ARC TUBE SYSTEM

Filed Nov. 13, 1939 2 Sheets-Sheet 1

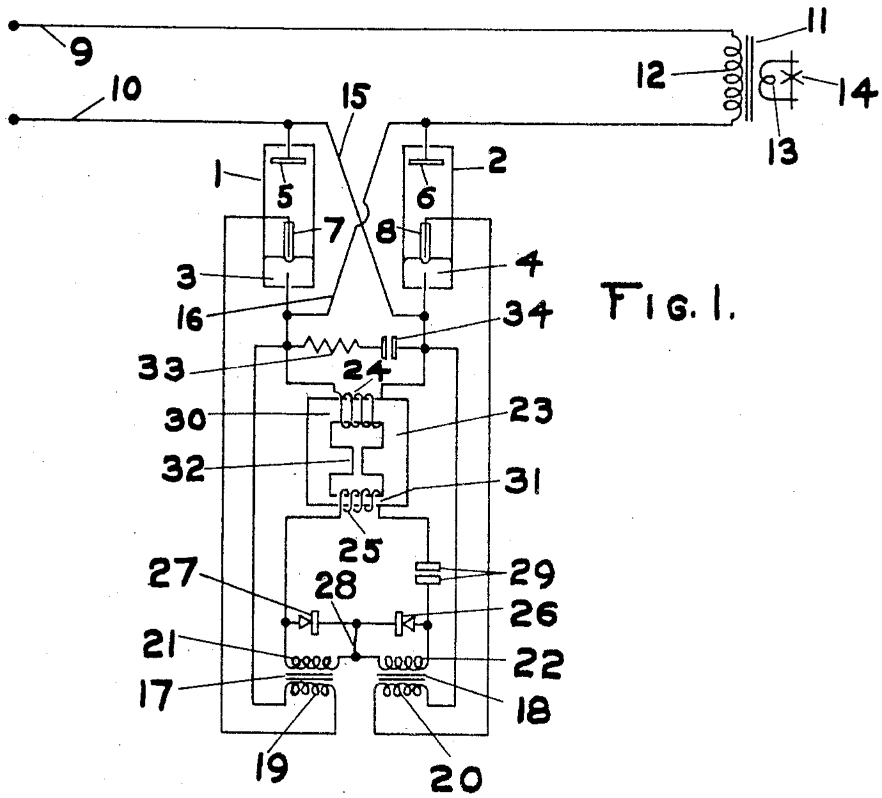
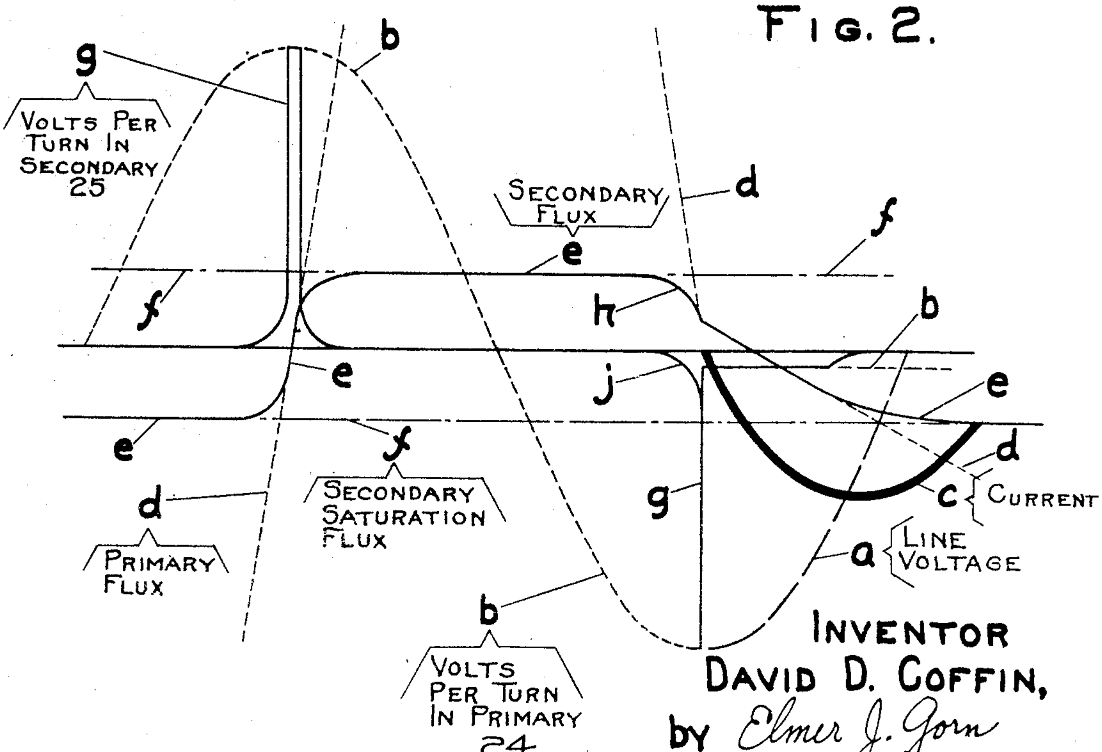


FIG. 1.

FIG. 2.



INVENTOR
DAVID D. COFFIN,
by Elmer J. Gorn
ATTY.

Nov. 5, 1940. D. D. COFFIN 2,220,077

ARC TUBE SYSTEM

Filed Nov. 13, 1939 2 Sheets-Sheet 2

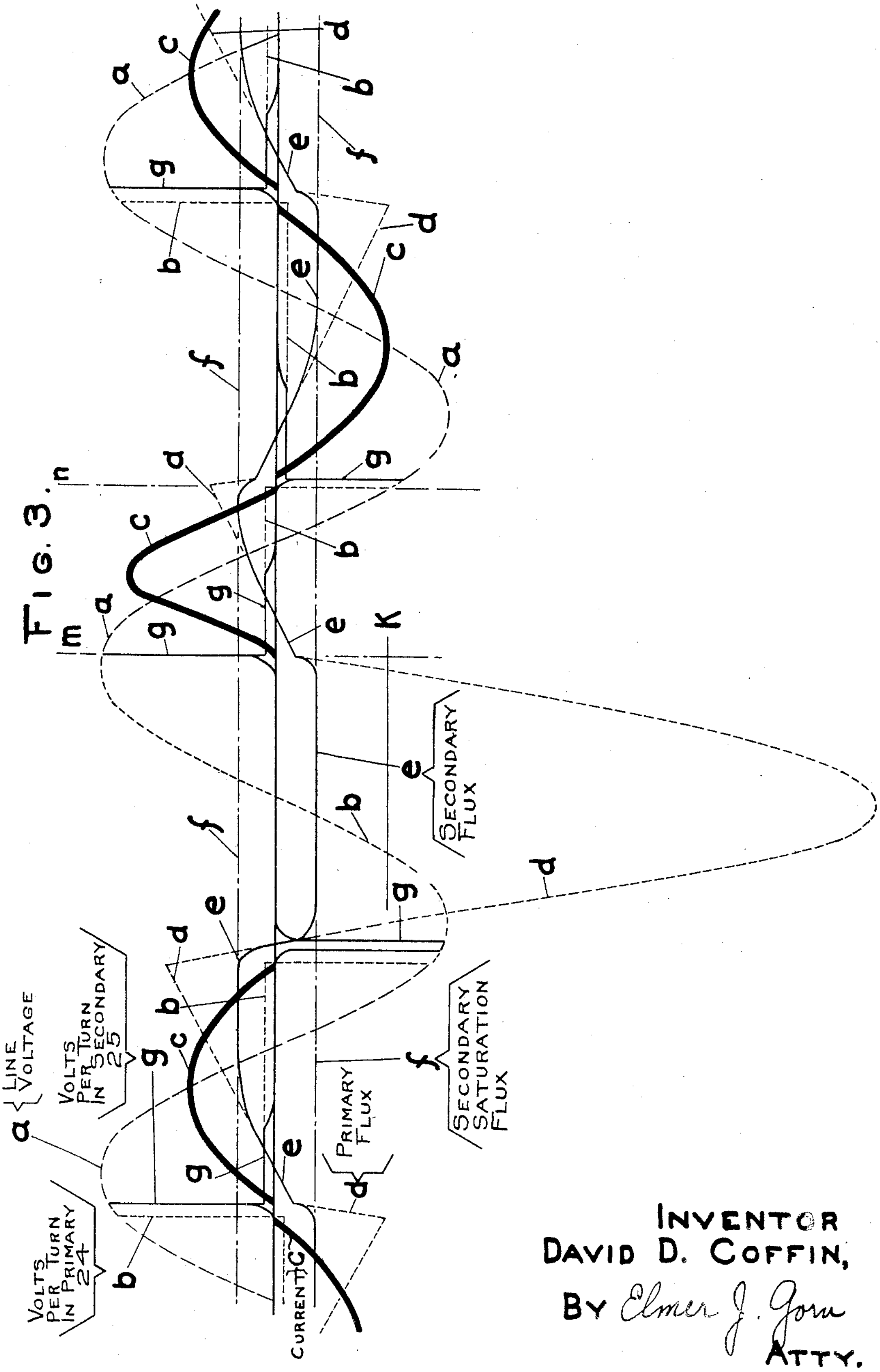


FIG. 3.

INVENTOR
DAVID D. COFFIN,
BY Elmer J. Gorn
ATTY.

Patented Nov. 5, 1940

2,220,077

UNITED STATES PATENT OFFICE

2,220,077

ARC TUBE SYSTEM

David D. Coffin, Waltham, Mass., assignor to Raytheon Manufacturing Company, Newton, Mass., a corporation of Delaware

Application November 13, 1939, Serial No. 303,956

9 Claims. (Cl. 175—354)

This invention relates to an arc tube system, and more particularly to such a system in which two controlled arc tubes are connected inversely in order to supply a controlled alternating current load, such as a resistance welding load.

In alternating current systems of this general nature, particularly in the case of resistance welding loads, it is desirable that if one of the arc tubes fails to conduct current upon the application of an igniting impulse to its igniting electrode, the other arc tube shall also be prevented from starting. If this is not done, the current supplied to the load has a substantially direct current component which is usually disadvantageous, especially when undesired magnetic saturation of magnetic elements in the load circuit may result.

An object of this invention is to devise means responsive to the absence of conduction in either tube for delaying the firing of the other tube during the succeeding half cycle to such an extent that said other tube delivers a small pulse of current to the load of insufficient value to produce any substantial deleterious effects.

The causes which prevent a tube from firing upon the application of an igniting impulse to the igniting electrode are often temporary in character, and therefore it is often desirable to repeat the application of igniting impulses to the tube which fails to fire. Another object of this invention is to devise means for doing this, which means, however, delays the igniting impulses to said other tube as long as the first tube fails to fire.

In arc tubes of the type utilizing an igniting electrode arrangement which initiates an arc in response to a high voltage impulse impressed on said igniting electrode arrangement, it is desirable that the magnitudes of the peak values of such igniting impulses be kept substantially uniform under various conditions of operation. A further object of this invention is to provide for such uniform igniting impulses.

The foregoing and other objects of this invention will be best understood from the following description of an exemplification thereof, reference being had to the accompanying drawings, wherein:

Fig. 1 is a diagrammatic representation of a circuit embodying the present invention; and

Figs. 2 and 3 contain curves illustrating the operation of the system shown in Fig. 1.

The embodiment illustrated consists of two arc tubes 1 and 2, preferably of the mercury pool cathode type. These tubes contain mercury pool cathodes 3 and 4, and anodes 5 and 6, respectively, and are provided with igniting electrode arrangements 7 and 8. Although these igniting electrode arrangements may be of any type which initiate an arc on the mercury pool cathode by means of an igniting impulse supplied thereto, they preferably are of the type which consists of a conductor separated from the mercury pool by an insulating layer which preferably consists of glass. More particularly these igniting electrodes may be of the form described and claimed in the copending application of Percy L. Spencer, Serial No. 259,355, filed March 2, 1939, for an improvement in Arc starting devices. In igniting electrodes of this kind, the glass layer on the igniting electrode conductor is in contact with the surface of the mercury pool, and the arc tends to form at some such point of contact. The upper ends of the electrodes 7 and 8 may be left exposed to the discharge so as to provide discharge paths in parallel with the respective cathodes and igniting electrodes.

Two alternating current lines 9 and 10 are connected to supply a suitable alternating current load which may consist of a transformer 11 having a primary 12, a secondary 13, and a load 14. In the particular system shown, the load 14 may consist of a resistance welding load. The arc tubes 1 and 2 are interposed in one of the conductors 10 in order to control the flow of current to the load. In order to permit alternating current to flow through the tube system, the two tubes are reversely connected by means of the crossed conductors 15 and 16. If the tubes 1 and 2 are conducting, current pulses of one polarity will flow through tube 1, and current pulses of the opposite polarity will flow through tube 2, thus delivering alternating current to the load. If, however, tubes 1 and 2 are non-conducting, the load is deenergized.

Igniting transformers 17 and 18 are provided to supply igniting impulses to the igniting electrodes 7 and 8, respectively. These igniting transformers are provided with secondary windings 19 and 20. The secondary winding 19 is connected between the igniting electrode 7 and the cathode pool 3, while the secondary winding 20 is connected between the igniting electrode 8 and the cathode pool 4. The transformers 17 and 18 are also provided with primary windings 21 and 22 which are supplied with igniting voltage impulses through a control circuit which is energized from a special "peaking" transformer 23 having a primary winding 24 connected directly across the tubes 1 and 2. For this purpose the two ends of the primary winding 24 are connected respectively to the two conductors 15 and 16. The transformer 23 also has a secondary winding 25 which supplies voltage pulses or peaks to the control circuit. The control circuit may be of any suitable kind, such as the one illustrated, which is a control circuit more fully described and claimed in the copending application of John W. Dawson, Serial No. 284,502, filed July 14, 1939, for an improvement in Arc tube systems. In this arrangement the secondary winding 25 is connected to the primary winding 21 through a rectifier 26, and to the primary winding 22 through a rectifier 27. The rectifiers 26 and 27 are preferably of the copper-oxide type. A conductor 28 connects the point intermediate the rectifiers 26 and 27 to the point intermediate the primary windings 21 and 22. The time during which the control circuit is caused to operate may be determined by any suitable means, such as a pair of control contacts 29, operated from some suitable timing arrangement.

The peaking transformer 23 is of the type in which the magnetic circuit for the secondary winding 25 contains a portion which becomes saturated upon the application of a relatively low M. M. F. to the primary winding 24. For example, the core of the transformer 23 has a leg 30 upon which the primary winding 24 is wound, and a leg 31 of greatly reduced cross-sectional area upon which the secondary winding 25 is wound. The cross-sectional area of the leg 31 is so chosen as to become saturated upon the application of a relatively low voltage to the primary winding 24. For example, the voltage drop across tubes 1 and 2 during conduction, if continued for only a fraction of a cycle, preferably should be sufficient to saturate the leg 31. A third leg 32 having an air gap therein is provided to carry the excess flux from the leg 30 during saturation of the leg 31.

Connected directly across the tubes 1 and 2 is a series circuit consisting of a resistance 33 and a condenser 34. This circuit is to enable the incipient arc spots initiated by the igniting impulses supplied to the igniting electrodes 7 and 8 to progress rapidly into true arc spots irrespective of the nature of the main load. This feature is more fully described and claimed in the copending application of Wilcox P. Overbeck, Serial No. 271,679, filed May 4, 1939, for an improvement in Arc tube systems.

The operation of the system described above can be best understood by referring to the curves shown in Figs. 2 and 3. These curves do not purport to show quantitatively the current and voltages involved. However, they do represent in a general qualitative manner the operation of the system. In Figs. 2 and 3 the sine wave *a* represents the line voltage which appears across the conductors 9 and 10. The dotted curve *b* represents the voltage across the tubes 1 and 2, shown as volts per turn in the primary winding 24 for comparison purposes. When the tubes are nonconducting, voltage *b* is equal to the voltage *a*. When, however, the tubes are conducting, the voltage *b* falls to the relatively small constant value of the tube arc drop, as represented by the horizontal portion of the curve *b*. The curve *c* represents the load current flowing to the primary winding 12. In the systems which are contemplated, particularly resistance welding systems, the current *c* lags the voltage *a*, and in the particular instance shown, this lag is about 60 degrees. The dotted curve *d* represents the magnetic flux in the primary leg 30. It will be noted that the curve *d* is of such a form that the rate of change of flux represented by this curve produces a voltage in coil 24 equal to the voltage *b* across the tubes, inasmuch as this is the voltage which is impressed on the winding 24. Since the reluctance in the path of flux *d* is mainly that of the air gap 32, curve *d* also represents the M. M. F. across the air gap and therefore the M. M. F. across the saturable leg 31. Thus curve *d* represents substantially the M. M. F. producing the flux in the saturable leg 31. The curve *e* represents the magnetic flux in the saturable leg 31. The horizontal lines *f*—*f* represent the saturation value of this flux. The curve *g* represents the voltage generated in the secondary winding 25, also shown as volts per turn in the secondary winding 25 for comparison purposes. Since this voltage is proportional to the rate of change of flux in the leg 31, voltage *g* is proportional to the rate of change of the flux *e*.

Fig. 2 represents the conditions of operation upon initially closing the control contacts 29. In this figure only part of the larger sine wave representing the primary flux *d* is shown. Before closing the contacts 29, the primary flux *d* lags the voltage *a* or *b* by about 90 degrees, and therefore *d* crosses the zero axis at about 90 degrees on the curve *b*. As *d* enters the region between *f*—*f*, representing the non-saturated region for the flux *e*, flux *e* which was substantially equal to said saturation value begins to respond to the change in M. M. F. represented by *d* and gradually leaves said saturation and takes over substantially the entire rate of change of flux *d* necessary to counterbalance the voltage impressed on the primary winding 24. The reason that flux *e* does not abruptly take over this value in its rate of change when it leaves the saturation value is the presence of the knee of the saturation curve of the leg 31. As long as *d* remains between said saturation values *f*—*f*, *e* follows substantially said curve *d*. As *d* leaves the non-saturated region, *e* gradually leaves said curve *d* and again approaches and substantially equals the saturation value *f*. Here again the gradual transition is due to the presence of the knee of the saturation curve of the leg 31. Due to the change of the flux *e* at 90 degrees on the curve *b*, a pulse of voltage *g* is generated in the coil 25 at about 90 degrees on said voltage *b*. Since, however, the control contacts 29 are open, none of this pulse is transmitted to the igniting transformers 17 and 18, and thus the tubes 1 and 2 are not ignited, leaving the load 14 deenergized.

If the control contacts 29 are closed at any time after this pulse of voltage has occurred, no igniting voltage is supplied to the tubes until the primary flux *d* again comes into and passes through the *f*—*f* region which, as stated above, occurs at about 90 degrees on the voltage curve *a* or *b*. As *d* enters the *f*—*f* region, the secondary flux *e* again is varied to generate another pulse of voltage *g*, shown below the axis in Fig. 2. This pulse of voltage is delivered to the control circuit, and as described in said Dawson copending application, the rectifier 26 or 27 causes said voltage pulse to energize the primary winding 21 or 22 so as to impart an igniting voltage impulse to one of the igniting electrodes 7 or 8, whereupon the coresponding tube 1 or 2 fires and conducts the current represented by the curve *c* in Fig. 2. When current *c* starts, the voltage *b* across the tubes falls to the value of the tube drop, and *d* continues along a straight line of diminished slope so that its rate of change may generate the decreased value of the voltage *b*. The secondary flux *e* follows *d* until it starts to leave the region *f—f*, when *e* again approaches the lower value of *f*. Thus the voltage *g*, upon ignition of the tube, falls to a relatively low constant value which gradually decreases to zero as *e* approaches the constant saturation flux value.

From the foregoing it will be seen that upon the initial closing of the control contacts **29**, the current is delayed until about 90 degrees on the voltage wave applied to the tubes **1** and **2** without any necessity for closing the contacts **29** at any particular time. If current were permitted to start at zero degrees, a large initial surge of current would flow in the load circuit. In the ordinary resistance welding system, the usual steady state current lag is about 60 degrees, as indicated above. If the initial tube were ignited at a 60-degree delay when the current would normally start from its zero value, the full normal value of the current would flow immediately. By firing slightly late, the loop of current *c* shown in Fig. 2 is somewhat smaller than the corresponding loop of current after steady state conditions have been established. This is not disadvantageous and avoids the initial surge which is undesirable. If it were desired to fire the initial tube at 60 degrees, the power factor of the circuit of transformer **23** could be made something other than zero per cent. by introducing some resistance into the circuit of the primary winding **24**. This would cause the flux curve *d* to cross the zero axis at about 60 degrees on the voltage wave *e*, thus giving the initial firing impulse at the time that the load current would normally start from its zero value. This likewise would avoid any initial surge of current. However, it is simpler and more reliable to provide the circuit arrangement as described previously with the substantially 90-degree phase shift in the initial firing.

If in a system of the type as shown in Fig. 1 a large voltage were suddenly applied to either winding **21** or **22**, shock excitation of the circuits connected thereto might result. Such shock excitation sets up oscillations in said circuits which give higher voltage peaks in the secondary windings **18** and **19** than would otherwise occur. Such higher voltage peaks are usually undesirable. The system as described herein avoids such shock excitation. As previously described, as the secondary flux curve *e* transfers from its steady state to a rapidly changing state, or vice versa, it follows a gradual transition curve as represented, for example, at *h* in Fig. 2. This, as previously indicated, is due to the presence of a rounded knee in the saturation curve of the leg **31**. Thus the secondary voltage *g* in each case as it changes from zero to a relatively large value, or vice versa, changes along a curve as shown, for example, at *j* in Fig. 2. This gradual approach to the high values of the secondary voltage *g* avoids shock excitation. It will be noted that this lack of shock excitation exists throughout the varying types of operation of the system, as described herein.

The left-hand portion of Fig. 3 shows the operation of the system after the current has become stabilized. Under these conditions the current *c* drops to zero at 60-degree delay. When this happens, the tube which was conducting goes out and the voltage *b* across the tubes rises from the value of the tube drop to the full line voltage at that point. Thus the slope of the primary flux *d* reverses and becomes steeper, causing it to drop into the *f—f* region. This introduces a variation into the secondary flux *e* which supplies a pulse of secondary voltage *g*. As described above, such a pulse is delivered to the igniting electrode of the previously non-conducting tube, and said tube is then ignited, restarting the flow of current *c* in the opposite direction. As long as each tube fires upon the application of a firing voltage thereto, operation continues as long as the control contacts **29** are closed, and under these conditions alternating current of substantially full load value is delivered to the load.

If upon application of an igniting impulse to one of the tubes **1** or **2**, such tube fails to ignite, the operation is shown in the section of Fig. 3 following that described above. As the current *c* falls to zero, the voltage *b* reverses from the value of the tube drop to the value of the line voltage at that point. Thereupon flux *d* starts to decrease, and enters the *f—f* region causing the flux *e* to vary and give a voltage pulse *g*. This, however, does not fire the tube, and so the voltage impressed on the primary coil **24** follows the line voltage. Thus *d*, after dropping to zero, increases in the opposite direction along a sine wave. As it emerges from the *f—f* region, *e* again approaches *f* and the voltage *g* drops to zero. It will be seen that the voltage impulse *g* under these conditions exists for a substantial length of time indicated by the width of the voltage impulse *g* below the axis. This time is substantially that which is required for *d* to pass through the *f—f* region. Thus if a temporary cause tends to make the tube not fire, an appreciable time interval is available during which the igniting voltage is applied to give the tube an opportunity to fire. If it still does not fire, *d* continues along a sine wave whose zero axis lies substantially along the line *k* and whose period is equal to that of the line voltage *a*. It will be seen that due to the foregoing conditions, the core **23** is given a substantially unidirectional flux bias, as represented by the value *k*. Due to the fact that the flux which is built up in the transformer **23** must be reduced before *d* again enters the *f—f* region, *d* enters said region much later in the voltage cycle than usual. Therefore the voltage surge of *g* occurs later, at about the point *m*. This produces ignition of the following tube, and the current *c* restarts in the same direction as before, at the point *m*. Due to the fact that the failure of the previous tube to fire has given a D. C. component to the load current, transformer **11** will become somewhat saturated and the loop of current *c* after the point *m* will be somewhat peaked and of increased maximum value. However, due to the lateness of the starting point of this loop, the peak value of the current is not excessive, and is only a small fraction of the current surge which would have been produced if the same tube were fired at its normal firing point of about 60 degrees under these conditions, or much earlier than its normal firing point as is usually the case with other systems.

Since the current *c* starts late at *m*, it drops to zero early at about *n*, which is less than 60 degrees along the line voltage *a*. As *c* drops to zero, an igniting pulse of the voltage *g* is produced so as to fire the following tube which had previously failed to fire. If at this time the tube does not fire, the current *c* will start in the opposite direction. Since it starts somewhat early, it will be slightly larger in peak value than a normal current loop but not sufficiently larger to be detrimental. Substantially in the following cycle conditions may be stabilized so that the igniting voltage impulses thereafter occur at substantially the normal firing points.

If at point *n* the tube fails to fire, the resulting loop of flux *d* will be still larger than that preceding the point *m*, because it will start earlier. Thus the next ignition of the good tube will occur still later than that in the case of point *m*, and the ensuing current loop will be still smaller. This effect is cumulative so that if one tube continues to fail to fire, the good tube fires later and later, tending to approach a firing point of substantially 180 degrees when no current will flow in either tube. In a practical system a full delay of 180 degrees is not secured due to the presence of losses in the windings and core of the transformer 23, in the arc drop, etc. However, the small loops of current supplied by the good tube are not large enough to damage either the tube or the associated apparatus.

Of course it is to be understood that this invention is not limited to the particular details described above as many equivalents will suggest themselves to those skilled in the art. For example, various other means of giving the core 23 a unidirectional flux bias so as to delay the firing of the associated tubes might be utilized. The various other changes and additions may be made to the system as disclosed. It is accordingly desired that the appended claims be given a broad interpretation commensurate with the scope of the invention within the art.

What is claimed is:

1. In combination, a load, circuit means for connecting said load to a source of alternating voltage, a pair of inversely-connected discharge rectifiers interposed in said circuit means for controlling the flow of current to said load, control means for initiating a discharge in each of said rectifiers, means for supplying each of said control means with discharge initiating impulses, and means responsive to the failure of one discharge device to start conducting current for delaying the time of the next discharge initiating impulse in the other tube until late in the normally conductive half of the voltage wave supplied to said latter tube.

2. In combination, a load, circuit means for connecting said load to a source of alternating voltage, a pair of inversely-connected discharge rectifiers interposed in said circuit means for controlling the flow of current to said load, control means for initiating a discharge in each of said rectifiers, a transformer having a magnetic core with a saturable core member, primary winding means for exciting said transformer core with alternating flux, secondary winding means excited by the flux in said saturable core member for supplying said control means with discharge-initiating impulses, and means responsive to the failure of one discharge device to start conducting current for giving to said core a unidirectional flux bias, whereby the succeeding igniting impulse supplied by said secondary winding is delayed until late in the succeeding half of the alternating voltage wave.

3. In combination, a load, circuit means for connecting said load to a source of alternating voltage, a pair of inversely-connected discharge rectifiers interposed in said circuit means for controlling the flow of current to said load, control means for initiating a discharge in each of said rectifiers, a transformer having a magnetic core with a saturable core member, primary winding means for exciting said transformer core, said primary winding being coupled across said tubes, and secondary winding means excited by the flux in said saturable core member for supplying said control means with discharge-initiating impulses.

4. In combination, a load, circuit means for connecting said load to a source of alternating voltage, a pair of inversely-connected discharge rectifiers interposed in said circuit means for controlling the flow of current to said load, control means for initiating a discharge in each of said rectifiers, a transformer having a magnetic core with a saturable core member, primary winding means for exciting said transformer core, said primary winding being coupled across said tubes, secondary winding means excited by the flux in said saturable core member, and means for delivering said impulses of one polarity to one of said control means and for delivering said impulses of opposite polarity to the other of said control means.

5. In combination, a load, circuit means for connecting said load to a source of alternating voltage, a pair of inversely-connected arc discharge devices interposed in said circuit means for controlling the flow of current to said load, each of said arc discharge devices comprising an anode, a pool type arc cathode, and an igniting electrode means for initiating an arc spot on said cathode, means for supplying each of said igniting means with discharge-initiating impulses, and means responsive to the failure of one discharge device to start conducting current for delaying the time of the next discharge-initiating impulse in the other tube until late in the normally-conductive half of the voltage wave supplied to said latter tube.

6. In combination, a load, circuit means for connecting said load to a source of alternating voltage, a pair of inversely-connected arc discharge devices interposed in said circuit means for controlling the flow of current to said load, each of said arc discharge devices comprising an anode, a pool type arc cathode, and an igniting electrode means for initiating an arc spot on said cathode, a transformer having a magnetic core with a saturable core member, primary winding means for exciting said transformer core with alternating flux, secondary winding means excited by the flux in said saturable core member for supplying said igniting means with discharge-initiating impulses, and means responsive to the failure of one discharge device to start conducting current for giving to said core a unidirectional flux bias, whereby the succeeding igniting impulse supplied by said secondary winding is delayed until late in the succeeding half of the alternating voltage wave.

7. In combination, a load, circuit means for connecting said load to a source of alternating voltage, a pair of inversely-connected arc discharge devices interposed in said circuit means for controlling the flow of current to said load, each of said arc discharge devices comprising an anode, a pool type arc cathode, and an igniting electrode means for initiating an arc spot on said cathode, a transformer having a magnetic core with a saturable core member, primary winding means for exciting said transformer core, said primary winding being coupled across said tubes, secondary winding means excited by the flux in said saturable core member for supplying said igniting means with discharge-initiating im-

pulses, and means for delivering said impulses of one polarity to one of said igniting means and for delivering said impulses of opposite polarity to the other of said igniting means.

8. In combination, a load, circuit means for connecting said load to a source of alternating voltage, a pair of inversely-connected arc discharge devices interposed in said circuit means for controlling the flow of current to said load, each of said arc discharge devices comprising an anode, a pool type arc cathode, and an igniting electrode means for initiating an arc spot on said cathode, means for supplying each of said igniting means with discharge-initiating impulses, and means responsive to the failure of one discharge device to start conducting current for delaying the time of the next discharge-initiating impulse in the other tube until late in the normally-conductive half of the voltage wave supplied to said latter tube.

9. In combination, a load, circuit means fo connecting said load to a source of alternatin voltage, a pair of discharge rectifiers interpose in said circuit means for controlling the flow o current to said load, control means for initiat ing a discharge in each of said rectifiers, a trans former having a magnetic core with a saturabl core member, primary winding means for excit ing said transformer core with alternating flux secondary winding means excited by the flux i said saturable core member for supplying sai control means with discharge-initiating impulses and means responsive to the failure of one dis charge device to start conducting current for giv ing to said core a unidirectional flux bias, where by the succeeding igniting impulse supplied b said secondary winding is delayed until late i the succeeding half of the alternating voltag wave.

DAVID D. COFFIN.

CERTIFICATE OF CORRECTION.

Patent No. 2,220,077. November 5, 1940.

DAVID D. COFFIN.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 2, second column, line 72, for "coresponding" read --corresponding--; page 3, second column, line 50, for "later" read --late--; line 72, strike out the word --not--; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 10th day of December, A. D. 1940.

Henry Van Arsdale,
Acting Commissioner of Patents.

(Seal)

Nov. 5, 1940. A. E. LARSEN **2,220,109**

AIRCRAFT SUSTAINING ROTOR

Filed Nov. 4, 1938 5 Sheets-Sheet 1

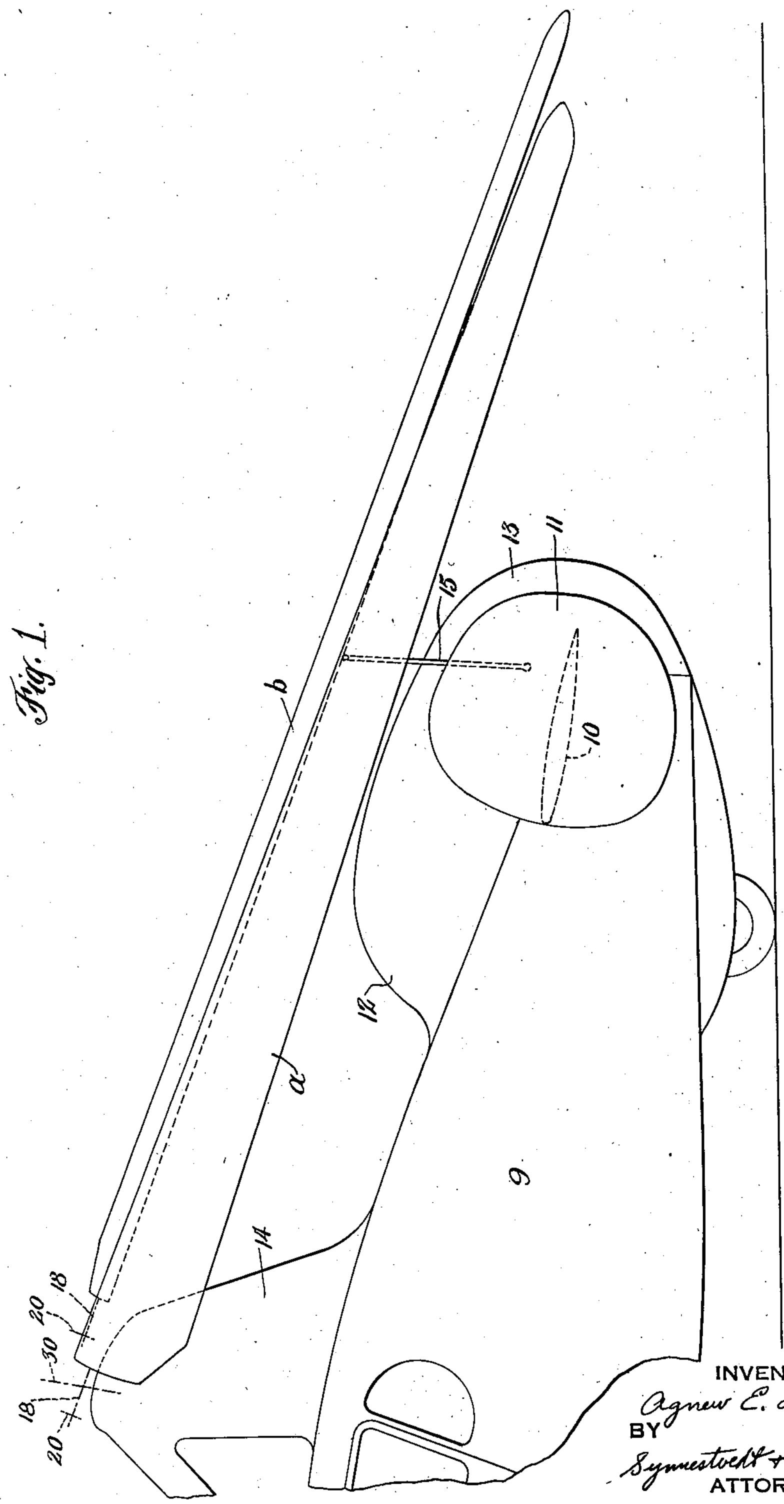


Fig. 1.

INVENTOR
Agnew E. Larsen
BY
Synnestvedt + Lechner
ATTORNEYS