

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