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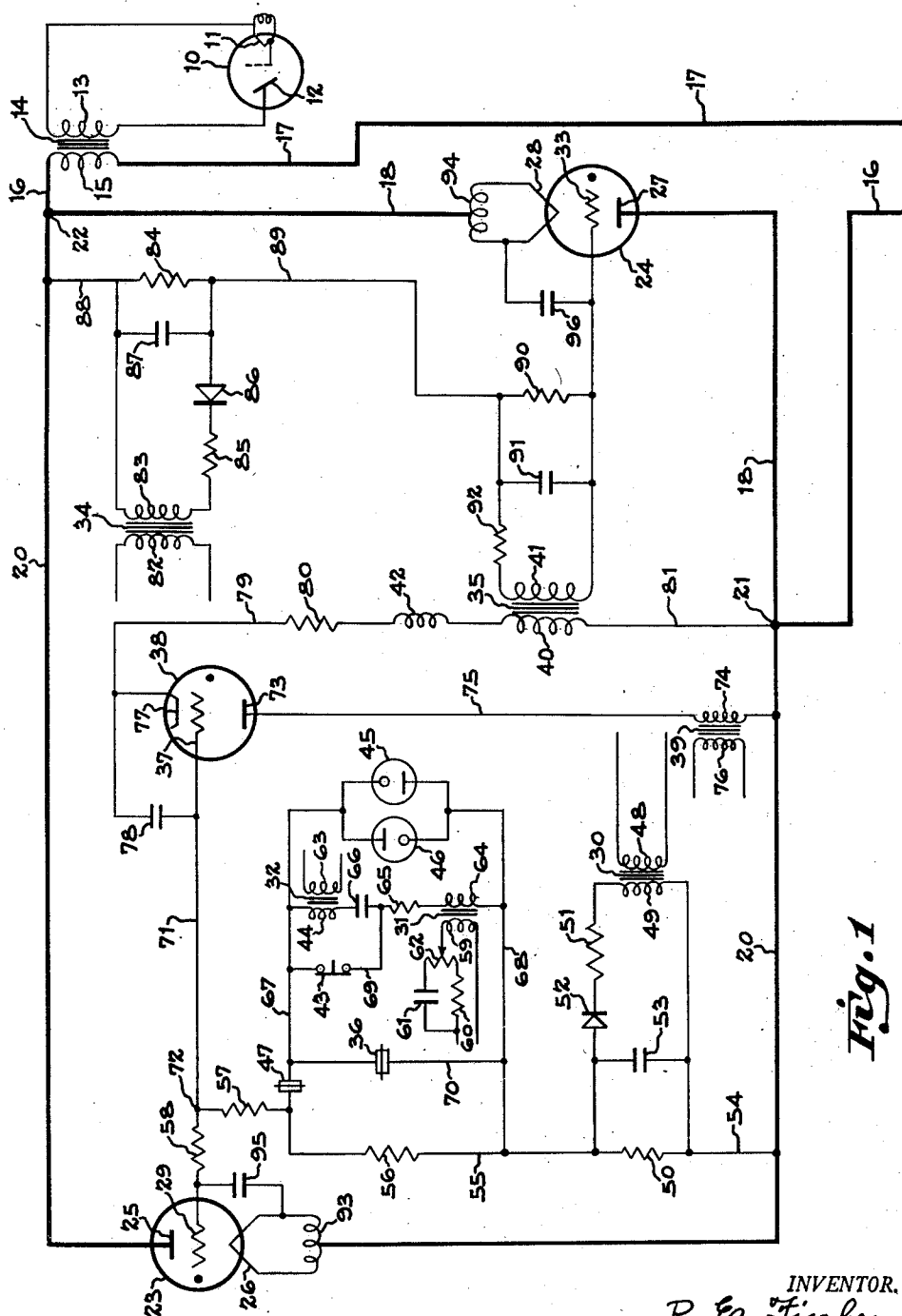
R. E. FISCHER

2,584,007

ELECTRONIC CONTACTOR

Filed Dec. 1, 1950

2 SHEETS—SHEET 1



INVENTOR.
R. E. Fischer
 BY
Wood, Argy, Henson & Evans
 ATTORNEYS.

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2 SHEETS—SHEET 2

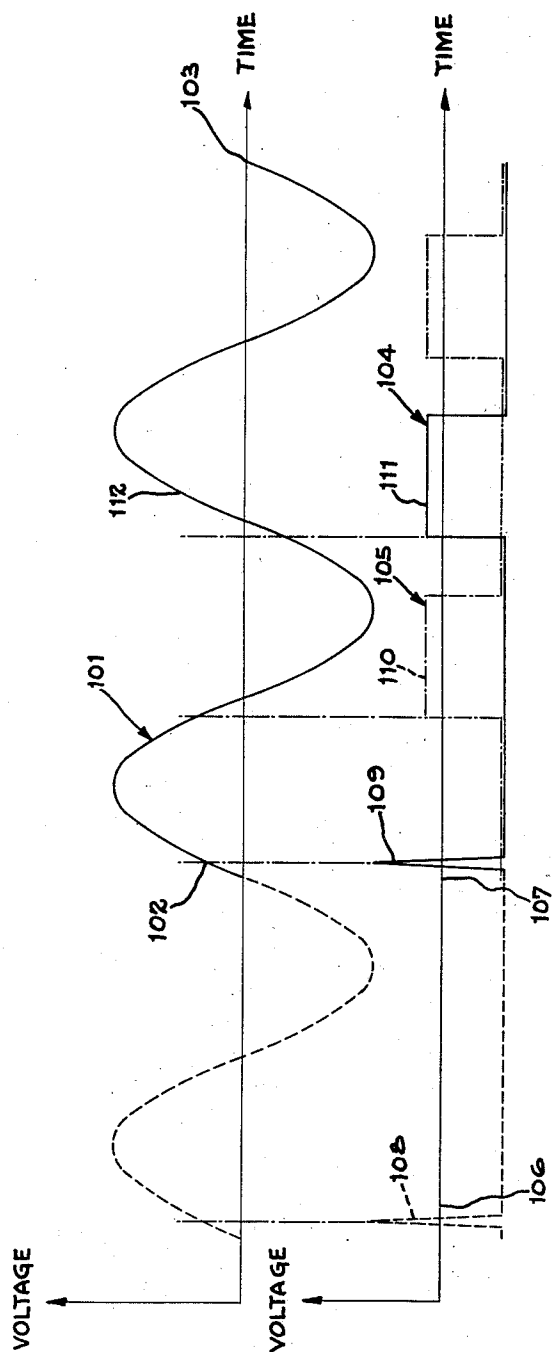


Fig. 2

INVENTOR.
R. E. Fischer.
BY
Wood, Gray, Heron & Evans.
ATTORNEYS.

UNITED STATES PATENT OFFICE

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ELECTRONIC CONTACTOR

Robert E. Fischer, Cincinnati, Ohio, assignor to
The Liebel-Flarsheim Company, Cincinnati,
Ohio, a corporation of Ohio

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This invention relates to an electronic contactor through which an electric power circuit may be completed to an electrical device. The invention is disclosed particularly in relation to X-ray radiography, in which the present contactor is employed as a circuit controlling switch through which energy is applied to an X-ray tube from a transformer for a given period of time.

A principal objective of the invention has been to provide a stable electronic contactor capable of reliably providing, under widely varying load conditions, a conductive path for a predetermined period or interval of time which commences and terminates in predetermined relationship to the phasing of the line or power voltage. However, in order that the significance of this objective may be fully appreciated, it is helpful briefly to describe the problems which have been encountered in X-ray radiography with the use of presently available instrumentalities.

In radiography, X-rays are passed through the subject under investigation to a sensitized photographic film which, upon development, varies in density according to the X-ray opacity of the various portions of the subject. Usually, the X-ray tube is connected across the high potential terminals of a transformer secondary winding, either directly or through rectifying means, and exposure is governed by making and breaking the power circuit to primary winding of the transformer. With the advent of X-ray tubes capable of being operated at higher potential, higher current, or both, and hence capable of furnishing more powerful X-ray beams, the time of exposure required for radiographing a given subject has been decreased appreciably. It is not unusual, in present day techniques, for exposures to be made in as little time as $\frac{1}{16}$ to $\frac{1}{32}$ of a second.

Simple mechanical or magnetic contactors inherently are incapable of providing the accuracy which is required in short exposure radiography. Thus, the response of a magnetic contactor operated mechanically is unpredictable and differs not only from day to day because of variations in temperature, contact wear, the fit of the parts, and the degree to which they are lubricated, but is incapable of controlling the circuit discriminately in respect to cyclic variations of the current which is to be passed through it. Errors in timing caused by such factors cause undesirable variations in the photographic quality of the final X-ray pictures. This is especially true for short exposures wherein even a small

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timing error may constitute a substantial percentage of the total exposure time.

To avoid timing imperfections inherent in such apparatus, electronic contactors have been proposed, embodying gas-filled tubes capable of being rendered conductive under grid control, with the time interval during which conductivity conditions are permitted to prevail being governed either manually, electrically, or mechanically by means of an interval timer or time switch. Electronic contactors of this type display less unpredictable time lag, and therefore, are inherently more accurate than mechanical contactors. However, in the use of such devices, perplexing variations in film density have occurred which cannot be attributed to mechanical time lag, improper pilot interval timing, or unintended cyclic indiscrimination.

One reason which has been proffered to explain such variations is that high frequency transients usually occur in the transformer secondary circuit when the transformer windings are energized at random. In an alternating current circuit, both the voltage and the current vary from zero to maximum twice during each cycle. If the circuit to the primary winding of the transformer is closed when the voltage is other than zero, the high inductance of the secondary winding of the transformer, together with the distributed capacity of the transformer itself and the X-ray tube and cable, cause voltage oscillations to be produced having a frequency higher than the frequency of the applied voltage; they may be called high frequency transients.

Since these transients are produced essentially in the secondary circuit of the transformer, they are reproduced as voltage variations on the X-ray tube, in the form of appreciable surges which exist for an indefinite, though usually short, period of time following circuit completion. Under continued energization of the transformer, these transients largely disappear and the voltage at the tube conforms to the steady state or rated output voltage of the transformer. However, so long as they exist, the tube is energized at higher potential, and the increased X-ray energy from it disproportionately affects the photographic film. Moreover, the appearance of high frequency transients in a transformer secondary circuit introduces serious complications into the X-ray exposure of photographic film through a Bucky diaphragm, since the abnormal energization of the X-ray tube causes grid lines from the Bucky diaphragm to appear upon the film, no matter what the rate

of actuation of the diaphragm. High frequency transients, therefore, introduce photographic exposure errors which are of great significance in short exposures.

It has been appreciated that completion of the load circuit at the instant the applied or supply voltage becomes zero in its cycle is capable of preventing the transformer from introducing high frequency transient voltages into the circuit. However, even when the circuit is closed at zero voltage, and high frequency transient effects have thus been eliminated, variations in film density still occur for which the causes and correction have not previously been determined or available.

While both the voltage and the current in an alternating circuit vary from maximum to minimum during each cycle, the precise moments at which current and voltage are zero differ by the phase relationship between the current and voltage wave fronts. If the primary circuit to the transformer of an X-ray apparatus is closed at the moment when the voltage is zero, in order to eliminate high frequency transients, then a separate or different transient effect is impressed upon the X-ray tube. This second transient, which may be called a low frequency transient, continues throughout the duration of at least several cycles. We have discovered that the magnetic effects in the transformer which cause such low transients to occur, introduce variations into the tube voltage, in the momentary periods following circuit completion, and such variations produce exposure errors equally, if not more, important than those produced through high frequency transients.

When the circuit to the primary winding of a transformer is closed at the moment the wave front of the current would be at zero magnitude if steady state conditions had been established (i. e., at the natural power factor angle of the circuit), then the low frequency transients do not occur and their effect upon exposure is eliminated. However, in such a circumstance, the voltage wave front at the instant of circuit closure is not zero, but is positive or negative by an amount depending upon the natural power factor angle of the circuit. Hence, an undesirable high frequency transient of appreciable magnitude is introduced into the circuit, and the radiographic results are little better than they were before. From these considerations it is apparent that both high and low frequency transients cannot simultaneously be eliminated from an alternating current transformer circuit having a power factor other than 1. Actually, the power factor and operating characteristics of X-ray transformers vary appreciably from one type or design to the next throughout the country, and ideal power factor conditions are never found. In a practical sense, therefore, the simultaneous elimination of both high and low frequency transients cannot be accomplished. I have found, however, that by causing circuit completion to be made after voltage zero, but before the natural power factor angle of the circuit, or by deliberately allowing some high frequency transients to occur, then the significant photographic effects of both high and low frequency transients upon the film may be virtually eliminated, and radiographs of desirably uniform density may be produced even within the shortest exposure periods during which it is now feasible to operate.

In consequence of these determinations, the present invention, briefly, contemplates an elec-

tronic contactor capable, in response to signal or timer switch control, of causing power circuit completion at a predetermined point in relation to zero voltage of the alternating current cycle to provide optimum elimination of both high and low frequency transients. Thus, by selectively rendering the contactor conductive at a point in the cycle after the zero point of the voltage, but before the natural power factor angle of the circuit, the influence of both low frequency transients and high frequency transients is reduced to a minimum, and uniformity in the perfection of the radiographic results is attained.

An important further objective of the present invention has been to eliminate radiograph variations by insuring uniformity, in successive exposures, in the state of magnetic polarization of the X-ray transformer prevailing at the time the circuit is closed. After current ceases to flow in the primary winding of a transformer, the transformer core nevertheless remains magnetically polarized by virtue of its residual magnetism, the direction or state of such polarization being dependent upon the direction of current flow prevailing in the last alternation at the time the primary circuit was opened. If the polarity existing at the time of transformer energization is the same as the polarity which prevailed during the last half cycle of previous transformer energization, the transformer current will vary appreciably, and radiographic results will suffer. However, in accordance with this invention, an electronic contactor is rendered conductive over periods of time defined by one discrete cycle or multiples thereof. Otherwise expressed, if it is assumed that opposite alternations are respectively positive and negative, the present invention contemplates circuit completion in a positive alternation and circuit deenergization in a negative alternation, or vice versa. As a result of this discrimination by the contactor, the X-ray transformer, following exposure, is always left in the same direction of magnetic polarization as it was at the start of the previous exposure and radiographic uniformity is obtained.

For the reasons just discussed, energization of the transformer for whole cycle intervals eliminates variations in direction of residual transformer magnetism, and thus improves radiographic uniformity from exposure to exposure. On the other hand, the limitation of low frequency transients provides a further distinct advantage in minimizing the effects of transformer magnetization upon exposure. For example, even through the transformer may be deenergized at the end of a phase alternation opposite that at which energization was commenced, still, if a low frequency transient prevails at the moment of deenergization, the low frequency transient will cause the transformer to be left in an abnormal state of magnetization, and this abnormality would manifest itself as an exposure error in the next successive use of the X-ray apparatus. By minimizing low frequency transients in accordance with the present invention, such a possible condition of abnormality becomes a negligible factor in day to day performance and results. Thus, by controlling the period of conductivity of the contactor so that its duration is defined in terms of discrete cycles, and by additionally reducing the magnitude of low frequency transients, the deleterious effects of the polarization of the X-ray mag-

netic transformer on radiographic exposures is effectively eliminated.

Briefly, the electronic contactor of the present invention comprises gas-filled, grid-controlled electronic tubes, or thyratrons, connected in opposed parallel relationship so as to be alternately rendered conductive during one or more respective half cycles of the alternating load current. These tubes, referred to as the lead and trail tubes, are adapted to conduct a current for only half of each cycle, the tubes being rendered conductive by applying a voltage pulse upon their grids during the intervals when the anodes are positive with respect to the cathodes. A peaking transformer energized in response to push button or timer switch actuation is employed to selectively fire, or apply a positive potential to the grid of one of the tubes during the initial half cycle of conduction. However, the exact point at which the peaking transformer applies the firing voltage to the grid of the lead thyatron is selectively controlled by a phase shifting device which is adapted to control the point at which the firing voltage is produced so that it may appear on the lead tube grid at a predetermined time after the zero point of the voltage wave and before the natural power factor angle of the circuit.

The trail tube is arranged so that it will conduct in the half cycle subsequent to every half cycle in which the lead tube has been rendered conductive. This is accomplished by supplying a firing pulse to the grid of the trail tube from a pulse transformer which is energized by a trigger tube, in turn rendered conductive by the same firing pulses applied to the grid of the lead tube. Hence, each time the lead tube fires, the pilot thyatron is fired, thereby energizing a transformer which in turn supplies a firing voltage to the trail tube.

When the trail tube and the lead tube in a so-called back to back thyatron tube electronic contactor are dependent upon one another, such that the lead tube causes the trail tube to be fired, operation under certain load conditions becomes uncertain and complete loss of the circuit control by the contactor may be brought about through self-sustained conduction of the trail tube or failure of the tubes to fire. This difficulty repeatedly has been encountered in the operation of previous known electronic contactors at high kilovoltage and low milliamperage settings of the X-ray machine. In the present invention, stability of operation is conferred upon the contactor by utilizing a separate firing circuit for the trail tube which is independent of the cathode-anode circuit of the lead tube, and by this arrangement the present contactors are adapted for use with circuits carrying currents varying from a few to hundreds of milliamperes.

This method of conditioning the trail tube for conductance, however, presents the problem of insuring that both the lead tube and trigger tube will always become conductive whenever suitable pulses are supplied to their respective grid circuits. Thus, since the lead tube and trigger tube are fired from the same circuit, it is possible that the trigger tube may fire slightly before the lead tube, and consequently deprive it of the pulse necessary to render the lead tube conductive. I have determined that this possibility may be eliminated by placing the load of the trigger tube in its cathode circuit and coupling the cathode circuit with the grids of the lead and trigger tube. With this arrangement, even if the trigger

tube should fire before the lead tube, the only effect will be to drive the grid of the lead tube to a higher positive potential, thus insuring that the tube will be rendered conductive.

When an electronic contactor of the type discussed is to be used for multiple cycle operation, it is essential that the operation of its lead and trail tubes be highly dependable so that there is no likelihood of either tube failing to conduct during the predetermined time set for exposure. In order to insure maximum dependability of the circuit, the present invention contemplates means independent of the peaking transformer and trail tube for firing the lead tube on cycles subsequent to the first. If the peaking transformer were utilized for firing the lead tube on cycles subsequent to the first, the voltage peaks supplied by the transformer would have to be shifted to coincide with the point on the voltage wave where the anode voltage is just sufficient to cause the lead tube to conduct, and such requirement would necessitate critically precise timing of the voltage peaks in order to provide uniformity in the current flow. The present invention, on the contrary, is directed to the concept of using a broad firing pulse which will condition the lead tube to conduct over a considerable portion of the cycle from a time slightly before the voltage wave has reached a zero value, so that whenever sufficient voltage appears across the tube to cause it to fire, it will do so without further control.

To summarize the principles of the invention which have been discussed in the preceding paragraphs, it will be seen, first, that the firing of the lead tube by means of a narrow firing voltage pulse enables phase adjustment which permits energization of the transformer to commence at a point most favorable to the elimination of both high and low frequency transients. Next, firing of the trail tube independently of the lead tube on alternate half cycles following the first, insures positive reliable conduction of the circuit under varying load conditions. In addition, firing of the lead tube on half cycles following the first half cycle, by means of an applied voltage wave other than the narrow initial lead tube firing impulse, conditions the lead tube to fire as soon as its anode voltage becomes positive; therefore, the necessity for precision timing is eliminated which would otherwise be required if the narrow firing impulse had to reappear at precise times in the voltage cycle to cause tube conduction, and also enables the contactor to tolerate variations in the phase angle which may occur progressively during the use of the apparatus in X-ray service or the like. It is further to be noted that the control exerted by loaded cathode circuit of the trigger tube upon the grid of the lead tube provides dependability in the firing of both the lead and trail tubes regardless of the various load conditions which may be reflected into the electronic contactor in its use. By virtue of these provisions and advantages, electronic contactors of the present invention are adapted for widely varying load or service conditions, as encountered in X-ray radiography, fluoroscopy and therapy, as well as other uses wherein voltage current and power factor angle are highly dissimilar.

As a direct consequence of the method devised for firing the lead tube on the initial half cycle and for subsequently firing the trail tube, slightly inaccurate primary timing means may be used without introducing corresponding errors in the

actual exposure time of the X-ray machine. More specifically, the initial switch actuation, which energizes the peaking transformer, and the terminating switch actuation, may be made at any point over a range of almost a complete cycle, but still the duration of current flow through the contactor will be timed exactly.

While this invention has been discussed with respect to X-ray radiography, it will be appreciated that its use may be advantageous in many diverse fields involving timed or sequential operations presenting similar problems to those discussed. Also, from the foregoing discussion of the principles upon which the invention is predicated and the following detailed description of the drawings in which a typical embodiment of the invention is illustrated, those skilled in the art readily will comprehend the various modifications to which the invention is susceptible.

In the drawings:

Figure 1 is a schematic circuit diagram of the contactor.

Figure 2 is a graph of the load voltage and lead and trail tube grid voltages showing their timed relationship.

The circuit illustrated in Figure 1 comprises an X-ray tube 10 having its cathode 11, and its anode 12 connected respectively across the terminals of a secondary winding 13 of a power transformer 14. Power is supplied to the primary winding 15 of the transformer through alternating voltage supply lines 16 and 17. One of these supply lines, 16, contains the electronic contactor of the present invention through which power supply to the transformer is controlled.

The contactor apparatus comprises parallel circuits 18 and 20, joining one another at the terminals designated 21 and 22. Each of the circuits 18 and 20 is connected through a grid-controlled, gaseous tube, or thyatron; these are designated 23 and 24. Therefore, if or when a circuit is completed through the thyatron valve in either one of the parallel branches 18 or 20, current will pass through the contactor to the primary winding 15 of the transformer, and the X-ray tube will be commensurately energized from the transformer secondary winding 13.

The thyatron tubes of the contactor display unidirectional conductivity only, and are capable of conducting current only when their cathode is negative with respect to their anode; in this sense, they act as rectifiers. However, full cycles of alternating current energy are caused to pass to the transformer through the tubes by arranging them inversely, or in so-called back to back relation. Thus, when the anode 25 of tube 23, hereafter called the lead tube, is positive with respect to its cathode 26, the tube is capable of furnishing a low resistance conductive path; likewise, when the anode 27 of tube 24, hereafter called the trail tube, is positive with respect to the trail tube cathode 28, the latter will furnish a similar low resistance conductive path to the transformer.

Normally, the thyatrons are non-conductive. However, when a voltage, positive with respect to the cathode and of sufficient magnitude is applied to the control grid of each tube, the tube becomes conductive provided its anode is also sufficiently positive with respect to its cathode at that particular instant. Since this action takes place almost instantaneously after appearance of a suitable grid voltage, the tubes are said to "fire," and the voltage is identified as the tube firing voltage. Once fired, a thyatron tube re-

mains conductive until the potential of the anode equals or is less than the cathode potential, and when this condition occurs the tube cannot again be fired until the anode again becomes positive with respect to the cathode and the grid firing voltage is reapplied.

As discussed at a later point in the specification, a control grid 29 of the lead tube 23 is normally biased negatively by a rectified negative voltage supplied by a bias transformer 30, and a positive impulse voltage greater than the negative bias, for firing the lead tube, is supplied, on the first cycle, by a peaking transformer 31, and on successive cycles by a high voltage transformer 32. Similarly, a negative bias voltage is applied to a control grid 33 of the trail tube 24 by a bias transformer 34; but this tube is fired in response to an impulse voltage supplied by a transformer 35 which hereinafter is called a pulse transformer, this device preferably having a low flux density, and translates the discharge voltage of the trigger tube into a firing voltage for the trail tube.

Initial functioning of the contactor may be controlled in any suitable way; in the circuit shown in the drawings, the service is performed by a switch indicated generally at 36. In the arrangement illustrated, the opening of this switch allows an impulse voltage peak from the peaking transformer 31 to appear on the grid 29 of the lead tube 23, with sufficient magnitude to overcome the negative bias thereon. The peaking transformer 31 is energized at the same frequency as the voltage of power supply lines 16 and 17; this may be accomplished either by energizing the peaking transformer directly from the power circuit or from another suitable source of the same frequency. In either event, in consequence to the appearance of the peak voltage on the grid of lead tube 23, the grid is driven positive, and the primary circuit of the X-ray tube is closed through line 20.

The voltage peaks produced by the peaking transformer 31 are also applied to a grid 37 of a grid-controlled, gaseous tube or thyatron 38, which may be called a trigger tube. Hence, the voltage peaks render that tube conductive simultaneously with the lead tube. When the trigger tube 38 is fired, the voltage supplied by a transformer 39 appears in its cathode circuit which includes a primary winding 40 of the pulse transformer 35. A secondary winding 41 of the pulse transformer 35 is thereby energized, and it supplies a phased firing pulse to the grid 33 of the trail tube 24 rendering that tube conductive on the half cycle following the conductive period of the lead tube. Thus, a complete cycle of current is supplied to the X-ray transformer 14, through line 18 by the firing of the trail tube.

When the transformer is to be energized through a time interval of more than one cycle, as when an X-ray exposure of two or more cycle intervals is required, the lead tube is fired on cycles subsequent to the first by firing means independent of the peak voltage supplied by the peaking transformer 31. More specifically, a coil 42 of a quick acting relay is energized by the impulses passing through the cathode circuit of the trigger tube 38. It is preferable that the relay be sufficiently rapid in response to provide discrimination between peak firing on the first half cycle and independent firing means on successive half cycles. In operation, on a sixty cycle alternating current, this result is readily achieved by quick acting relays which are now

available. However, if the frequency of the alternating current circuit is significantly higher, then the relay may not be sufficiently sensitive to respond in time and provide its discrimination in the very first half cycle. Its result then will not be apparent in the circuit until the second or even third successive half cycle. However, even though this condition may occur in the use of the apparatus on relatively high frequency alternating current circuits, the benefits of the arrangement still are substantially utilized, and therefore, the invention is intended to comprehend contactor circuit operation in which the transition from the peak to the independent wave firing occurs either in the very first half cycle or the first few half cycles.

When the coil 42 is energized, a relay contact 43 opens, allowing the voltage produced in a secondary 44 of the high voltage transformer 32 (which had heretofore been shorted by the relay contact 43) to appear in series with the voltage peaks produced by the peaking transformer 31. The vectorial voltage sum is preferably but not necessarily limited by two regulator tubes 45, 46, and the voltage, as limited by them, is applied to the grid of the lead tube 23 to condition that tube for conductance during the first half of subsequent cycles. The trial tube 24 is conditioned for conduction in the second half cycle immediately following a half cycle in which the lead tube is conductive by means of the trigger tube 38 and pulse transformer circuit as just outlined.

The primary winding 15 of power transformer 14 will continue to be energized on half cycles of one polarity by current passing through the line 29 and on half cycles of the other polarity by current passing through the line 13 until a terminating switch 47 is actuated to prevent the lead and trail tubes from firing. This switch, like the initiating switch 36, may be inserted in the circuit in any suitable manner, or for that matter, the operation of switches 36 and 47 may be reversed or combined or rearranged, as will be readily understood by those skilled in the art. Also, switching functions can be performed by the application of suitable voltages. When the terminating switch 47 is opened in the arrangement shown, the circuit which applies the firing pulse to the grid 29 of the lead tube 23 and the grid 37 of the trigger tube 38 is disrupted and the grids are restored to their normally non-conductive condition by the negative bias supplied by transformer 30.

The primary control of initiating switch 36 and terminating switch 47 which respectively govern the functioning of the contactor and the termination of its functioning may be operated manually, or they may be operated in timed sequence by means of a mechanical timer switch or the like. For most purposes, a mechanical time switch is preferred, but since such apparatus forms no part of the present invention, it is not described here in detail.

A more detailed description of the subcircuit arrangements embodied in the contactor illustrated in the drawings follows:

LEAD TUBE FIRING CIRCUIT

The negative bias transformer 30 for firing the lead tube has a separately excited primary winding 48 and a secondary winding 49 which is connected across load or bleeder resistance 50, through current limiting resistance 51 and rectifier 52. A condenser 53 is connected across the

secondary winding 49, in parallel relationship to resistance 50. One side of the resistance 50 is grounded to the load line 20, through lead 54. The other side of the resistance 50 is connected to the grid 29 of the lead tube 23, through line 55 and circuit continuity resistance 56 and current limiting resistances 57 and 58.

A primary winding 59 of the peaking transformer 31 is separately excited through a phase shifter network comprising a resistance 60 and a condenser 61 connected in parallel across a potentiometer 62. A primary winding 63 of the high voltage transformer 32 is also separately excited. A secondary winding 64 of the peaking transformer 31 appears in series with anti-ringing resistance 65, a condenser 66 and the secondary winding 44 of the high voltage transformer 32, which series combination is connected across the resistance 56, through leads 67 and 68. The condenser 66 functions to provide a slight lead in phase of the broad firing pulse so that it appears ahead of voltage zero. A shunt comprising the two parallel opposed voltage limiting tubes 45 and 46 is also placed across leads 67 and 68. Line 69, which is closed by relay arm 43, is connected across the secondary winding 44 of the high voltage transformer 32 and the condenser 66. Additionally, a conductor 70 containing the initiating contact 36 is connected across leads 67 and 68.

THE TRAIL TUBE FIRING CIRCUIT

Grid 37 of the trigger tube 38 is connected by lead 71 to the grid circuit of the lead tube at terminal 72 located between the resistors 57 and 58. Therefore, the same potential appearing on the grid 29 of the lead tube appears on the grid 37 of the trigger tube 38. Anode 73 of the trigger tube 38 is connected to a secondary winding 74 of the transformer 39 through lead 75. The transformer 39 is energized through a separately excited primary winding 76. It is to be noted in connection with transformer 39, as well as transformers 31, 32 and 35, that their windings are so arranged as to preserve the continuity of instantaneous polarity with respect to the instantaneous polarity of the supply circuit through lines 16 and 17. Cathode 77 of the trigger tube 38 is tied to the grid 37, through bypass condenser 78, and the cathode, through lead 79, current limiting resistance 80 and relay coil 42 is also connected to the primary winding 40 of the pulse transformer 35. One side of the pulse transformer primary winding 40 is connected back to the secondary winding 74 of transformer 39 and to the load line 20 through lead 81.

Bias transformer 34 has a separately excited primary winding 82, and a secondary winding 83 connected across bleeder resistance 84, through current limiting resistance 85 and rectifier 86. A filter condenser 87 is also connected across the secondary winding 83 parallel to resistance 84. One end of resistance 84 is connected to the load line 20, through lead 88, while the other end of resistance 84 is connected through lead 89 and resistance 90 to the cathode 33 of the trail tube 24. The secondary winding 41 of the pulse transformer 35 is connected across condenser 91 and resistance 90 through resistance 92. The resistance 90 is a safety device utilized to preserve continuity of the bias circuit in the event of failure of resistance 92 or the secondary winding 41 of transformer 35. It is also to be noted that condenser 91 and resistance 92 constitute a phase

shift network for advancing the front of the trail tube firing wave to a point preceding voltage zero of the supply circuit.

It will be noted that the usual filament windings 93 and 94 are provided for the lead and trail tube cathodes as well as by-pass condensers 95 and 96 which are connected between the cathode and grid of those tubes.

OPERATION OF THE CONTACTOR

Initial conduction through the lead tube

The bias transformer 30 normally supplies a negative bias, rectified by rectifier 52, filtered by the condenser 53 across the resistance 56. This bias voltage is applied to the grid 29 of the lead tube 23 through resistors 56, 57 and 58. So long as the grid of the lead tube is under this negative bias, the flow of current from terminal 21 to terminal 22 through the lead tube is prevented. In order to provide a positive pulse for producing a conductive state in the lead tube during the first positive half cycle, the peaking transformer 31 is energized through the phase shifter network consisting of fixed resistance 60, potentiometer 62, and condenser 61, as previously described.

The function of the phase shifter network of the peaking transformer primary winding 59 is to provide a means for making a phase angle setting at which the voltage peak will occur to condition the lead tube 23 for conduction. The phase shifting means shown is of a common, reactance-capacitance type utilizing a potentiometer 62 to vary the phase relationship of the voltage across the peaking transformer primary winding with respect to the main supply voltage across lines 16 and 17. Obviously, other phase shifter devices are also available for this purpose and may be substituted for the network shown.

The secondary winding 64 of the peaking transformer 31 is normally shorted by lead 10 containing the initiating contact 36. When a timing operation is to be commenced, the switch 36 is opened and the secondary winding 64 of the peaking transformer 31 is unshorted. As a result, the first voltage peak appearing in the secondary winding of the peaking transformer after the switch 36 is opened, is applied across the resistance 56 in series with the negative bias. The peaking pulse, superimposed upon the negative bias, is supplied to the grid 29 of the lead tube 23 through resistors 57 and 58, and is of sufficient peak magnitude to dominate the grid potential and render the grid positive. When this occurs, the tube becomes conductive, and the load current is supplied to the transformer 14.

The point of the alternating current cycle at which the peak voltage is applied to the grid of the lead tube 23 is to be located properly, for it is at this time that the supply voltage will first be applied to the transformer 14. As discussed at an earlier point, it is highly desirable, in order to minimize the effects of both high frequency and low frequency transients, to supply this voltage in the first half cycle at a point before the natural power factor angle of the system and after voltage zero. Thus, radiographs of reproducible good quality and density are obtained, when the phase position of this peak impulse is located in accordance with this principle. Such positioning is provided by the phase shifter network in the primary circuit of the peaking transformer 31.

The power factor prevailing in various installa-

tions will differ from one type or design of apparatus to the next, and will also vary during the use of given apparatus. Under a heavy load, a power factor as favorable as perhaps .95 may be encountered; on the other hand, under adverse light load conditions, as when only magnetizing current is flowing to a transformer, the power factor may be extremely low, for example, .50, or worse. Since it is intended that the contactor of the present invention be sufficiently universal in its functioning to accommodate this range of variabilities, the potentiometer 62 provides the adjustment which is necessary to set the apparatus to perform the best control service for the power factor encountered at a given installation.

By adjusting the potentiometer in one direction, the point in the voltage cycle at which the lead tube firing pulse first appears moves closer to voltage zero, while adjustment in the opposite direction causes the point at which the lead tube firing voltage to appear, approaches the natural power factor angle or may even recede beyond it. In my experience the setting most useful in the majority of X-ray transformer installations is that in which the lead tube firing pulse appears sufficiently before the natural power factor angle to reduce high frequency transients to a tolerable point, and sufficiently after voltage zero to reduce low frequency transients. The precise setting for a given installation is best determined empirically, either by oscillograph or radiograph inspections which readily may be conducted by those skilled in the art.

Firing the trail tube

The function of the trail tube firing circuit is to render the trail tube conductive during the half cycle immediately following each half cycle during which the lead tube is made conductive. The trail tube 24 is normally prevented from conducting by the presence of a negative bias on its grid, as supplied by the secondary winding 83 of the transformer 34 which is connected across resistance 84 in the trail tube grid circuit. Current produced in the secondary 83 first passes through resistance 85, then is rectified by rectifier 86, and filtered by the condenser 87 before being applied to the grid 33 of the trail tube 24 through resistance 90.

In order to properly condition the trail tube 24 for conduction, this negative grid bias must be overcome during the half cycle when the trail tube anode 27 is positive with respect to its cathode 28. The positive voltage for removing the negative bias is provided by the secondary winding 41 of pulse transformer 35, which is connected across resistance 90 in series with the negative bias. The primary winding 40 of the pulse transformer is energized whenever the anode-cathode circuit of the trigger tube 38 containing the secondary winding 74 of the transformer 39 is closed; that is, whenever the trigger tube 38 is conductive. Thus, firing the trail tube 24 is seen to depend upon firing the trigger tube 38.

It will be noted that grid 37 of the trigger tube 38 is subjected to the same negative bias to which the grid 29 of the lead tube 23 is subjected, since it is connected to the grid circuit of the lead tube 23 at terminal 72. Thus, the negative bias voltage supplied by transformer 30 appears on the grid 37 of the trigger tube 38 as well as the grid of the lead tube. The secondary winding 64 of the peaking transformer

which fires the lead tube is also connected in series with the negative bias. Hence, whenever a peak appears across resistance 56 to fire the lead tube 23, it also appears in the grid circuit of the trigger tube 38, overcoming the negative grid bias and rendering that tube conductive also.

When the trigger tube 38 is so conditioned, the voltage supplied by the secondary winding 74 of transformer 39 appears in the cathode circuit of the trigger tube and a pulse is transmitted to the primary winding 40 of the pulse transformer 35 through the resistance 80 and relay coil 42. This pulse, appearing in the primary winding 40 of the pulse transformer, causing energization of the secondary winding 41 and application of a voltage across resistance 90 is sufficient to overcome the negative trail tube grid bias.

The firing pulse supplied by the secondary winding 41 of transformer 35 is phased by the resistance 92 and condenser 91 so that it appears shortly before the lead voltage becomes negative; that is, shortly before the end of the half cycle during which the lead tube is conductive.

In the above explanation of the trail tube firing circuit, it was assumed that when the firing pulse, supplied by the peaking transformer 31 is applied to the grids of the lead tube 23 and the trigger tube 38, they will fire simultaneously. It is immaterial to the firing of the trigger tube whether the tubes fire simultaneously or the lead tube fires first, for if the lead tube fires first, the grid 37 of the trigger tube which is connected to the grid circuit of the lead tube is driven further positive and the trigger tube is certain to fire.

However, under certain conditions, particularly in the case of light loads (fluoroscopic therapy, etc.) the power factor of the load transformer may be low and this condition will tend to cause the lead tube 23 to fire after the trigger tube 38. The difficulty which this might cause is apparent, for in such a case, the grid of the lead tube would then be deprived of the positive charge necessary to fire the tube. To eliminate the possibility of the lead tube not firing under these circumstances, the load elements, resistance 80, the relay coil 42, and the primary winding 40 of the pulse transformer are all placed in the cathode circuit of the trigger tube which is tied through condenser 78, to the grid 37 of the trigger tube, and also the grid 29 of the lead tube. Thus, should the trigger tube 38 fire before the lead tube 23, the cathode 77 and grid 37 of the trigger tube will assume a high positive potential, effectively causing a high positive voltage to appear on the grid 29 of the lead tube 23, thus insuring that the lead tube will fire even should the trigger tube fire first.

This much of the control unit then operates:

(1) to regulate that portion of the cycle during which the current is first supplied to the load by the circuit passing through the lead tube, and

(2) to automatically condition the trail tube for conduction in each half cycle immediately following a half cycle in which the lead tube is conductive.

Firing of the lead tube on cycles subsequent to the first

When the contactor is to allow the load current to pass through it for a time interval of

more than one cycle, means must be provided for firing the lead tube on alternate half cycles subsequent to the first in order to keep the contactor conductive. When a peaking transformer 31 is used to control the firing of the lead tube on the second and successive cycles, there is inherently a time delay while the voltage, supplied by the peaking transformer, is building up to a point where it is sufficient to overcome the grid bias to permit current flow. However, in the present apparatus, critically precise timing or shifting is not necessary since the lead tube is caused to be fired on all cycles subsequent to the first by means of a separate firing voltage produced independently of the trail tube circuit and which may be applied at a time prior to the time at which the power supply voltage has reached the zero point in its variation from negative to positive.

The means shown in the drawings for firing the lead tube on subsequent cycles comprise the quick acting relay 43 which includes a coil 42, energized by the impulse passing through the cathode circuit of the trigger tube 38, and a high voltage transformer 32 connected in series through a condenser 66 with the peaking transformer secondary winding 64. When the relay coil 42 is energized, its contact 43 opens, allowing phased sinusoidal voltage produced in the secondary winding 44, which had heretofore been shorted by the conductor 69 and relay 43, to appear in series with the secondary winding 64 of the peaking transformer 31. These two voltages are then superimposed, but their vectorial sum is limited by the opposed parallel connected regulator tubes 45 and 46 so that the voltage peak is effectively removed and a phased voltage of modified wave form (e. g. substantially square) now appears in series with the negative bias across the resistance 55 slightly before the end of the half cycle during which the trail tube is conductive. This arrangement, therefore, automatically provides tolerance in the contactor apparatus which enables it to accommodate phase or load variations appearing in the X-ray transformer circuit during its operation.

The voltages produced by the peaking transformer 31 and the high voltage transformer 32 are, of course, allowed to reach sufficient magnitude to overcome the negative bias supplied by the transformer 30 and produce a positive grid voltage on the lead and trigger tubes sufficient to fire these tubes. Thus, on the first impulse of the second cycle and on all subsequent cycles the lead tube 23 and the trigger tube 38 are fired by a modified wave rather than the voltage peak that fired them on the initial half cycle.

The actual shape of the firing pulse for the lead tube and trigger tube for all cycles subsequent to the first has been described as a substantially square wave and in the embodiment shown, actually approaches such a shape due to the clipping effect of the tubes 45 and 46. However, it will be understood that a shaped wave of other than square form may be used so long as its magnitude exceeds, for a substantial portion of half a cycle, the minimum value required to overcome the negative bias and bring the grid voltage to such potential that the lead and trigger tubes are rendered conductive. Furthermore, while the firing pulse has been shown as phased so that it appears shortly before the end of the preceding cycle, it may appear at any point before or coincident with the cycle's end.

The lead tube 23 and trail tube 24 will be alternately conditioned for conductance in the man-

ner described above until the terminating contact 46 is opened by the mechanical or electrical timing means. Upon the opening of the terminating switch, the circuit which applies the modified wave firing pulses across the resistor 56 in series with the negative bias is broken. Therefore, negative grid bias only appears on the grids of the lead tube, the trigger tube, and consequently on the grid of the trail tube, thereafter causing the contactor to remain inactive.

The relationship between the timed actuation of switches 36 and 47 and the electronic contactor is illustrated in Figure 2 of the drawings, which depicts the sequence of events in operation of the contactor during an interval in which two complete cycles of the load current are allowed to pass through the contactor from the power source to the transformer 14. In this figure, sinusoidal line 101 represents the load voltage as it appears across lines 16 and 17 on the inlet side of the contactor unit. In the diagram shown, the contactor is conducting from point 102, shortly after the voltage has become positive at the beginning of a cycle, to point 103 at the end of the second complete cycle. Lines 104 and 105 represent idealized versions of the grid voltage on the lead and trail tubes respectively.

Voltage peaks 108 are normally shorted by switch 36 when it is closed, and the lead tube does not become conductive until its grid is made positive by a firing impulse from the peaking transformer 31. It is assumed, in the figure, that the switch 36 is opened at some time between point 106 and point 107. This actuation allows a peak impulse 109 to appear at a point shortly after the power line voltage has passed through zero in the next positive half cycle. Thus, no matter when the switch 36 is opened during a period of almost an entire cycle, electrical conduction will begin at a point in the next cycle predetermined by the position of the firing peak 109 of the peaking transformer. Furthermore, it is apparent that the conduction through the contactor unit is always begun at the same relative point in the cycle shortly after the voltage has become positive. Thus, the problem of transformer polarity which occurs when a random contactor is employed is avoided.

The firing pulses of the trail tube and the firing pulses for the lead tube on cycles subsequent to the first are shown as square waves 110 and 111 respectively which appear at the grids of the lead and trail tubes at times slightly before the half cycles in which those tubes are to become conductive. It will be recalled that the firing pulse 110 for the trail tube appears every time the lead tube is fired and can appear only after a half cycle in which the lead tube has been made conductive.

In order to terminate the conduction of the contactor unit, the terminating switch 47 may be opened at any time after the lead tube has fired on the positive half cycle, as at 112, until the end of the succeeding half cycle as at 103. No matter at what point in this interval the switch is opened, the contactor will continue to conduct until the prevailing cycle is terminated, and then will cease to be conductive. As a result of this inter-relationship between the timing switches and the functioning of the electronic contactor means, the timing of the switches may be inaccurate to the extent of almost a full cycle without introducing error into actual time of energization of the transformer.

Having described my invention, I claim:

1. A timing system for use in supplying current through a load from an alternating current voltage supply comprising, gas-filled, grid-controlled electronic tubes having their respective anodes and cathodes inversely connected in parallel and constituting lead and trail electric valves, means for negatively biasing the control grids of said lead and trail valves to render them non-conductive, first circuit means including a peaking transformer energized at the frequency of the alternating current supply for removing the negative bias of the grid of the lead valve to cause it to become conductive, the said first circuit means including a phase shifting device for causing the peak of the peaking transformer voltage to appear at the grid of the said lead valve after voltage zero in the cycle of the alternating current supply voltage and before the natural power factor angle thereof, and second circuit means responsive to the voltage of the peaking transformer for removing the negative bias of the grid of the trail valve to cause it to become conductive independently of a conductivity state of the lead valve.

2. A timing system for use in supplying current through a load from an alternating current voltage supply comprising, gas-filled, grid-controlled electronic tubes having their respective anodes and cathodes inversely connected in parallel and constituting lead and trail electric valves, means for negatively biasing the control grids of said lead and trail valves to render them non-conductive, first circuit means including a peaking transformer energized at the frequency of the alternating current supply for removing the negative bias of the grid of the lead valve to cause it to become conductive, the said first circuit means including a phase shifting device for causing the peak of the peaking transformer voltage to appear at the grid of the said lead valve substantially after voltage zero in the cycle of the alternating current supply voltage, but substantially before the natural power factor angle thereof, and second circuit means responsive to the voltage of the peaking transformer for removing the negative bias of the grid of the trail valve to cause it to become conductive independently of a conductivity state of the lead valve, said second circuit means comprising, a gaseous, grid-controlled electric valve having its grid in connection with the grid of the lead valve, and having a loaded cathode circuit which is coupled with the grid of the trail valve, and which is also in conductivity controlling connection with the grid of the lead valve.

3. A timing system for use in supplying current through a load from an alternating current voltage supply, comprising a pair of grid-controlled, gas-filled electric valves having their anodes and cathodes inversely connected in parallel, means for negatively biasing the control grids of said valves to render them non-conductive, first circuit means including a peaking transformer energized at the frequency of the alternating current supply, for removing the negative bias on the grid of one of said valves to cause it to become conductive, and second circuit means including a gas-filled, grid-controlled electric valve having its grid responsive to the voltage of the peaking transformer, and being coupled with the grid of the other of the electric valves of the pair, for rendering the said other of the electric valves conductive.

4. An electronic contactor which comprises gas-

filled tubes having respective control grids and anodes and cathodes, the said tubes having their respective anodes and cathodes connected in opposed parallel relation in a load circuit, whereby the tubes, when alternately made conductive, are capable of furnishing a bi-directional conductive load path, means for negatively biasing the control grids of said tubes to render them normally non-conductive, a peaking transformer, a source of energy for energizing the peaking transformer at a frequency corresponding to the load circuit frequency, said peaking transformer being in energizing connection with the control grid of one of said tubes for exerting a positive voltage thereon which is sufficiently greater than the negative bias thereof to cause said tube to become conductive in the first half cycle of proper polarity following energization of said peaking transformer, means independent of said peaking transformer for exerting a positive voltage on the control grid of the other of said tubes to cause it to become conductive in the second and successive alternate half cycles following energization of said peaking transformer, and means also independent of the voltage of the peaking transformer for causing the first of said tubes to become conductive in the succession of alternate half cycles following the first half cycle in which the first of said tubes was rendered conductive by the voltage impulse from the peaking transformer.

5. A timing system for use in supplying current through a load from an alternating current voltage supply, comprising a pair of grid-controlled, gas-filled electric valves having their anodes and cathodes inversely connected in parallel, means for negatively biasing the control grids of said valves to render them non-conductive, first circuit means including a peaking transformer energized at the frequency of the alternating current supply, for removing the negative bias on the grid of one of said valves to cause it to become conductive, and second circuit means including a gas-filled, grid-controlled electric valve having its grid responsive to the voltage of the peaking transformer, and being coupled with the grid of the other of the electric valves of the pair, for rendering the said other of the electric valves conductive, but also having a loaded cathode circuit which is in connection with the grid of the first of the electric valves of the pair, whereby the said first circuit means is effective for insuring conduction of both the first and second electric valves of the pair in successive half cycles.

6. A timing system for use in supplying current to the primary winding of a power transformer from an alternating current supply voltage comprising, a pair of grid-controlled, gaseous electronic tubes arranged in back to back relation and adapted to be fired alternately and thereby furnish a complete conductive path for alternating currents, grid control means for normally rendering the valves non-conductive, a primary switch, first circuit means including a peaking transformer energized at the frequency of said alternating current supply in response to actuation of said primary switch, for applying a voltage impulse to the grid of one of said valves to cause it to become conductive, a phase shifting device for causing the voltage impulse from said peaking transformer to appear at the grid of the said one of said valves after voltage zero in the first half cycle of supply voltage alternations and before the natural power factor angle,

whereby high and low frequency transient effects in the secondary of said power transformer, incident to energization of the primary winding through the conduction of said valve, are substantially reduced, and means responsive to energization of the peaking transformer for firing the other of said valves in the second and successive alternate half cycles.

7. A timing system for use in supplying current to the primary winding of a power transformer from an alternating current supply voltage comprising, a pair of grid-controlled, gaseous electronic tubes arranged in back to back relation and adapted to be fired alternately and thereby furnish a complete conductive path for alternating currents, grid control means for normally rendering the valves non-conductive, a primary switch, first circuit means including a peaking transformer energized at the frequency of said alternating current supply in response to actuation of said primary switch, for applying a voltage impulse to the grid of one of said valves to cause it to become conductive, a phase shifting device for causing the voltage impulse from said peaking transformer to appear at the grid of the said one of said valves after voltage zero in the first half cycle of supply voltage alternations and before the natural power factor angle, whereby high and low frequency transient effects in the secondary of said power transformer incident to energization of the primary winding through the conduction of said valve are substantially reduced, means responsive to energization of the peaking transformer for firing the other of said valves in the second and successive alternate half cycles, and means independent of the peaking transformer for refiring the first of said valves on the alternate half cycles following initial firing of the second of said valves.

8. An electronic contactor for supplying energy through a load from an alternating current supply voltage, comprising gas-filled, grid-controlled electronic tubes having their anodes and cathodes inversely connected for lead and trail conduction in respect to cyclic alternations in the supply voltage, means for normally rendering the tubes non-conductive, first circuit means including a transformer for supplying a peak voltage of short duration sufficient in magnitude to render the first tube conductive at a selected point in respect to the cyclic alternation of the supply voltage, second circuit means for rendering the second tube conductive in the next successive half cycle of supply voltage alternation following conduction of the first tube, and means for supplying the first tube, on successive alternate half cycles of supply voltage alternation following the first half cycle, with a conductivity controlling voltage which is longer in duration than the said peak voltage of short duration.

9. In an electronic impulse contactor having inversely arranged gas-filled conductor tubes having respective anodes, cathodes and grids, said tubes having their grids normally biased negatively to render the tubes non-conductive and having their anodes and cathodes inversely connected for alternate conduction when the tubes are made conductive, and means for applying voltages to the conductor tube grids to render them sequentially conductive, said means comprising a gas-filled trigger tube having its own conduction controlling grid, means for normally negatively biasing the said grid of the trigger tube to render it non-conductive, means for rendering the trigger tube conductive, a cir-

cuit energized in response to conduction of the trigger tube for causing one of the said conductor tubes to become conductive, and a second circuit including a transformer energized in response to conduction of the trigger tube for rendering the second of the tubes conductible whenever a suitable voltage appears across its anode and cathode.

10. An electronic impulse contactor for use in supplying current through a load from an alternating supply voltage, comprising inversely arranged gas-filled conductor tubes having their grids normally biased negatively to render them respectively non-conductive, means for applying voltages to the grids of said tubes to render them sequentially conductive, said means comprising a gas-filled trigger tube having its grid normally biased negatively so as to be non-conductive, means for applying a voltage to the grid of the trigger tube to render it conductive at a selected point in the cycle of supply voltage alternation, a first circuit energized in response to conduction of the trigger tube for causing one of the inversely arranged gas-filled conductor tubes to become conductive, and a second circuit energized in response to conduction of the trigger tube for rendering the other of the inversely arranged gas-filled conductor tubes to become conductible in the next successive half cycle alternation of the supply voltage.

11. An electronic contactor for supplying energy through a load from an alternating supply voltage, said contactor comprising, a primary control switch, thyratron tubes connected to provide a sustained path for conducting cyclic energy from said alternating supply voltage to the load when the tubes are made conductive, electric circuit means energized in response to actuation of said primary switch for automatically rendering one of said tubes conductive at a selected point in the cycle of the alternating supply voltage which is after voltage zero and before the natural power factor angle, and means responsive to the actuation of said switch for automatically so conditioning another of said thyratron tubes for conduction that it will conduct as soon as the voltage in the alternating supply reaches a predetermined value in the half cycle of alternation whose polarity is opposite that of the voltage prevailing in the half cycle in which the first thyratron tube was rendered conductive.

12. In a timing system for use in supplying current through a load from a voltage supply, a contactor having an initiating switch and terminating switch, said switches being adapted to be actuated by a timing mechanism, said contactor having a lead tube and a trail tube arranged in opposed parallel relationship, means for biasing the current of said lead and trail tubes whereby said tubes are normally rendered non-conductive, first circuit means for removing the bias on said lead tube, said means being responsive to the actuation of said initiating contact, second circuit means for removing the bias from the trail tube, said second circuit means being responsive to said first means whereby the trail tube will be rendered conductive during half cycles following half cycles of conductivity of said lead tube, said terminating contact being adapted to disrupt said first and second circuit means in such a manner that conductivity will cease only after a half cycle in which said trail tube is conductive.

13. An electric contactor comprising, a pair of

gas-filled, grid-controlled tubes arranged in an opposed parallel relationship, grid biasing means normally rendering said tubes non-conductive, firing means for counteracting the bias on one of said tubes at a predetermined point in the initial half cycle in which said tube is to be made conductive, means for counteracting the negative bias on the other of said tubes on alternate half cycles, said second means being responsive to the firing means used to counteract the bias of the first tube, and third means for counteracting the bias on the first tube on cycles subsequent to the first, which third means are independent of the conduction of the second of said tubes and independent of the means provided to condition the first tube for conduction in the initial half cycle.

14. An electronic impulse contactor comprising gaseous, grid-controlled tubes having their anodes and cathodes inversely connected in an electric circuit through which cyclic voltage may be applied by alternate conduction of the tubes, means for normally rendering both tubes non-conductive, first circuit means for rendering the one of the tubes conductive at a particular point in the cycle of voltage alternation, second circuit means for rendering the other of the tubes conductive in the next successive opposite half cycle of voltage alternation, and means independent of the first circuit means for rendering the first of said tubes conductive in the successive half cycles of voltage alternation corresponding to the first half cycle of voltage alternation in which the first of said tubes was rendered conductive by the first circuit means.

15. In a contactor for applying a cyclic supply voltage to a load, said contactor having a pair of gas-filled, grid-controlled tubes arranged in an opposed parallel relationship and grid biasing means normally rendering such tubes non-conductive, means including a peaking transformer for counteracting the bias on one of said tubes in the first cycle in which said tube is to be rendered conductive, a source of energy for said peaking transformer, a phase shift network interconnecting said peaking transformer and said source of energy, said phase shifter network having a variable element through which the cyclic relationship of the peak voltage of the peaking transformer may be altered with respect to said supply voltage and means for rendering said tube conductive on cycles subsequent to the first, comprising a second transformer, a relay normally rendering said second transformer ineffective and means including said peaking transformer for de-commissioning said relay in response to supply voltage alternations whereby the second transformer is cyclically rendered effective to counteract the bias on said tube.

16. In a contactor adapted to supply a current from a voltage supply to a load, said contactor having a pair of gas-filled, grid-controlled tubes which are arranged in an opposed parallel relationship and having grid biasing means for normally rendering said tubes non-conductive; means for counteracting the grid bias of one of said tubes, said means comprising a gas-filled, grid-controlled trigger tube having an anode and a cathode, grid bias means normally rendering said trigger tube non-conductive, a peaking transformer for counteracting said grid bias, a trigger tube anode-cathode circuit, said circuit including a pulse transformer and means for energizing said pulse transformer, said pulse transformer being connected to the grid of said first

named tube whereby that tube is rendered conductive by said pulse transformer whenever said pulse transformer is energized, the time of energization of the pulse transformer coinciding with the conductivity periods of the trigger tube.

17. In a contactor adapted to apply a cyclic voltage supply to a load, said contactor having gas-filled, grid-controlled lead and trail tubes, said lead tube and said trail tube being arranged in an opposed parallel relationship, and grid biasing means for normally rendering said tubes non-conductive, means for counteracting the grid bias on said lead tube and the grid bias on said trail tube alternately during periods corresponding to half cycles of the supply voltage, said means comprising, a gas-filled, grid-controlled trigger tube, a peaking transformer, said peaking transformer being connected to the grids of said lead tube and said trigger tube, whereby the bias on those tubes may be counteracted in the first half cycle in which the contactor is to be rendered conductive, said trigger tube having an anode-cathode circuit comprising a pulse transformer winding and an energizing transformer, said pulse transformer having a second winding connected to the grid of said trail tube whereby that tube is rendered conductive responsive to said pulse transformer energization, phasing means interconnecting said pulse transformer winding and trail tube grid, whereby said trail tube is conditioned for conduction during half cycles subsequent to half cycles of lead tube conduction, a high voltage transformer, said high voltage transformer being connected to the grid of said lead tube, a relay normally short circuiting said high voltage transformer, a coil of said relay being energized during the periods of trigger tube conductivity whereby said high voltage transformer is unshorted, phasing means interconnecting said high voltage transformer and the grid of said lead tube whereby the volt-

age of said high voltage transformer appears on said grid during half cycles subsequent to half cycles of trail tube conduction.

18. In a contactor for applying a cyclic supply voltage to a load, said contactor having a pair of gas-filled, grid-controlled tubes arranged in an opposed parallel relationship and grid biasing means normally rendering such tubes non-conductive, means including a peaking transformer for counteracting the bias on one of said tubes in the first cycle in which said tube is to be rendered conductive, a source of energy for said peaking transformer, a phase shift network interconnecting said peaking transformer and said source of energy, said phase shifter network having a variable element through which the cyclic relationship of the peak voltage of the peaking transformer may be altered with respect to said supply voltage and means for rendering said tube conductive on cycles subsequent to the first, comprising a second transformer, a relay normally rendering said second transformer ineffective and means including said peaking transformer for de-commissioning said relay within the first half cycle of contactor conduction whereby the second transformer is rendered effective to counteract the bias on said tube on all cycles subsequent to the first.

ROBERT E. FISCHER.

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