

June 25, 1946.

J. W. DAWSON
CIRCUIT FOR ELECTRICAL SPACE DISCHARGE
DEVICES AND METHOD OF OPERATING SAME
Filed June 2, 1942

2,402,607

2 Sheets-Sheet 1

FIG. 1.

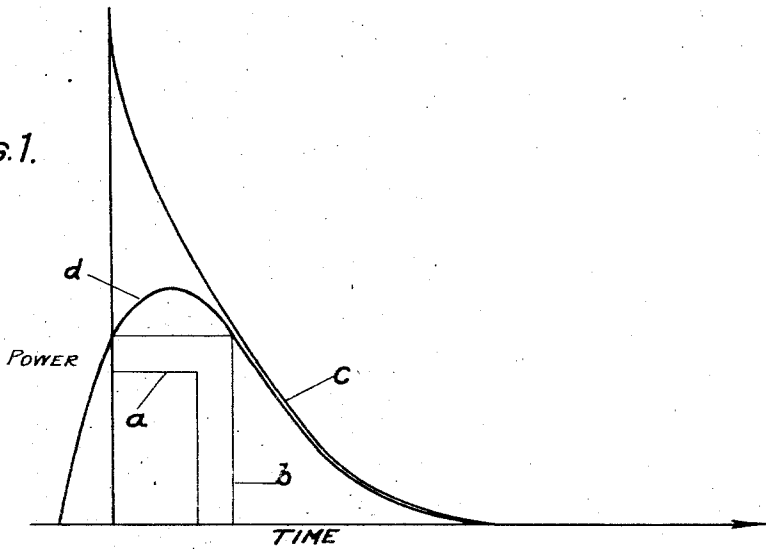


FIG. 2.

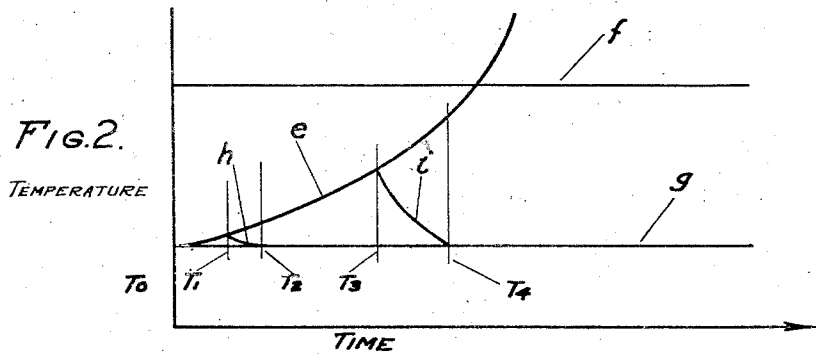
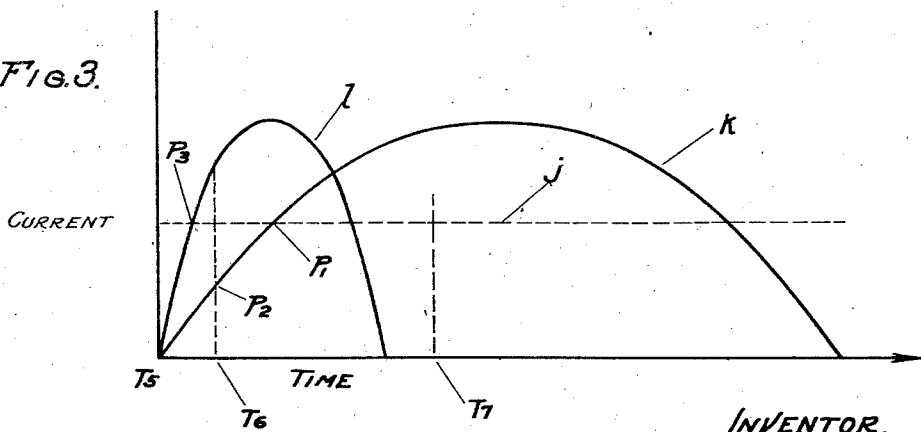


FIG. 3.



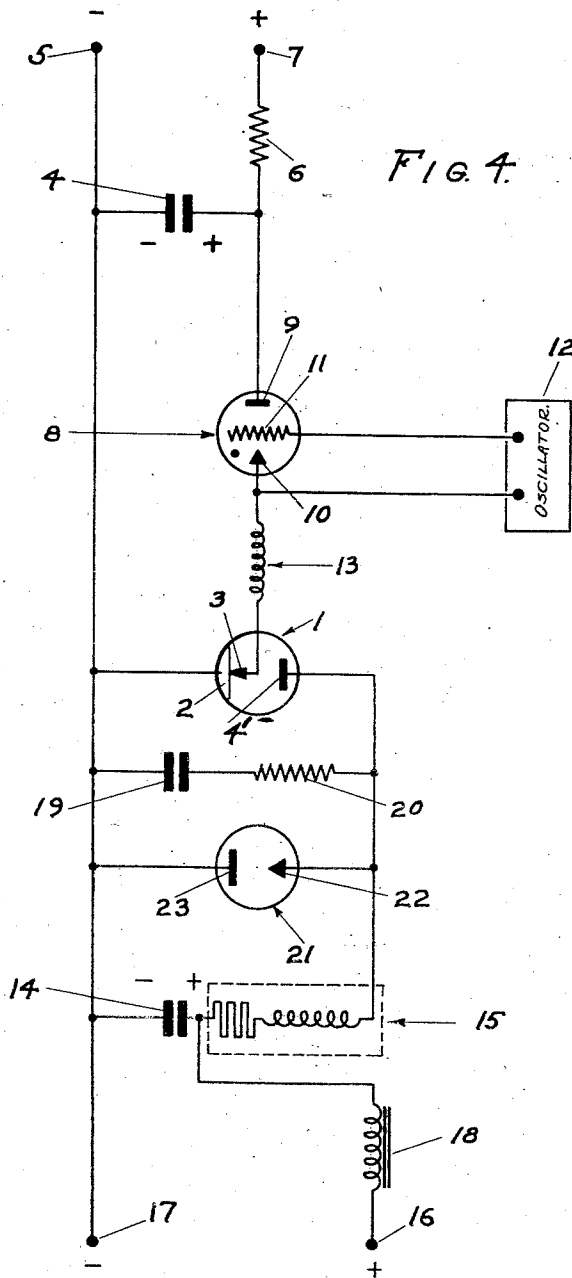
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UNITED STATES PATENT OFFICE

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CIRCUIT FOR ELECTRICAL SPACE DIS-
CHARGE DEVICES AND METHOD OF OPER-
ATING SAMEJohn W. Dawson, West Newton, Mass., assignor
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Application June 2, 1942, Serial No. 445,467

33 Claims. (Cl. 315-234)

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This invention relates to a method of operat-
ing, and to circuits for electrical space discharge
devices having pool cathodes and igniting elec-
trodes of the resistance-immersion type, such de-
vices being generally known as "ignitrons."

Ignitrons are adapted to be fired by pulses of
electrical energy supplied to their igniting elec-
trodes. Each of these pulses of energy is adapted
to produce an incipient arc spot, which becomes
a true arc spot when the discharge is established
within the ignitron. The igniting electrodes re-
ferred to herein are constructed of a poorly con-
ducting or semi-conducting material, for example
boron carbide or silicon carbide. This material
is immersed in the cathode pool in intimate con-
tact therein.

Heretofore the firing of ignitrons has been lim-
ited to a frequency of the order of the frequency
of the available power supply line, such as for
example 60 cycles. I have discovered how to
reliably fire ignitrons at a frequency of 1,000 times
per second or more. To enable the firing of
ignitrons at such relatively high frequencies, I
have found that there are two critical conditions
which must be met. First, there is a certain mini-
mum critical time, for the duration of the pulses
of electrical energy supplied to the igniting elec-
trode, and at all values above said minimum criti-
cal time reliable firing will be produced. This
critical time is a function of the ignitron em-
ployed and is particularly dependent upon the
geometry of the tube. Secondly, in regard to the
characteristics of the circuits in which ignitrons
are arranged, there is a critical time within which
said circuits must be able to supply a given amount
of current so that the incipient arc spot produced
by a pulse of energy of such relatively short dura-
tion may be picked up to produce a steady arc.

In order to produce an incipient arc spot a
certain amount of power must be applied to the
igniting electrode, the amount of power required
depending upon the characteristics of the ignitron
employed and particularly the temperature of
the igniting electrode. This power is applied for
a certain time, the amount of energy in each
igniting pulse being equal to the product of power
and time. The critical minimum time that I have
discovered for the duration of the pulse of elec-
trical power applied to the igniting electrode is
of a totally different order of magnitude than
has been heretofore used, and is considerably
shorter. The total energy of each pulse supplied
to the igniting electrode in accordance with my
discovery is considerably less than the amount of
energy supplied according to the teachings of

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the prior art and, therefore such pulses may be
supplied to the igniting electrode at the rate of
1,000 or more per second without overheating the
igniting electrode. However, in order that in-
cipient arc spots produced by pulses of such short
duration may be converted into true arcs, it is
necessary to match the circuit supplying current
to the cathode and select its constants, in accord-
ance with the duration of the pulses. Under such
conditions I have been able to fire ignitrons at
the rate of 1,000 or more ignitions per second.

An object of this invention is the provision of
a method and a system for reliably firing ignitrons
at relatively high frequencies, such as, for ex-
ample, at a frequency of 1,000 or more times a
second.

Another object of this invention is the pro-
vision of a method and a system of supplying
pulses of electrical energy to the igniting electrode
of an ignitron to produce incipient arc spots at
the aforementioned relatively high frequency,
without thereby overheating said igniting elec-
trodes or causing them to lose their effectiveness.

A further object of the present invention is
the provision of a circuit for supplying current
to the cathode of an ignitron which enables an
incipient arc spot produced by a pulse of rela-
tively short duration to be transformed into a
steady arc.

Other and further objects and advantages of
the present invention will become apparent and
the foregoing best understood from the following
description, reference being had to the drawings
in which:

Figs. 1, 2, and 3 are sets of curves to which
reference is made in explaining my invention, said
curves being intended to express qualitatively
rather than quantitatively certain aspects of my
invention; and

Fig. 4 is a schematic diagram of a circuit in
connection with which my invention is illustrated.

In order to form an incipient arc spot which is
capable of being transformed into a steady arc,
a certain minimum power must be applied to the
igniting electrode. The value of this minimum
power depends upon the construction of the ig-
nitron and particularly that of the igniting elec-
trode. This minimum value of power tends to
be of the order of 1 kilowatt with the standard
igniting electrode of the resistance-immersion
type. In supplying this power a voltage of about
200 volts or more is preferably applied to such
igniting electrodes. Such igniting electrodes
usually have a resistance of from 10-20 ohms at
20° C.

As stated hereinbefore, I have discovered that there is a minimum critical time during which power must be applied to the igniting electrode in order to form an incipient arc spot. This minimum time is of the order of .2 of a microsecond. Referring now to Fig. 1 in which power is plotted against time, *a* represents the minimum critical time during which a given power must be applied to the igniting electrode to form an incipient arc spot. Due, however, to the fluctuations in operation of ignitrons, it is preferred, in order that reliable firing may be secured, that the time during which said power is applied to the igniting electrode be longer than the critical minimum time indicated by *a*. It is, therefore preferred that the pulses of energy supplied to the igniting electrode have a duration of the order of 2 microseconds. However, pulses of from about 20 microseconds down to the minimum critical time may be employed in firing ignitrons at relatively high frequencies. In Fig. 1, *b* represents a pulse of electrical energy having a duration of the order of 2 microseconds which is a desirable value for securing reliable ignition. To further insure reliable firing the power supplied during the time indicated by *b* may be somewhat greater than the minimum power necessary to produce an incipient arc spot.

For supplying pulses of the high frequency hereinabove indicated, various means, such as for example an oscillator, may be employed. However, I have found that the most convenient source of such pulses is the discharge from a condenser. Since it is desired that such pulses have a relatively short duration, the condenser employed is preferably of small capacity, for example of about .02 to 1 microfarad. These condensers are charged to a potential sufficient to produce a pulse of the required energy content, the energy content being preferably of the order of .01 watt-second. For example, a group of condensers having the following values may be charged to the voltage indicated: 1 microfarad at 200 volts, .25 microfarad at 260 volts, .1 microfarad at 400 volts, .05 microfarad at 800 volts, and .02 microfarad at 2000 volts.

Referring now to Fig. 1, curve *c* represents the discharging energy of a condenser charged to a voltage as hereinabove indicated. It will be seen that the amount of energy supplied by the discharge of this condenser is of greater value than that required by *b*, *b* representing the preferred value. The discharge of the condenser, as indicated by curve *c*, will reliably produce an incipient arc spot, and the energy produced during this discharge is of such a relatively low value that the condenser may be discharged at a frequency of 1000 or more times per second without overheating the igniting electrode or rendering it inoperative. However, as will be seen by comparing curve *c* with *b*, a substantial amount of the energy of curve *c* may be eliminated by inserting an impedance in series with the discharging condenser. The discharging energy will then take the form represented by curve *d* in Fig. 1. It will be seen that the power thus delivered to the igniting electrode rises gradually to its maximum and then gradually declines. The form of curve *d* approximates more closely the idealized form of *b*, and therefore less of the energy represented by curve *c* is wasted. It has been found that the impedance employed in series with the condenser may be an air core coil having an inductance of the order of 10^{-4} or 10^{-5} henries and having a built-in resistance of the order of 20

ohms. Of course it will be understood that while the foregoing values apply in one specific case, these may be varied to correspond to the characteristics of the particular ignitron employed, and the characteristics of the circuit in which said ignitron is employed. By using such an impedance, the size of the condenser or the amount of energy stored therein may be decreased.

Each pulse of energy supplied to the igniting electrode tends to raise the temperature of said electrode. As the temperature of the electrode rises, more power is required in order to produce an incipient arc spot. When, however, the temperature of said electrode rises above a certain critical value, the electrode will fail to produce an incipient arc spot regardless of the amount of power applied thereto. This failure of the igniting electrode to operate above a given temperature may be due to the fact that the material of which said electrode is made has a negative temperature coefficient of resistivity. Therefore, when the temperature of the electrode rises, its resistance diminishes; the potential gradient, which appears to be essential, according to certain theories of the operation of such devices, is no longer maintained.

The temperature of the igniting electrode depends on the rate at which electric energy is supplied thereto and the rate at which heat is dissipated therefrom. As the temperature of the electrode rises, the rate of dissipation of heat also tends to increase. Since each pulse of electrical energy supplied to the electrode represents an increment of heat, if said pulses are supplied to the electrode at a rate greater than the rate of heat dissipation, the temperature of the electrode rises and will continue to rise until a point of equilibrium is reached, at which point the rate of dissipation of heat is equal to the rate at which increments of heat in the form of electrical energy pulses are supplied to the igniting electrode.

According to the practice of the prior art, the total amount of energy in each pulse supplied to the igniting electrode was such that pulses could only be supplied at a comparatively low frequency. Attempts to supply such pulses at a higher frequency would produce overheating of the igniting electrode beyond the critical temperature at which the igniting electrode loses its effectiveness. In accordance with my invention the total energy content of these pulses is relatively so low that pulses may be supplied at the rate of 1,000 or more times per second without producing overheating of the igniting electrode. Moreover, since each pulse has such relatively low total-energy content, the temperature of the igniting electrode is raised only slightly during each of such pulses. Thus the igniting electrode may be operated at a lower temperature than was the practice heretofore, and consequently less power is needed for each pulse, since within certain limits the power required is proportionate to the temperature of the igniting electrode.

The foregoing will be more readily understood from the following description referring to Fig. 2, in which temperature is plotted against time. Curve *e* of said figure represents the rise in temperature of an igniting electrode during the time in which electrical energy of a given power is supplied thereto. It will be noted that, at a certain point, curve *e* intersects line *f*. Line *f* represents approximately the critical temperature at which the igniting electrode becomes inoperative. It will be seen that if an electrical impulse

of a given power is delivered to the igniting electrode for a long enough time, the temperature of the igniting electrode will rise to a point where the igniting electrode will be unable to produce an incipient arc spot. In Fig. 2, line *g* represents the starting temperature of the igniting electrode before any energy has been supplied thereto.

If a pulse of energy of a given power is applied to the igniting electrode for a short time, as for example from T_0 — T_1 , which is preferably of the order of two microseconds, it will be seen that the temperature of the igniting electrode will be raised but slightly. Thereafter, if no energy is supplied for a relatively short period T_1 — T_2 , then, due to the dissipation of heat from said electrode, its temperature will fall back to the line *g*, as indicated by curve *h*. If the pulses supplied to the igniting electrode have the relatively short duration indicated between T_0 — T_1 , they may be repeated frequently with only small waiting periods between each pulse. This may be done without overheating the igniting electrode. In contrast with the teachings of my invention, the practice of the prior art was to apply power to the igniting electrode for a relatively long time, such as for example that indicated by the time T_0 — T_3 . Such relatively long pulses had a proportionately greater energy content and raised the temperature of the igniting electrode to a relatively higher point. In order to prevent raising of the temperature of the igniting electrode to a point at which it would cease to be operative, it was necessary to wait a relatively long time T_3 — T_4 between pulses to permit the heat produced in the igniting electrode to dissipate so that the temperature of the igniting electrode would decline, for example, to line *g* as indicated by curve *i*. Due to the long waiting interval required, such method of operation does not permit of firing the ignitron more rapidly than at a comparatively low frequency. Attempts to operate at a higher frequency under such conditions will cause the temperature of the igniting electrode to rise with each pulse until finally line *j* is crossed and the igniting electrode becomes ineffective or burns out.

I have hereinabove pointed out that the igniting pulses according to my invention are of high frequency and short duration. Due to the consequent "skin effect" these pulses tend to travel along the outer surface of the igniting electrode. Since incipient arc spots are produced where the outer surface of the electrode touches the mercury pool, the current traveling along the outer surface of the electrode is the effective current, whereas current through the inside of the electrode is ineffective and merely introduces heat and wastes energy. Consequently, I am able to produce incipient arc spots with greater efficiency, using a lesser amount of energy and dissipating less energy in heat in the igniting electrode.

As stated hereinbefore, the firing supplied to the igniting electrode produces incipient arc spots on the surface of the cathode pool. In order that said incipient arc spots may be converted into true arcs, it is essential that the current drawn from an incipient arc spot rise to a value sufficient to sustain a true arc during the period of time in which the incipient arc spot is produced. In the prior art practice, in which each firing impulse had a comparatively long duration, the period of time during which the current supplied to the ignitron could rise to the required value was correspondingly long. Thus, ordinarily in this prior art practice special design

of the circuit supplying current to the ignition was unnecessary. However, when igniting pulses of such comparatively short duration as those called for by this invention are employed, the current which picks up the arc, converting the incipient arc spot into a true arc, must rise to the required value in the hereinbefore indicated short time. It therefore becomes essential to match the circuit and its constants with the length of duration of the igniting impulses.

The foregoing will be better understood with reference to the curves of Fig. 3 in which current supplied to the ignitron is plotted against time. Line *j* represents the minimum amount of current required to convert an incipient arc spot into a true arc. The interval of time from T_5 — T_6 represents the duration of igniting pulses in accordance with my invention, which duration may be of the order of 2 microseconds. Time T_6 — T_7 represents the relatively longer duration of pulses supplied in accordance with the practice of the prior art. If curve *k* represents the rate at which current supplied to the ignitron can rise in a certain circuit, it will be seen that the current at point P_1 will have risen to the required value a substantial time before the expiration of the pulse of igniting current indicated by T_5 — T_7 . On the other hand, it will be seen that if a circuit having the current time constants indicated by curve *k* is used with an ignitron to which igniting impulses of the relatively short duration indicated by T_5 — T_6 are supplied, at the end of the igniting pulse T_5 — T_6 the current will only have risen to the point P_2 which is substantially under the minimum current value required for converting an incipient arc spot into a steady arc. It therefore will be apparent that where pulses of such relatively short duration are employed, a circuit having a much shorter current time constant must be employed. The constants of the circuit and the circuit employed, when using igniting pulses of such relatively short duration, must be selected and matched with said igniting impulses. Curve *l* of Fig. 3 represents the current time characteristics of a circuit which is suitable when igniting impulses of the length of time indicated by T_5 — T_6 are employed. It will be seen that according to curve *l* the current rises in a comparatively short time to the line *j* which latter represents the minimum required current necessary for picking up the arc. It will be seen that point P_3 , where curve *l* meets line *j* is well within the time T_5 — T_6 during which the igniting pulse is supplied to the igniting electrode. The minimum required current for converting an incipient arc spot into a true arc is approximately 4 or 5 amperes with standard types of ignitrons now in use. With such ignitrons and with pulses of the duration of the order of 2 microseconds, the circuit employed must be capable of supplying a current of the order of magnitude of 4 or 5 amperes within said time of duration of the igniting impulse.

Most ignitron circuits, particularly in industrial power circuits, are incapable of supplying the required current within the time indicated. With such circuits a suitable auxiliary pick-up circuit may be used in conjunction therewith to enable the firing of ignitrons in such circuit at a frequency of 1,000 or more times per second. A circuit employing such pick-up means is illustrated in Fig. 4, and its method of functioning will now be described in connection with said figure.

Referring now to Fig. 4, an ignitron 1, having

a mercury pool cathode 2, an igniting electrode 3 of the resistance-immersion type, and an anode 4' is adapted to be fired at a frequency of 1,000 or more cycles per second. Igniting impulses for this purpose are obtained from a condenser 4 having a capacity of approximately .01 microfarad and being adapted to be charged to 400 volts. To charge condenser 4, the negative side thereof is connected to a terminal 5, and the positive side thereof is connected through a series, current-limiting resistance 6 to another terminal 7. Terminals 5 and 7 are adapted to be connected to a suitable source of direct current supply.

To control the discharge of condenser 4, I prefer to utilize a controlled gaseous rectifying tube 8. This tube is interposed in series between the positive side of condenser 4 and the igniting electrode 3, with its anode 9 connected to the positive side of said condenser, and its cathode 10 connected to the igniting electrode 3. Tube 8 has a control grid 11. The control grid 11 is connected to an oscillator 12 adapted to make said grid positive at the rate of 1,000 or more times per second to thereby fire tube 8 and discharge condenser 4 at said rate. To complete the igniting circuit the negative side of condenser 4 is connected directly to the cathode 2 of tube 4. The power supplied by condenser 4 to the igniting electrode would tend to take the shape of curve *c* in Fig. 1. In order to utilize the more satisfactory curve *d* of said figure, I prefer to interpose in series with condenser 4 an inductance 13. This inductance may have a value of 10^{-4} to 10^{-5} henries and a built-in resistance of the order of 20 ohms. Of course, these values may be varied to suit the particular conditions which are met.

Ignitron 1 may be used to control the discharge of a relatively large condenser 14 into a load circuit 15. Since such a load circuit usually includes both inductance and resistance, it may be represented as in Fig. 4 diagrammatically by an inductance and resistance. The condenser 14 is charged with current from input terminals 16 and 17 through an impedance 18 which is preferably an inductance. The value of this impedance is so chosen as to maintain the proper charging rate of the condenser 14. During actual operation of this system, the impedance 18 tends to compel the current to flow therefrom at a substantially constant value. The condenser 14 is adapted to be discharged into the load 15 by connecting the negative side of said condenser to cathode 2, and the positive side of said condenser to one end of the load 15, the other end of said load 15 being in turn connected to the anode 4' of ignitron 1. It will therefore be seen that when ignitron 1 is fired, condenser 14 will be discharged into the load.

If, however, as stated hereinbefore, the ignitron 1 is to be fired at the relatively high frequency of 1,000 or more times per second, it is essential that the current supplied by condenser 14 to said ignitron rise in a very short time to a value sufficient to convert the incipient arc spot into a true arc. However, the delay in the rise of this current, due to the inductance of the load circuit, may be such as to prevent the current from rising to the required value within a short enough time to pick up the arc. Where the inductance in the circuit associated with the ignitron is of such value as to require too long a time for the rise of current supplied to the ignitron to permit the ignitron to pick up the incipient arc spot, additional means may be provided to overcome this

defect. Such means may consist of a pick-up circuit consisting of a condenser 19 in series with a non-inductive resistance 20, said pick-up circuit being arranged in shunt across the ignitron 1. To further limit the effect of inductance in delaying the rise of current supplied to said ignitron, the pick-up circuit is preferably arranged close to said ignitron.

It will be seen that condenser 19 is charged from terminals 16 and 17 through load 15 and resistance 20. When, thereafter, an incipient arc spot is produced in ignitron 1 by a pulse of electrical energy supplied to the igniting electrode 3, condenser 19 will almost immediately begin to discharge through said ignitron. As the current supplied by condenser 19 diminishes, the current supplied by the discharge of condenser 14 through the load will gradually rise and will thereby maintain the arc initially picked up by the discharge of condenser 19.

It will of course be understood that the pick-up circuit may be dispensed with where the load circuit is selected and matched so that its current time constant is short enough to pick up the arc.

Because of the inductance associated with the circuit into which condenser 14 discharges, the discharge of said condenser tends to be oscillatory. Thus as condenser 14 discharges into the load the potential across said condenser falls as the current flowing from said condenser increases, until the voltage reaches a zero value at the time the current reaches its maximum. Thereafter, as the current continues to flow in the same direction the potential across said condenser reverses. The current then declines to a zero value and tends to flow in the reverse direction. To permit this reverse flow of current, I prefer to arrange a gaseous rectifying tube 21 in shunt across ignitron 1, the cathode 22 of tube 21 being connected to anode 4' of the ignitron, and the anode 23 of tube 21 being connected with the cathode 2 of the ignitron. The cathode 22 of tube 21 is preferably of the permanently-energized type. The reverse current flows through tube 21 and the condenser again becomes charged in the original direction. Further oscillations will be prevented if ignitron 1 is no longer conducting. If, however, ignitron 1 is conducting, another complete cycle will occur. It will be seen that the potential across condenser 14 when the next cycle is completed is again in the same direction as the direction in which the condenser was originally charged. Thus, all the energy which was not absorbed in the load 15 during the discharge of condenser 14 is restored to the condenser 14 in the proper polarity so as to again be available to be dissipated into the load 15 upon the next ignition of ignitron 1. Due to the conservation of this energy, the system operates very efficiently with a minimum of energy loss.

From the foregoing description it will be seen that I have provided a method and a means enabling the firing of ignitrons at relatively high frequencies, such as for example of the order of 1,000 or more times per second. Furthermore, it will be seen that I have devised a method of supplying igniting impulses to the igniting electrodes of such devices at the rate of 1,000 or more times per second without overheating said igniting electrodes or causing them to lose their effectiveness. Furthermore, I have described hereinbefore how the constants of the load circuit of such ignitrons may be selected in order to enable the ignitrons to be fired at such relatively high frequencies. Moreover, I have shown a means whereby a load

circuit having a too high current time constant may be arranged to enable it to pick up arcs from igniting impulses of relatively short duration.

Modifications will readily suggest themselves. For example, an ignitron employing an auxiliary anode may be employed. The auxiliary anode may be connected to a source of current through a substantially non-inductive circuit. Thus the auxiliary anode will pick up the arc quickly within the time of duration of a short igniting impulse. Therefore, even if the current supplied to the main anode rises too slowly to pick up the arc from the igniting electrode, it can pick up the arc from the auxiliary anode. The arrangement of such a system will be apparent to those versed in the art. Therefore, while I have described one circuit in which an ignitron is fired at the relatively high frequency characterizing my invention, it is, of course, to be understood that this circuit was described solely as an illustration, and that numerous other circuits embodying the teachings of my invention may be made. Furthermore, while I have described certain constants and indicated their values under specific conditions, it will also be apparent that certain of these values may be changed to conform to the other conditions that may be encountered. It is accordingly desired that the appended claims be given a broad interpretation commensurate with the scope of this invention within the art.

What is claimed is:

1. In the method of firing an electrical space discharge device of the type having a pool cathode, an anode, and a resistance-immersion igniting electrode, the steps of applying a voltage between said cathode and anode for producing a flow of current therebetween, supplying igniting impulses to said igniting electrode for initiating said current flow, and limiting said igniting impulses to a duration of the order of the critical minimum time required to produce an incipient arc spot capable of being converted into an arc.

2. In the method of firing an electrical space discharge device of the type having a pool cathode, an anode, and a resistance-immersion igniting electrode, the steps of applying a voltage between said cathode and anode for producing a flow of current therebetween, supplying igniting impulses to said igniting electrode for initiating said current flow, and limiting said igniting impulses to a duration of the order of two microseconds.

3. In the method of firing an electrical space discharge device of the type having a pool cathode, an anode, and a resistance-immersion igniting electrode, the steps of applying a voltage between said cathode and anode for producing a flow of current therebetween, supplying igniting impulses to said igniting electrode for initiating said current flow, and limiting said igniting impulses to a duration of about twenty microseconds or less.

4. In the method of firing an electrical space discharge device of the type having a pool cathode, an anode, and a resistance-immersion igniting electrode, the steps of applying a voltage between said cathode and anode for producing a flow of current therebetween, supplying igniting impulses to said igniting electrode for initiating said current flow, and limiting said igniting impulses to a duration of approximately from .02 to 20 microseconds.

5. In the method of firing an electrical space discharge device of the type having a pool cathode, an anode, and a resistance-immersion ignit-

ing electrode, the steps of applying a voltage between said cathode and anode for producing a flow of current therebetween, supplying igniting impulses to said igniting electrode for initiating said current flow, and limiting said igniting impulses to a duration of approximately from .2 to 20 microseconds.

6. In the method of firing an electrical space discharge device of the type having a pool cathode, an anode, and a resistance-immersion igniting electrode, the steps of applying a voltage between said cathode and anode for producing a flow of current therebetween, supplying igniting impulses to said igniting electrode for initiating said current flow, and limiting said igniting impulses to a duration of the order of the critical minimum time required to produce an incipient arc spot capable of being converted into an arc and an energy content of about .1 watt-second or less.

7. In the method of firing an electrical space discharge device of the type having a pool cathode, an anode, and a resistance-immersion igniting electrode, the steps of applying a voltage between said cathode and anode for producing a flow of current therebetween, supplying igniting impulses to said igniting electrode for initiating said current flow, and limiting said igniting impulses to a duration of the order of two microseconds and an energy content of about .1 watt-second or less.

8. In the method of firing an electrical space discharge device of the type having a pool cathode, an anode, and a resistance-immersion igniting electrode, the steps of applying a voltage between said cathode and anode for producing a flow of current therebetween, supplying igniting impulses to said igniting electrode for initiating said current flow, and limiting said igniting impulses to a duration of the order of two microseconds and an energy content of the order of .01 watt-second.

9. In the method of firing an electrical space discharge device of the type having a pool cathode, an anode, and a resistance-immersion igniting electrode, the steps of applying a voltage between said cathode and anode for producing a flow of current therebetween, supplying igniting impulses to said igniting electrode for initiating said current flow at the rate of 1000 or more impulses per second, and limiting said igniting impulses to a duration of the order of the critical minimum time required to produce an incipient arc spot capable of being converted into an arc.

10. In the method of firing an electrical space discharge device of the type having a pool cathode, an anode, and a resistance-immersion igniting electrode, the steps of applying a voltage between said cathode and anode for producing a flow of current therebetween, supplying igniting impulses to said igniting electrode for initiating said current flow at the rate of 1000 or more impulses per second, and limiting said igniting impulses to a duration of the order of two microseconds.

11. In the method of firing an electrical space discharge device of the type having a pool cathode, an anode, and a resistance-immersion igniting electrode, the steps of applying a voltage between said cathode and anode for producing a flow of current therebetween, supplying igniting impulses to said igniting electrode for initiating said current flow at the rate of 1000 or more impulses per second, and limiting said igniting impulses to a duration of the order of two microsec-

onds and an energy content of about .1 watt-second or less.

12. In the method of firing an electrical space discharge device of the type having an anode, a pool cathode, and a resistance-immersion igniting electrode, the steps of supplying igniting impulses to said igniting electrode, limiting said igniting impulses to a duration of the order of the critical minimum time required to produce an incipient arc spot capable of being converted into an arc, supplying current surges between said anode and cathode, and causing said current surges to rise to at least the minimum critical value required to pick up the arc within said time of duration of the igniting impulses.

13. In the method of firing an electrical space discharge device of the type having an anode, a pool cathode, and a resistance-immersion igniting electrode, the steps of supplying igniting impulses to said igniting electrode, limiting said igniting impulses to a duration of the order of two microseconds, supplying current surges between said anode and cathode, and causing said current surges to rise to at least the minimum critical value required to pick up the arc within said time of duration of the igniting impulses.

14. In the method of operating an electrical system including an electrical space discharge device of the type having at least an anode, a pool cathode, and a resistance-immersion igniting electrode, and a circuit for supplying current to said cathode, the steps of supplying igniting impulses to said igniting electrode, limiting said igniting impulses to a duration of the order of the critical minimum time required to produce an incipient arc spot capable of being converted into an arc, supplying current surges to said cathode, and causing said current surges to rise to at least the minimum critical value required to pick up the arc within said time of duration of the igniting impulses.

15. In the method of operating an electrical system including an electrical space discharge device of the type having at least an anode, a pool cathode, and a resistance-immersion igniting electrode, and a circuit for supplying current to said cathode, in which load circuit current can rise only at a relatively slow speed, the steps of supplying igniting impulses to said igniting electrode, limiting said igniting impulses to a duration of the order of two microseconds, supplying current surges between said anode and cathode, and causing said current surges to rise to at least the minimum critical value required to pick up the arc within said time of duration of the igniting impulses, and to have a duration sufficient to maintain the arc until the current from said load circuit has risen to the value necessary to continue said arc.

16. In combination, an electrical space discharge device having an anode, a pool cathode, and a resistance-immersion igniting electrode, and means for supplying igniting impulses to said igniting electrode, said igniting impulses having a duration of the order of the critical minimum time required to produce an incipient arc spot capable of being converted into an arc.

17. In combination, an electrical space discharge device having an anode, a pool cathode, and a resistance-immersion igniting electrode, and means for supplying igniting impulses to said igniting electrode, said igniting impulses having a duration of the order of two microseconds.

18. In combination, an electrical space discharge device having an anode, a pool cathode,

and a resistance-immersion igniting electrode, and means for supplying igniting impulses to said igniting electrode, said igniting impulses having a duration of about twenty microseconds or less.

19. In combination, an electrical space discharge device having an anode, a pool cathode, and a resistance-immersion igniting electrode, and means for supplying igniting impulses to said igniting electrode, said igniting impulses having a duration of approximately from .02 to 20 microseconds.

20. In combination, an electrical space discharge device having an anode, a pool cathode, and a resistance-immersion igniting electrode, and means for supplying igniting impulses to said igniting electrode, said igniting impulses having a duration of approximately from .2 to 20 microseconds.

21. In combination, an electrical space discharge device having an anode, a pool cathode, and a resistance-immersion igniting electrode, and means for supplying igniting impulses to said igniting electrode, said igniting impulses having a duration of the order of the critical minimum time required to produce an incipient arc spot capable of being converted into an arc and an energy content of about .1 watt-second or less.

22. In combination, an electrical space discharge device having an anode, a pool cathode, and a resistance-immersion igniting electrode, and means for supplying igniting impulses to said igniting electrode, said igniting impulses having a duration of the order of two microseconds and an energy content of about .1 watt-second or less.

23. In combination, an electrical space discharge device having an anode, a pool cathode, and a resistance-immersion igniting electrode, and means for supplying igniting impulses to said igniting electrode, said igniting impulses having a duration of the order of two microseconds and an energy content of the order of .01 watt-second.

24. In combination, an electrical space discharge device having an anode, a pool cathode, and a resistance-immersion igniting electrode, and means for supplying igniting impulses to said igniting electrode at the rate of 1000 or more impulses per second, said igniting impulses having a duration of the order of two microseconds.

25. In combination, an electrical space discharge device having an anode, a pool cathode, and a resistance-immersion igniting electrode, and means for supplying igniting impulses to said igniting electrode at the rate of 1000 or more impulses per second, said igniting impulses having an energy content of the order of .01 watt-second.

26. In combination, an electrical space discharge device having an anode, a pool cathode, and a resistance-immersion igniting electrode, means for supplying igniting impulses to said igniting electrode, said means including a condenser having a capacity of the order of the range of from .02 to 1 microfarad and adapted to be charged to an energy value of .1 watt-second or less, and means for discharging said condenser through said igniting electrode.

27. In combination, an electrical space discharge device having an anode, a pool cathode, and a resistance-immersion igniting electrode, means for supplying igniting impulses to said igniting electrode, said means including a condenser having a capacity of about one microfarad or less and adapted to be charged to an energy value of the order of .01 watt-second, and means

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for discharging said condenser through said igniting electrode.

28. In combination, an electrical space discharge device having an anode, a pool cathode, and a resistance-immersion igniting electrode, means for supplying igniting impulses to said igniting electrode, said means including a condenser having a capacity of about one microfarad or less and adapted to be charged to an energy value of .1 watt-second or less, and means for discharging said condenser through said igniting electrode at the rate of 1000 or more times a second.

29. In combination, an electrical space discharge device having an anode, a pool cathode, and a resistance-immersion igniting electrode, means for supplying igniting impulses having a duration of the order of two microseconds to said igniting electrode, and a circuit for supplying surges of current to said cathode, said circuit having a current time constant sufficiently small to supply within the time of duration of one of said igniting impulses sufficient current to establish an arc.

30. In combination, an electrical space discharge device having an anode, a pool cathode, and a resistance-immersion igniting electrode, means for supplying igniting impulses having a duration of the order of two microseconds, and a circuit for supplying surges of current to said cathode, said circuit being capable of supplying within the time of duration of one of said igniting impulses sufficient current to establish an arc.

31. In combination, an electrical space discharge device having an anode, a pool cathode, and a resistance-immersion igniting electrode, means for supplying igniting impulses having a duration of the order of two microseconds, a circuit for supplying surges of current between said anode and cathode, said circuit being incapable of supplying within the time of duration of one of said igniting impulses sufficient current to establish an arc, and an auxiliary circuit, including an electrical energy storage means, connected to feed energy between said cathode and anode, said storage means being sufficiently large and the impedance of said auxiliary circuit to current surges being sufficiently small to produce a current surge between said anode and cathode of

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sufficient magnitude to establish an arc upon said igniting electrode being supplied with an igniting impulse.

32. In combination, an electrical space discharge device having an anode, a pool cathode, and a resistance-immersion igniting electrode, means for supplying igniting impulses having a duration of the order of two microseconds, a circuit for supplying surges of current between said anode and cathode, said circuit being incapable of supplying, within the time of duration of one of said igniting impulses, sufficient current to establish an arc, and an auxiliary circuit, including an electrical energy storage means, connected to feed energy between said cathode and anode, said storage means being sufficiently large and the impedance of said auxiliary circuit to current surges being sufficiently small to produce a current surge between said anode and cathode, within the time of duration of one of said igniting impulses, of sufficient magnitude to establish an arc upon said igniting electrode being supplied with an igniting impulse.

33. In combination, an electrical space discharge device having an anode, a pool cathode, and a resistance-immersion igniting electrode, means for supplying igniting impulses having a duration of the order of two microseconds, a circuit for supplying surges of current between said anode and cathode, said circuit being incapable of supplying within the time of duration of one of said igniting impulses sufficient current to establish an arc, and an auxiliary circuit including an electrical energy storage means connected to feed energy between said cathode and anode, said storage means being sufficiently large and the impedance of said auxiliary circuit to current surges being sufficiently small to produce a current surge between said anode and cathode, within the time of duration of one of said igniting impulses, of sufficient magnitude to establish an arc upon said igniting electrode being supplied with an igniting impulse, said auxiliary circuit being capable of supplying at least sufficient current to maintain said arc until the current in the main circuit has risen to a value sufficient to sustain the arc.

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