Nov. 3, 1964 G. S. JANES 3,155,797

DESTRUCTIBLE FUSE ELEMENTS

Original Filed Oct. 10, 1958 5 Sheets-Sheet 1

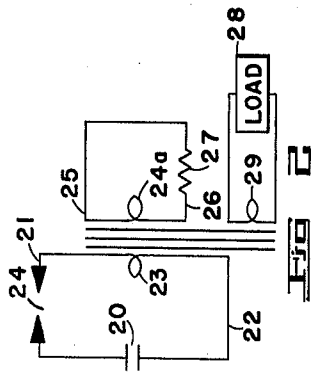


Fig 2

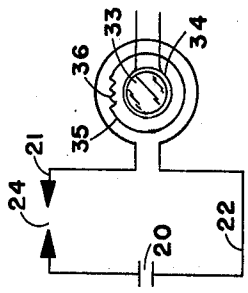


Fig 4

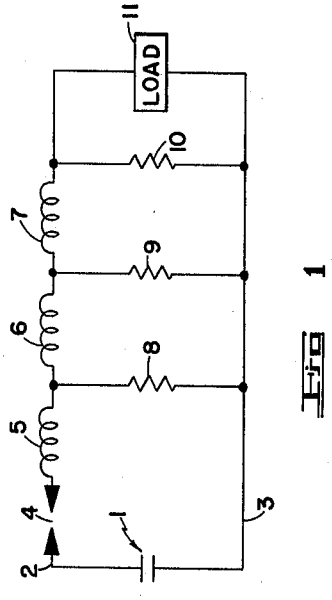


Fig 1

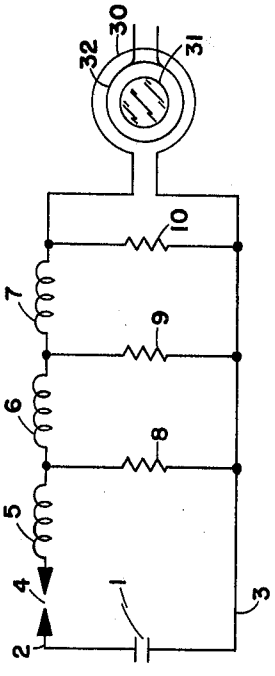


Fig 3

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DESTRUCTIBLE FUSE ELEMENTS

Original Filed Oct. 10, 1958 5 Sheets-Sheet 2

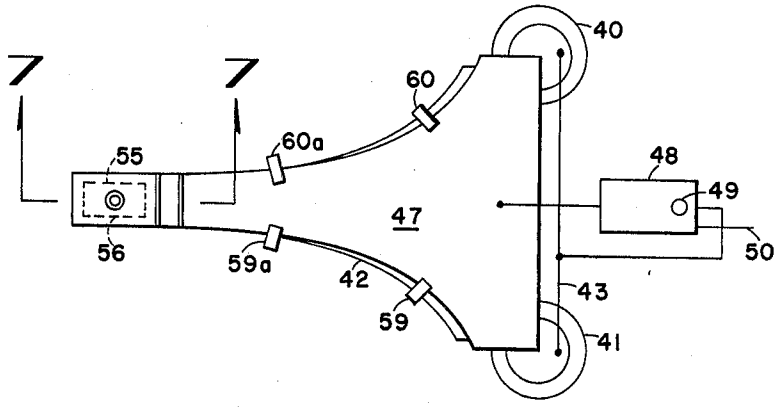


Fig 5

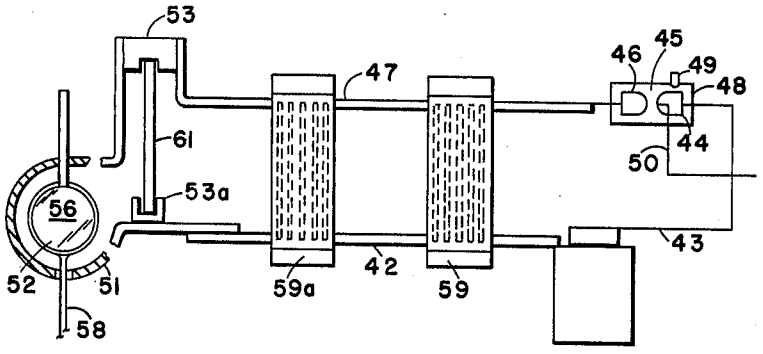


Fig 6

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DESTRUCTIBLE FUSE ELEMENTS

Original Filed Oct. 10, 1958 5 Sheets-Sheet 3

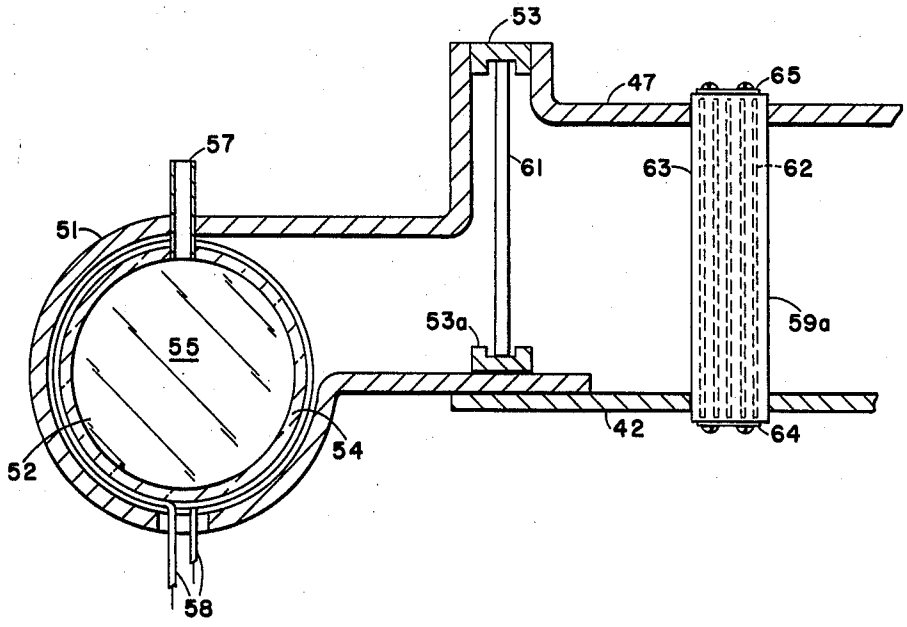


Fig 7

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DESTRUCTIBLE FUSE ELEMENTS

Original Filed Oct. 10, 1958

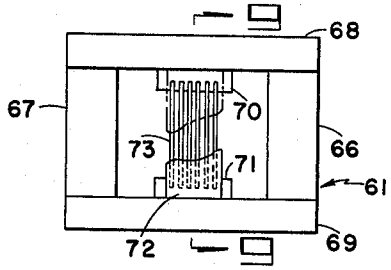


Fig 8

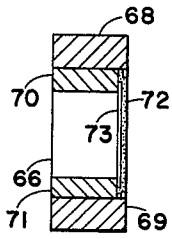


Fig 9

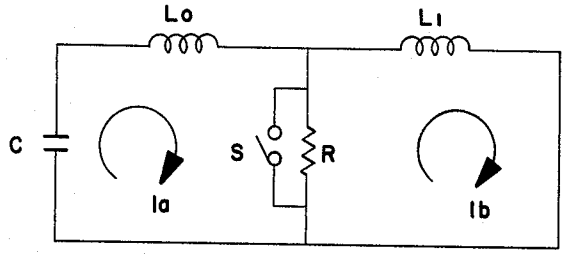


Fig 10

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DESTRUCTIBLE FUSE ELEMENTS

Original Filed Oct. 10, 1958 5 Sheets-Sheet 5

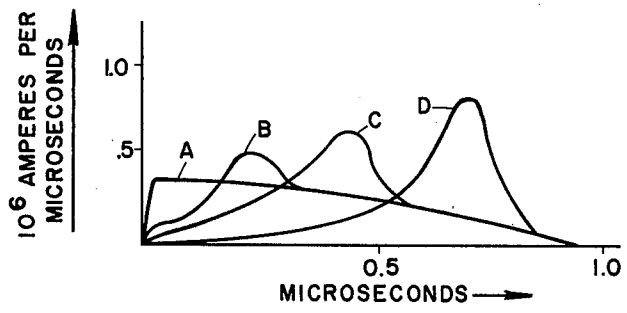


Fig 11

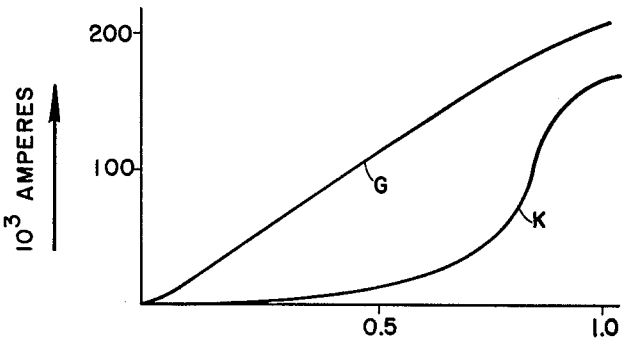


Fig 12

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United States Patent Office 3,155,797 Patented Nov. 3, 1964

3,155,797

DESTRUCTIBLE FUSE ELEMENTS

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Original application Oct. 10, 1958, Ser. No. 766,552, now Patent No. 3,035,206, dated May 15, 1962. Divided and this application Nov. 23, 1960, Ser. No. 72,029

3 Claims. (Cl. 200—135)

The present invention relates to destructible circuit elements and more specifically to fuse links which may be used to accelerate gases rapidly. Although the invention is not limited to such applications, it may be used in the production of magnetic surges within a low pressure mass of gas whereby the gas is subjected to very large accelerations producing temperatures in the order of 10^{6}° Kelvin and will be described in this connection.

More specifically the invention relates to destructible circuit elements for use in a device inductively storing electrical energy and for suddenly discharging the energy through an associated load. In accordance with the present invention, sudden discharge of energy may be effected by sudden interruption of the current flowing in the inductance, which is used as an energy storage medium. The present application is filed in response to a requirement for division in application Serial No. 766,552, filed October 10, 1958, now Patent No. 3,035,206, issued May 15, 1962.

Recent studies in the field of magnetohydrodynamics have led to investigations of gaseous phenomena under extremely high temperature conditions. When such phenomena are fully understood, it is believed that they will lead to the successful production of power by fusion of elements and may make possible dynamic strides in the field of space propulsion. Through use of the present invention, it is possible to study such phenomena in gases under conditions where the Larmor radius of ions within the gas is in the order of one millimeter and the mean free path of collisions is much larger, in the order of one centimeter. Such conditions prevail in gases having a temperature of 10^{6}° Kelvin at particle densities in the order of 10^{16} per cubic centimeter.

In accordance with the said application, high temperature is produced in a low pressure gaseous medium by accelerating the gas to extremely high velocities and allowing the kinetic energy of the gas to be partially randomized by collisions within a fast moving shock front. A simple calculation based on conservation equations for mass, momentum and energy (neglecting radiation and wall loses) indicates that an equilibrium temperature of 10^{6}° Kelvin can be attained behind a shock front moving at 23 cm./μsec. in deuterium or 32 cm./μsec. in hydrogen. Such velocities are beyond the range of conventional chemical shock tubes where the maximum theoretical velocity even in hydrogen is in the order of one centimeter per microsecond.

In the said application there is disclosed means for and a method of generating electrical and magnetic pulses comprising means for storing a large amount of electrical energy, as in a capacitor bank, which may be suddenly connected to an inductance connected in series with switch means through which the circuit is completed.

In accordance with the preferred embodiments of the present invention, the switch means may take the novel form of a plurality of fine, electrically-conductive wires which suddenly fuse and vaporize to provide a predetermined failure time as a result of the large current flowing from the capacitor bank. For convenience, the plurality of wires may be referred to as a "fuse link," the destruction of which breaks the circuit connecting the inductance to the capacitor bank and releases the energy of the associated inductance so that it surges into an associated circuit, which may comprise a series of additional inductances or some special form of load.

For purposes of illustration the invention will be described with particular application to the acceleration of ionized hydrogen gas, although it should be understood that the invention may be used in the acceleration of other elements in gaseous form and, broadly considered, may be used to advantage as a fuse and whenever a sudden surge of electrical energy is required, as in producing surges of magnetic flux.

In view of the foregoing, it will be understood that a broad object of the present invention is to provide means for producing surges of electrical energy and, more specifically, surges of magnetic flux.

It is the purview of the invention to provide means for suddenly interrupting an electrical circuit.

More specific objects of the invention are as follows:

(*a*) Provision of means for suddenly discharging inductively stored electrical energy to produce a current surge.

(*b*) Provision of means for suddenly releasing stored energy in a magnetic field to an associated load.

(*c*) Means for suddenly interrupting an electrical circuit through destruction of an associated circuit element.

(*d*) Provision of a plurality of fuse links in association with a plurality of inductive energy storage means whereby a surge of electric current may be established sequentially through the inductive means and the fuse links.

The novel features that are considered characteristic of the present invention are set forth in the appended claims; the invention itself, however, both as to its organization and method of operation, together with additional objects and advantages thereof, will best be understood from the following description of specific embodiments when read in conjunction with the accompanying drawings, in which:

FIGURE 1 is a simplified circuit diagram of the preferred form of a current surge generator incorporating the present invention;

FIGURE 2 shows a modified form of a current surge generator;

FIGURE 3 is a circuit diagram of a preferred current generator utilizing the present invention in association with means for rapidly accelerating a gaseous medium;

FIGURE 4 is a circuit diagram of a modified generator of FIGURE 2 in association with means for rapidly accelerating a gaseous medium;

FIGURE 5 is a plan view of a device for rapidly accelerating gases and producing high temperatures;

FIGURE 6 is a side elevational view of the device shown in FIGURE 5;

FIGURE 7 is a cross sectional view taken on plane 7—7 of FIGURE 5 showing certain structural details of the device to an enlarged scale;

FIGURE 8 is an elevational view of a specific form of fuse link;

FIGURE 9 is a cross sectional view of the fuse link taken on plane 9—9 of FIGURE 8;

FIGURE 10 is a simplified circuit equivalent illustrating the principles of the present invention;

FIGURE 11 is a graph of induced voltage-versus-time of a control solenoid associated with the devices of FIGURES 5 and 6, the graph showing the effect of using different numbers of fuse links in the device; and,

FIGURE 12 is a plot of flux-versus-time produced by the device of FIGURE 5 when operated without fuse links or with a plurality of fuse links.

General Description

The general principles underlying this invention can best be understood by reference to FIGURE 1. Shown

diagrammatically is a capacitor bank, generally designated 1, which is connected to conductors 2 and 3. A switch in the form of a spark gap is provided at 4, making it possible to complete connection through conductor 2 to a plurality of inductances 5, 6 and 7 which are connected in series. Connected in parallel between each pair of inductances and conductor 3 is a plurality of fuse links 8, 9 and 10. Conductors 2 and 3 are connected with load 11 as indicated.

Using any conventional current source, capacitor bank 1 is charged to a very high potential. When it is desirable to establish a surge of current in load 11, spark gap 4 is triggered, completing the circuit through inductance 5 and fuse link 8. Since the fuse link has a very low resistance and acts substantially like a short circuit, a very large current flows through the inductance 5 and the fuse link. In this way a large amount of energy is stored in the magnetic field associated with inductance 5.

As the current flowing through fuse link 8 increases, the link is rapidly heated until it fuses and eventually vaporizes to provide a predetermined failure time as will be described later in the application. Destruction of the fuse link suddenly breaks the circuit and permits the energy stored in the magnetic field of inductance 5 to surge into inductance 6. The current now flows through inductances 5 and 6 and fuse link 9. Energy stored in the magnetic fields associated with these inductances is suddenly released to inductance 7 when fuse link 9 vaporizes under the large current flow to which it is subjected.

The process is repeated with respect to fuse link 10, the end result of the process being the delivery of a very large surge of current through load 11. In this way the rate of change of current flowing in load 11 can be made several times larger than that which could be obtained by simply connecting the load across the capacitor bank.

As an alternative, the circuit of FIGURE 2 may be employed. This circuit includes a capacitor bank 20 in circuit with conductors 21 and 22 which are connected to a transformer primary 23. In this case, the transformer may simply have single turn coils. When spark gap 24 is triggered, current suddenly flows through primary coil 23, inducing current flow in the right hand portions of the circuit through magnetic coupling of flux with coils 24*a* and 29. Coil 24*a* is connected through conductors 25 and 26 to a shorting fuse link 27. In this configuration, destruction of the fuse link induces a very high voltage in coil 29 and produces a rate of change of current flowing through load 28 greatly in excess of that which could be produced if the fuse link and associated coil were omitted. The energy is initially stored in the stray circuit inductances including the leakage inductance of the transformer.

As far as the basic operating principles of the invention are concerned, the nature of the loads 11 and 28 is immaterial, and the circuit may be adapted to produce either a large surge of current or a surge of magnetic flux, associated with the current, depending upon the nature of the load and the objective to be attained.

In FIGURES 3 and 4 the circuits of FIGURES 1 and 2 are used for producing high temperatures in gases. Directing attention first to FIGURE 3, the circuit, identified by reference numerals used in FIGURE 1 to identify similar components, is shown connected to a drive coil 30 which surrounds a cylinder 31 containing a low pressure gaseous medium. Also surrounding the cylinder is a preionization coil 32 which may be energized from a radio frequency source to partially ionize the gaseous medium. As the respective fuse links 8, 9 and 10 are vaporized, a sudden surge of magnetic flux is produced around the periphery of cylinder 31. The radially inwardly moving flux induces a circumferential flow of current in the ionized gas and the force resulting from the cross product of the flux and induced current drives the gas radially towards the center of the cylinder, creating an advancing shock wave behind which the gas is compressed and heated.

Directing attention now to FIGURE 4, the circuit of FIGURE 2, bearing similar reference numerals, is shown in association with a cylinder 33 within which a low pressure gas is partially ionized by coil 34. In this case, however, the secondary coil takes the form of a simple band of material 35 surrounding the exterior of the cylinder. The coil is connected across the ends of a fuse link 36. When the spark gap 24 is first triggered, the fuse link 36 acts like a short circuit and current starts to build up in the band 35, preventing magnetic flux from penetrating into the cylinder containing the gas. After the current has built up to a large value, heating of the fuse link 36 causes it to melt and then vaporize. The resulting high impedance of the band 35 allows the associated flux to leak suddenly into the interior of the cylinder 33 in a time considerably shorter than the original rise time of current in the circuit. The interaction of the flux and current induced within the gas, as described with reference to FIGURE 3, occurs in a similar manner, accelerating the gas particles towards the center of the cylinder and producing extremely high temperatures and pressures.

Description Of Gas Accelerator

FIGURES 5 through 9 illustrate the specific details of a particular form of gas accelerator utilizing the present invention, which has actually been constructed and found effective.

Referring first to FIGURES 5 and 6, there are shown a pair of large condensers 40 and 41, one side of each condenser being connected in parallel to a large copper plate 42. The other side of each condenser is connected to conductor 43 which in turn is connected to electrode 44 of spark gap 45. The other electrode 46 of the spark gap is connected to upper plate 47. The spark gap comprises a housing 48 of dielectric material to which gas may be supplied under pressure through connection 49. Nitrogen gas at about 140 p.s.i. pressure may be maintained within the housing to prevent spark discharge between the electrodes until such time as a trigger pulse, supplied by conventional means not shown, is applied to trigger electrode 50. At such time, a spark discharge is established beween electrodes 44 and 46 and the plates 42 and 47 are effectively connected across the condensers.

The condensers, which have a combined capacity of 1.4 microfarads, may be initially charged to a high potential, such as 66 kilovolts.

Plate 42 is directly connected to a stainless steel band 51. The band is cylindrical in form and surrounds a major portion of the periphery of a Pyrex glass cylinder 52 within which the gas to be accelerated is stored. The opposite end of the band is connected through a metallic block 53 to the upper plate 47. The details of the construction can be better understood by reference to FIGURE 7, to which attention is now directed.

As illustrated in FIGURE 7, the cylinder 52 comprises a cylindrical wall 54 bounded at its ends by impervious walls 55 and 56 (see FIGURE 5). Gas to be accelerated is supplied to the cylinder through conduit 57. Such gas may be hydrogen and may be maintained within the cylinder at a pressure of the order of 100μ of mercury.

Surrounding the exterior of the cylinder is a preionization coil 58. Construction of the coil is not critical but it has been found convenient to provide three turns of No. 10 high voltage insulated copper wire about the cylinder. The ends of the coil 58 may be connected to any conventional source of radio frequency energy. It has been found convenient to use a pulsed R.F. signal of five megacycles at 100,000 volts potential; the R.F. source should be capable of delivering about two joules of energy.

Connected between plates 42 and 47 are five fuse links designated 59, 59*a*, 60, 60*a* and 61. The construction of these fuse links may now be considered.

Fuse Links

Each fuse link comprises a plurality of parallel electrically conductive wires which are indicated in dash lines at 62 in FIGURE 7 as a part of fuse link 59*a*. For convenience these wires may be stuck to one surface of a piece of electrically nonconductive pressure-sensitive tape 63. The tape in turn is stuck at one end to plate 47 and at the other end to plate 42. Secure electrical connections between the wires and the plates is assured by clamp bars 64 and 65 which are secured, as by bolting, to the associated plates.

A preferred form of fuse link is shown at 62. This fuse link is shown in detail in FIGURES 8 and 9, to which reference is made. This fuse link is in the form of a frame having insulating side members 66 and 67 and metal end members 68 and 69 all of which are rigidly joined to form a hollow frame. Blocks 70 and 71 are secured to and project from end members 68 and 69, respectively. As illustrated in FIGURE 9, the blocks have a thickness slightly less than that of the end members, making it possible to stretch a piece of pressure sensitive tape 72 across the blocks without its projecting beyond the dimensions of the frame. As illustrated in FIGURE 8, a plurality of wires 73 are stuck to the tape and held by the tape in electrical connection with blocks 70 and 71.

A fuse link of the type illustrated in FIGURES 8 and 9 may be slidably supported by the bar 53 and a similar bar 53*a* which are in electrical connection with plates 47 and 42. A new fuse link may easily be inserted between the bars after the completion of a gas acceleration test.

The material of the wires used in the fuse links is not critical. It has been found convenient, however, to use copper wires of one mil diameter with a length between blocks 70 and 71 equal to about two inches. The desiderata of wire material is its conductivity relative to the energy required to vaporize it.

Depending upon the nature of the test to be performed and the initial charge of the capacitor bank, the number of wires used may be varied from 15 to about 50 in any fuse link. Although the wire diameter is quite small, the large number of wires connected in parallel present negligible impedance to current flow.

Operation

After the condensers 40 and 41 have been charged, a trigger pulse is applied to trigger electrode 50, establishing spark discharge between electrodes 44 and 46 and completing the circuit through the capacitor bank to the plates 42 and 47. The current surges through the plates and across the fuse links 59 and 60 which short circuit the current flow, practically none of which initially flows through the band and fuse links 59*a*, 60*a* and 61. The inductance of the plates stores energy during the short period of time before the current flowing through links 59 and 60 causes them to vaporize. As soon as vaporization has occurred, however, the inductively stored energy is released to fuse links 59*a* and 60*a* which in turn fuse, releasing the stored energy to fuse link 61. Fusing of link 61 releases the energy to band 51.

The sudden surge of current through the band, at a rate of rise of about 800,000 amperes per microsecond, establishes an enormous field which advances rapidly into the gas stored within cylinder 52. As the flux lines cut through the electrically conductive gas, a circumferential flow of current is established which reacts with the magnetic field, producing a radially inwardly directed force which accelerates the gas towards the center of the cylinder as has been explained.

Theory of Operation

FIGURE 10 is the simplified circuit equivalent of a pulse generator utilizing a single fuse link. In its simplified form, C represents the capacitor bank which is assumed to be charged, L_0 the lumped inductance of the transmission line, L_1 the load inductance, and R, together with switch S, constitutes the exploding wire fuse link. Prior to vaporization, the fuse link acts like a short circuit with the switch closed, but after vaporization, it acts substantially as an open circuit with the switch open, having an extremely high resistance approaching infinity in value.

Referring to FIGURE 10, it will be noted that just before switch S opens there is no current flowing in the right hand portion of the circuit and hence $I_b=0$. $I_a=I_0$ is the initial current flowing around the left hand portion of the circuit, including C, L_0, R and S. The energy U_0 associated with I_0, stored in the field of L_0, is:

$$U_0=\frac{L_0 I_0^2}{2} \tag{1}$$

After switch S is opened, the following voltage relationships are satisfied:

$$-I_bR+L_0I_a+I_aR=0 \tag{2}$$

$$I_aR+I_bR+L_1I_b=0 \tag{3}$$

From these equations, plus the boundary conditions, it follows that:

$$I_b=\frac{L_0}{L_1+L_0}I_0\left(1-e^{\frac{-Rt}{L''}}\right)\rightarrow I_0\frac{L_0}{L_1+L_0} \tag{4}$$

where

$$L''=\frac{L_0L_1}{L_0+L_1}$$

$$t\rightarrow\infty$$

The energy transfer or predetermined failure time is thus L''/R which in many cases can be made smaller than $\sqrt{(L_0+L_1)C}$ and the final energy is

$$U_f=I_b^2\left(\frac{L_0+L_1}{2}\right)\rightarrow U_0\left(\frac{L_0}{L_0+L_1}\right) \tag{5}$$

The increase of fuse link resistance as heating occurs tends to decrease the energy transfer time by reducing the L''/R ratio.

The foregoing analysis is based on the assumption that the capacitor voltage remains substantially constant and small during the time of switch opening. Experimental verification indicates that such assumption is justified.

Expanding the foregoing analysis to a system having *n* fuse links opening in sequence, the net inductance of the system is represented as

$$\sum_{i=0}^{i=n}L_i$$

after the *i*th switch has opened. From this it follows that:

$$U_f=U_0\frac{L_0}{\sum_{i=0}^{i=1}L_i}\times\frac{\sum_{i=0}^{i=1}L_i}{\sum_{i=0}^{i=2}L_i}\times\cdots\frac{\sum_{i=0}^{i=n-1}}{\sum_{i=0}^{i=n}}=U_0\left(\frac{L_0}{\sum_{i=0}^{i=n}L_i}\right) \tag{6}$$

The results of the foregoing analysis have been confirmed by a number of experiments in which the final magnetic field was shown to be independent of the fuse link configuration so long as the current through the link eventually dropped to zero.

Actual fuse links used in the device shown in FIGURE 5 have been made with a sum total of 192 copper wires, each one mil in diameter, the fuse links having a length of two inches. The minimum amount of energy required for heating and vaporizing such a mass of copper is about 375 joules. This would suggest that the energy eventually delivered to the load would be a function of the mass of copper to be vaporized. Although in an extreme case, involving wires of unusually large diameter, this would be true, it has been found that in practice ample energy

is available for vaporizing the fuse links. The dominant factor is the inductive parameter of the circuit and energy losses inherent in complete magnetic energy transfer, both of which are independent of the wire mass.

It was indicated in Equation 5 that the total energy in the system was equal to the product of

$$\frac{L_0}{L_0+L_1}$$

and the original energy U_0. For the described system having three sets of fuse links, calculation has shown that the value

$$\frac{L_0}{\sum_{i=0}^{i=n} L_i}$$

lies between .65 and .70. Assuming an average value of .68 and a total energy in the system as described equal to 2900 joules, it follows that the maximum energy within the system, after destruction of all fuse links, is in the order of 1972 joules, the energy difference being 928 joules, an amount well in excess of the 375 joules required for vaporizing the fuse links. The balance of the energy is dissipated as heat throughout the circuit.

Fuse proportionality is nevertheless a matter to be considered. A controlling consideration is that the fuse link length must not be reduced to such an extent that arcing occurs between the conductors, such as plates 42 and 47. It is apparent, however, that arbitrarily increasing the length of the fuse wires increases the mass of copper and hence the amount of energy that is dissipated in vaporizing the copper.

The question arises of how to proportion the fuse links when different total energies are used in the system. It has been found useful to use as a criterion the value of total energy per unit mass of copper. If this ratio is maintained constant, as well as the resistance through the fuse links, then the time history of the links during destruction will be constant. This has been verified experimentally, and it has been established that any variation in voltage of the capacitor bank should be accompanied by a corresponding linear variation in gap length within the fuse link and the number of wires used in the gap. In other words, the mass of copper should be maintained proportional to the energy which in turn should be maintained proportional to the square of the voltage. This results in a flux pulse at the load occurring with a constant time history regardless of the total energy within the system but with a peak pulse height determined by the voltage of the energy source.

The length of the wire within the fuse link gap cannot be varied arbitrarily. It is apparent that at zero length, the circuit would never be interrupted. At small gap lengths, the breakdown is sustained and continues after the wires vaporize. Sustained breakdown constitutes continued flow of current through the first fuse link and in effect shields the later fuse links from current flow. It has been found by experiment that a gap length of about two inches is desirable for the device shown in FIGURE 5. With such length, vaporization of the copper is the determining factor in opening the fuse link and no sustained breakdown occurs.

The effect of the invention in practice can be understood from a study of FIGURES 11 and 12. The curves in FIGURE 11 are a plot of voltage versus time as induced in a solenoid coil of small diameter (approximately one millimeter and 10 turns) placed at the position of the center of the gas mass normally being accelerated but in this case absent. Curve A is a plot of the induced voltage resulting from capacitor bank discharge without any fuse links installed in the device of FIGURE 5. As one would expect with an LS series circuit, the induced voltage signal varies as cos ωt where ω is equal to 2π times the frequency, the initial voltage rise being determined by the inductance of the main drive coil surrounding the cylinder of gas.

Curve B shows the variation of induced voltage when a single fuse link is used in the system. It will be noted that in this case, the control coil sees little field until the fuse link opens. This occurs when the current flow through the link is at a maximum at which time the magnetic field lines, like compressed rubber bands, expand into the gas space. The result of both the current and flux lines expansion is an increased voltage peak above the value of curve A.

Curves C and D illustrate the increase in induced voltage peaks resulting from the use of 2 and 3 fuse links in the device, respectively. It is readily apparent that higher induced voltages can be obtained through the use of plurality of fuse links, and it necessarily follows that these induced voltages are indicative of increased rate of change of flux lines at the control coil.

In terms of current flow through the drive coil, calculations indicate that an improvement is made in the rate of change of current from 300,000 amperes per microsecond to 800,000 amperes per microsecond.

The integral of the curves shown in FIGURE 11 are proprortional to the flux so that a plot of flux versus time, as shown in FIGURE 12, relates how closely a flux pulse is being approximated. In this figure, curve G indicates the change in flux versus time for the system without fuse links, whereas curve K shows the flux versus time for the system with three fuse links. Although the maximum flux attained by curve G is above that of curve K, due to energy dissipated in the system, it is quite obvious that the rate of change of flux in the middle region of curve K is much greater than that of curve G. As a measure of the difference in rate of change, the ratio of the times required for the flux to increase from 10% to 90% of its maximum can be compared. Results of a number of experiments indicated that the required time can be reduced readily to about 30%, representing a significant improvement over a system using no fuse links.

In term of flux, an accelerating field of 12,000 gauss is provided in a time comparable to gas velocity divided by radius of cylinder 52, i.e., one-quarter microsecond. The rapid rate of flux increase is necessary to prevent the gas from "running away from" the field before it has reached its peak value.

As indicated by FIGURES 11 and 12, use of a plurality of fuse links that are successively "exploded" materially increases the rate of change of flux. For one thing, by use of several fuse links in sequence, the last link to fuse can be made small—so small, in fact, that it is easily and quickly destroyed. This promotes a clean circuit break and high rate of change of flux. Further, the total time delay in the fusion of a link is proportional to the square of the mass of material in the link. For a given mass of material M, the time delay when the material is used in a single link will be proportional to M^2; distribution of this material among n links, however, results in a much smaller over-all delay proportional to M^2/n.

Multiple link systems, however, do tend to reach a practical limit in the number and size of fuse links that can be used. Such limitations arise because of the amount of energy required to fuse the links and the time that must be provided in any event for full capacitor discharge.

Conclusion

From the foregoing it will understood that the present invention is useful in providing a means for generating a large pulse of electrical energy, particularly magnetic energy. Although the invention is not limited to gas acceleration, it is particularly useful in such applications and has made it possible to attain gas temperatures in the order of several hundred thousand degrees Kelvin.

The various features and advantages of the invention are thought to be clear from the foregoing description. Others not specifically enumerated will undoubtedly occur to those versed in the art, as likewise will many variations and modifications of the preferred embodiment illustrated, all of which may be achieved without departing from the spirit and scope of the invention as defined by the following claims.

I claim:

1. In an electrical circuit having capacitance and inductance providing different total energies wherein the total energy is proportional to the square of the voltage of said circuit, a fuse link interconnecting a pair of conductors and having a predetermined failure time of the order or less than the square root of the product of the said capacitance and inductance comprising a piece of electrically nonconductive pressure-sensitive tape, and a plurality of fine wires having a high conductivity and fusing point of the order of that of copper, said wires being stuck to the surface of said tape and said tape being attached to said conductors and maintaining said wires in electrical contact therewith, the net resistance through said wires initially being a first predetermined value offering negligible impedance to current flow, and the total mass of said wires being such that the ratio of the total energy initially stored in the circuit to the total mass of said wires is a second predetermined value to provide said predetermined failure time.

2. In an electrical circuit having capacitance and inductance providing different total energies wherein the total energy is proportional to the square of the voltage of said circuit, a fuse link interconnecting a pair of conductors and having a predetermined failure time of the order of or less than the square root of the product of the said capacitance and inductance comprising a piece of electrically nonconductive pressure-sensitive tape, and a plurality of fine copper wires stuck to the surface of said tape in parallel and spaced relationship one with another, said tape being attached to said conductors and maintaining said wires in electrical contact therewith, the number of said wires being such that the net resistance through said wires is initially a first predetermined value offering negligible impedance to current flow, the diameter and length of said wires being such that the ratio of the total energy initially stored in the circuit to the total mass of said wires is a second predetermined value to provide said predetermined failure time.

3. In an electrical circuit having capacitance and inductance providing different total energies wherein the total energy at any one time is proportional to the square of the voltage of said circuit, a fuse link interconnecting a pair of conductors and having an accurately predetermined failure time of about one tenth of a microsecond comprising a piece of nonconductive pressure-sensitive tape, from about 15 to 50 wires having a high conductivity and fusing point of the order of that of copper, said wires having a diameter of about 1 mil and a length of about 2 inches, said wires being stuck to the surface of said tape in spaced relationship one with another and said tape being attached to said conductors and maintaining said wires in electrical contact therewith.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,155,797 November 3, 1964

George Sargent Janes

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 64, for "embodiments" read -- embodiment --; column 2, line 63, for "devices" read -- device --; column 5, line 12, for "62" read -- 61 --; column 6, equation (3), for "$I_aR+I_bR+L_1I_b=0$" read -- $-I_aR+I_bR+L_1I_b=0$ --; same column 6, equation (6), should appear as shown below instead of as in the patent:

$$U_f=U_0\frac{L_0}{\sum_{i=0}^{i=1}L_i}\times\frac{\sum_{i=0}^{i=1}L_i}{\sum_{i=0}^{i=2}L_i}\times\cdots\cdots\frac{\sum_{i=0}^{i=n-1}L_i}{\sum_{i=0}^{i=n}L_i}=U_0\left(\frac{L_0}{\sum_{i=0}^{i=n}L_i}\right)$$

column 7, line 73, for "LS" read -- LC --; column 8, line 41, for "term" read -- terms --; line 69, after "will" insert -- be --.

Signed and sealed this 20th day of April 1965.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents

UNITED STATES PATENT OFFICE
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