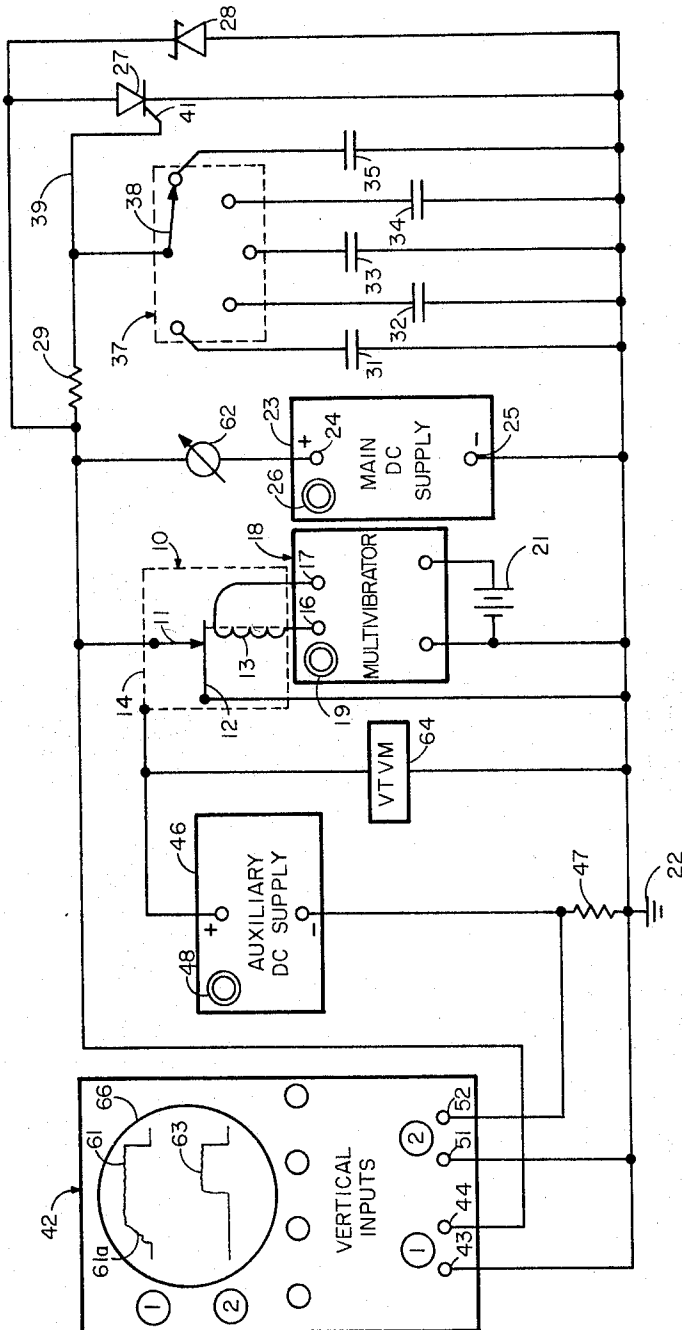


Nov. 15, 1966

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3,286,166

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FOR PARASITIC ARC SUSCEPTIBILITY BY CONTROLLING
THE CURRENT-TIME INTEGRAL OF THE ARC
Filed Jan. 21, 1963



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APPARATUS FOR NON-DESTRUCTIVE TESTING OF ENCLOSED RELAYS FOR PARASITIC ARC SUSCEPTIBILITY BY CONTROLLING THE CURRENT-TIME INTEGRAL OF THE ARC

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Filed Jan. 21, 1963, Ser. No. 252,977
7 Claims. (Cl. 324—28)

This invention relates to a relay test set and more particularly to an apparatus for the non-destructive testing of enclosed relays for parasitic arc susceptibility.

Small enclosed relays, such as miniature or micro-miniature relays, are often required to withstand voltages of up to 1,000 volts between contacts and metallic case. However, relays of this type are subject to catastrophic failure if the case is grounded and a parasitic arc develops between the relay contacts and the case. It has been found that if the relay is not properly designed such catastrophic failure may occur when switching A.-C. potentials as low as 25 volts. The failure occurs as the result of the generation of metallic vapor and metastable ions in the vicinity of the contacts by the arc formed between the contacts as they open. The vapor and the metastable ions provide a low resistance path between the relay contacts and the case, thereby allowing a parasitic arc to develop between the contacts and the case. Such parasitic arcing occurs when the case or enclosure of the relay or switch is positive with respect to the main arc. This parasitic arc phenomenon does not occur in unenclosed relays because the ionized contact material which is spewed out in the main arc is dissipated in the surrounding atmosphere and therefore does not provide a low resistance path over which a parasitic arc may develop. A detailed discussion of causes of parasitic arc failures of relays used to switch A.-C. power is to be found in the article, A Study of Discharge Transients in Relays with Grounded Cases, by Nunn and Halbeck, presented at the 9th National Conference on Electromagnetic Relays, April 1961.

Although it is desirable to test relays under conditions which approximate as nearly as possible actual operating conditions, difficulty is encountered in using an alternating current source for testing for parasitic arc susceptibility. The primary difficulty in using an alternating current source is the problem of synchronizing the contact opening with the desired portion of the A.-C. waveform. As pointed out in the above-cited article, the parasitic arc susceptibility is related to the quantity of the metallic vapor and metastable ions in the vicinity of the contact which is in turn proportional to the current-time integral of the arc. Therefore if the current-time integral of an arc produced when switching a D.-C. potential bears some fixed relation to the current-time integral of the arc under actual operating condition of the relay, the operation of the relay when switching an A.-C. potential can be predicted with reasonable certainty. While test circuits for establishing the point at which various relays fail due to parasitic arcing have been proposed, the means provided for controlling the current-time integral of the arc have not been entirely satisfactory.

It is an object of this invention to provide a novel means for controlling the time duration of an electrical arc.

An additional object of the invention is to provide a novel means for controlling the current-time integral of an electrical arc.

A further object of the invention is to provide a novel non-destructive test set for testing the parasitic arc susceptibility of relays or switches.

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Additional objects of the present invention are to provide novel means for

(a) Extinguishing the main arc between electrical contacts, and

(b) Controlling the length of time which an arc persists between two points.

In general the present invention comprises a constant current D.-C. source of supply connected across a pair of contacts, an integrating network connected in shunt with the contacts, a signal controlled rectifier connected in shunt with the contacts and the integrating network, and means connecting the integrator output to the control element of the rectifier for control of the operating state of the rectifier. The rectifier is connected to short circuit the electrical contacts upon conduction thereof. Means are provided for separating the contacts to initiate an arc therebetween. In the embodiment of the invention adapted for testing closed-case relays an auxiliary D.-C. source of supply is provided which may be connected between the metallic enclosure and one of the electrical contacts. Means may be provided for measuring the potential of the auxiliary D.-C. source of supply. An indicator such as a cathode ray tube may be provided for visually displaying traces representative of the main and auxiliary arcs.

In its preferred embodiment, the relay test set of this invention includes a suitable power supply for connection to the relay control winding for alternately opening and closing the relay contacts. An adjustable D.-C. constant current supply is connected across the relay contacts, and means are provided for connection of an auxiliary D.-C. current supply (which is also preferably adjustable) between the relay case and one of the relay contacts. A solid state controlled rectifier is connected across the constant current supply as is also a series-connected resistor and capacitor, and the junction between the resistor and capacitor is connected to the control element of the rectifier. When the relay contacts are opened, a main arc is established between the relay contacts which main arc exhibits a substantially constant potential drop which drop provides an input to the RC network. When the voltage across the capacitor of the RC network reaches a pre-determined level, the collector-to-control electrode voltage across the solid state controlled rectifier reaches a level to cause conduction of the rectifier. Upon conduction of the rectifier the relay contacts are short circuited through the rectifier thereby terminating the main arc. The duration of the main arc may be adjusted by control of the RC time constant of the RC network. Means are provided for sensing and/or observing the main arc current-time integral and also any parasitic arc current.

Other objects and advantages of the invention together with a better understanding thereof may be obtained from the following detailed description together with the accompanying drawings, the single figure of the drawing showing a schematic circuit diagram of a relay test set embodying this invention.

Referring to the drawing, the relay to be tested for parasitic arc susceptibility, designated 10, is of the closed-case type and is shown including a pair of contacts 11 and 12, a control winding 13, and a metallic case 14. The control winding 13 of the relay is adapted for connection to the output terminals 16 and 17 of a multivibrator 18 of the free-running type, which multivibrator is preferably adjustable in frequency by means of a frequency control knob 19. The multivibrator is energized by a suitable D.-C. source 21 shown connected thereto, one end of the source being connected to the ground terminal 22. Since frequency adjustable free-running multivibrators are well known in the prior art, no further details of the circuits of multivibrator 18 are shown in the draw-

ings. In one practical circuit arrangement which has been built and tested, the multivibrator was adjustable in frequency within the range of 2 to 6 cycles per second.

A main D.-C. source of supply 23 is connected across the relay contacts, the positive terminal 24 of the main D.-C. supply being connected to the fixed contact 11 while the negative terminal 25 of the supply is shown connected to the movable contact 12 by way of ground terminal 22. The main D.-C. supply source 23 is preferably of the constant current type for reasons which will become apparent in a description of the operation of the circuit hereinbelow. The current output from the main D.-C. supply source 23 is adjustable by means of a current control knob 26.

A solid state controlled rectifier 27 comprising, for example, a silicon controlled rectifier functioning as a normally open switching means is connected in shunt with the relay contacts 11 and 12. The anode of the solid state controlled rectifier is connected to contact 11 while the cathode thereof is connected to contact 12. For voltage transient protection a Zener diode 28 is connected across the silicon controlled rectifier 27.

An RC integrating network comprising a resistor 29 and any one of a plurality of capacitors 31, 32, 33, 34 or 35 is also connected across contacts 11 and 12, the resistor 29 being connected to any one of the capacitors through a switch 37. The movable switch contact 38 is directly connected to the resistor 29 while the fixed contacts of the switch are connected to the individual capacitors. The other end of the capacitors are connected together and to contact 12 by way of the ground terminal 22. The movable switch contact 38 (i.e., the junction between the resistor 29 and any one of the capacitors 31-35) is connected through a lead wire 39 to the control element 41 of the silicon controlled rectifier 27.

For observation of the main arc between the relay contacts 11 and 12, as the relay contacts are alternately opened and closed, an oscilloscope 42 of the dual-trace type may be provided. As seen in the drawing, one pair of horizontal inputs 43 and 44 of the oscilloscope is connected across the relay contacts 11 and 12.

An auxiliary D.-C. supply source 46 is connected between the relay case 14 and the common ground terminal 22 through a current-limiting resistor 47. The auxiliary D.-C. supply source 46 is also preferably adjustable by means of a voltage control knob 48, and in one practical embodiment of the invention, the auxiliary D.-C. supply source 46 is adjustable within a range of voltages between 0 and 1000 volts. A second set of vertical input terminals 51 and 52 of the oscilloscope 42 is connected across the series-limiting resistor 47 thereby providing a visual indication on the oscilloscope of any parasitic arc which may develop between the main arc and the relay case.

In operation, the normally closed relay contacts 11 and 12 are alternately opened and closed as the relay winding 13 is alternately energized and de-energized by the output from the multivibrator 18, the frequency at which the relay winding 13 is energized being controlled by the frequency control knob 19 of the multivibrator 18. Each time the relay contacts are opened, a main arc develops between the contacts 11 and 12 which arc is maintained by the constant current main D.-C. supply source 23. The voltage drop across the main arc, i.e., between contacts 11 and 12, is proportional to the distance between the separated contacts. Therefore, when the contacts are fully opened, the voltage across the contacts is substantially constant and nearly independent of the current therethrough. The current through the arc, therefore, is determined primarily by the setting of the control knob 26 of the constant current type main D.-C. supply source 23.

In the illustrated arrangement, the movable arm 38 of the switch 37 is shown connecting the resistor 29 to the capacitor 35. When the relay contacts 11 and 12 are in the closed condition as illustrated, the RC integrating

network comprising the resistor 29 and capacitor 35 is short circuited. When the relay contacts 11 and 12 are opened and an arc is developed thereacross, the arc voltage appears across the RC network and the capacitor 35 begins to charge through the resistor 29. After a period of time determined by the RC time constant of the resistor 29 and the capacitor 35, and the voltage drop across the arc between the contacts 11 and 12, a sufficient voltage appears at the output of the RC integrating network across the capacitor 35 to trigger the silicon controlled rectifier 27 to a conducting state from the normally open condition. I.e., the collector-to-control electrode voltage of the silicon controlled rectifier reaches a sufficient level to cause conduction of the rectifier. Upon conduction, the relay contacts 11 and 12 are short circuited through the rectifier thereby terminating the main arc. The resistor 29 is chosen of a sufficiently small value such that when the arc is terminated and the relay contacts 11 and 12 are still in the open condition, a sufficiently large current may be drawn therethrough to maintain the silicon controlled rectifier 27 in a conducting state even though capacitor 35 may partially discharge under such conditions. Re-establishment of the arc during the remainder of the test cycle during which the relay contacts are open is thereby prevented. By way of example but not limitation, the resistor 29 may have a resistance value of 4.7K ohms and the capacitors 31 through 35 may have the values of 2, 4, 6, 8 and 10 microfarads, respectively. Thus, by control of the RC time constant of the control circuit for the silicon controlled rectifier 27, the time duration of the main arc may be adjusted.

As mentioned above, the amount of metallic vapor and metastable ions in the vicinity of the contacts 11 and 12 during the arcing thereof has been found to be proportional to the current-time integral of the arc. The current of the arc may be adjusted by adjustment of the control knob 26 of the main constant current D.-C. supply source 23 while the time of the arc may be adjusted by the time constant selected by switch 37. The trace of the main arc voltage drop on the oscilloscope 42 provides a measure or indication of the current-time integral of the main arc, the trace of the main arc being designated 61 in the drawing. The slope, or chamfer, 61a of the main arc during the initial portion of the illustrated waveform is due to the increasing arc drop as the relay contacts are separating. Once the separation is complete, the arc drop voltage is substantially constant. An ammeter 62 may be included in series circuit with the main constant current D.-C. supply source 23 for measurement of the current therefrom.

During operation of the relay, a parasitic arc may form between the main arc between the relay contacts 11 and 12 and the case 14 whereupon a current path for the auxiliary D.-C. supply source 46 is completed, which path includes the relay case, the parasitic arc, the auxiliary D.-C. source 46 and the resistor 47. When a parasitic arc is produced causing current flow in the auxiliary circuit a voltage drop is created across the resistor 47 across which the second set of vertical input terminals of the oscilloscope 42 are connected. Thus, a trace of the parasitic arc, which trace is designated 63, is provided on the cathode-ray tube 66 of the oscilloscope. The resistor 47 is selected of a sufficiently large resistance value to prevent destruction of the relay 10 under test when a parasitic arc is drawn. A vacuum tube voltmeter 64 is shown connected between the case 14 and ground terminal 22 to provide a measure of the relay case voltage.

In testing the relay 10 for parasitic arc susceptibility, the output voltage from the auxiliary D.-C. supply source 46 is increased manually by turning knob 48 during operation of the relay. If a parasitic arc forms between the relay case 14 and the main arc, current will flow in the auxiliary current circuit in the manner described above. This will produce the trace 63. The voltage necessary to produce the parasitic arc may be read on voltmeter 64. The

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susceptibility to parasitic arcing, designated "K" hereinbelow, may range from zero (0) upwardly, with a small "K" rating indicating minimum susceptibility to parasitic arcing and a larger number, such as 8, indicating a greater susceptibility. The following empirical formula may be utilized in establishing the parasitic arc susceptibility, K, of relays tested by the circuit of this invention.

$$K = \frac{-I_{det} \log_{10} \left(\frac{P_{av} - 50}{E_{vtp}} \right)}{.4343(t - .4)} \quad (1)$$

where:

I_{det} = the current-time integral of the controlled arc in ampere-milliseconds, which is simply the product of the current times the time for D.-C. conditions,

P_{av} = the auxiliary voltage at the instant of the parasitic arc,

E_{vtp} = approximately the peak dielectric strength voltage rating between contacts and adjacent mutually insulated members, and

t = the controlled arc length in milliseconds.

The susceptibility to parasitic arcing, K, as determined by the above described circuit produces a parent curve for a family of curves related by the current-time integral of the main arc. A safe operating alternating current voltage for relays or switches at various R.M.S. current values in grounded A.-C. systems is determined by relating the current-time integral of alternating current waveform back to the above parent curve as follows:

$$S_{vrms} = \frac{.707}{2} \left[50 + E_{vtp} - \frac{\left(\frac{Z_t \times 10^3}{I_{dc}} - .4 \right) K}{Z_t \times 10^3} \right] \quad (2)$$

where:

S_{vrms} = the safe R.M.S. voltage for grounded A.-C. systems,

e = base of natural logarithms,

$Z_t \times 10^3$ = ampere-millisecond current-time integral for the alternating current which, in turn, equals

$$\frac{2I \text{ peak A.C.}}{2\pi F} \times 10^3$$

It will be apparent that the test circuit and operation thereof is in no way limited by the above formulas, the empirical Formula 1 and safe R.M.S. operating voltage Formula 2 being included merely to indicate means for obtaining a uniform measure of parasitic arc susceptibility and a safe voltage rating for the relay tested for worse-case conditions.

The invention now having been described in detail in accordance with the requirements of the Patent Statutes various changes and modifications will suggest themselves to those skilled in this art. For example, any suitable RC integrating network may be employed, and where a variable RC time constant is desired, either a variable resistor or variable capacitor could be employed instead of the illustrated switching arrangement. Further, although the circuit has been described in terms of a novel relay test set for the testing of the parasitic arc susceptibility of relays, it will be apparent that the circuit has other applications. For example, the main arc circuit could be employed in an arrangement for shorting out circuit elements after a specified over-voltage has existed for a predetermined length of time. It will be apparent that the time at which the silicon controlled rectifier conducts to thereby short out the elements would automatically adjust to the various values of over-voltage; shorting the circuit to be protected more quickly for large overload values than for small values. In such an arrangement, of course, the main D.-C. supply source could be of any type and would not necessarily be of the constant current type. Overload protection circuits of this general type are known as "crowbar" systems. In

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addition, the main arc circuit arrangement could be employed in an electric resistance welding arrangement for control of the welding current. Also, in practice, the parasitic arc may not only strike the case but may strike other relay components attached or connected thereto, such as the relay pole piece, armature, or header. It will be understood, therefore, that reference to a parasitic arc includes not only arcing between the main arc and case but also arcing from the main arc to other relay components. It is intended that the above and other such changes and modifications shall fall within the spirit and scope of the invention as recited in the following claims.

I claim:

1. Apparatus for controlling the duration and current intensity of an arc between first and second electrical contacts so that said arc is extinguished when the time integral of the current of said arc reaches a predetermined value, comprising

a D.-C. constant-current supply connected in shunt with said electrical contacts for establishing an arc between said electrical contacts upon opening of said contacts,

normally open switching means in shunt circuit with said electrical contacts,

means responsive to the voltage of said arc for producing a signal having a value dependent on said voltage and on the duration of said arc, said signal attaining a given value when the duration of the arc is such that said time integral attains said predetermined value,

and means responsive to said signal for closing said switching means when said signal has said given value, thereby to short circuit said contacts and extinguish said arc.

2. The invention as recited in claim 1 including means for alternately opening and closing said electrical contacts.

3. Apparatus according to claim 1, wherein said normally open switching means comprises a solid-state controlled rectifier including an anode, a cathode and a control electrode, and means connecting the anode-cathode path of said controlled rectifier directly in shunt with said electrical contacts;

said means for producing said signal comprises integrating means having an input and an output, means connecting said input directly in shunt with said electrical contacts, and means connecting said output between said control electrode and said cathode of said controlled rectifier, said integrating means producing across said output a potential difference the value of which depends on said voltage and said duration of said arc and attains said given value when said duration of said arc is such that said time integral attains said predetermined value, and

said means for closing said switch comprises said control electrode and said cathode of said controlled rectifier, said rectifier being responsive to said potential difference applied between said control electrode and said cathode to become conductive when said potential difference attains said given value, said rectifier short-circuiting said contacts and extinguishing said arc upon conduction thereof.

4. Apparatus for testing for parasitic arc susceptibility of a device which includes first and second electrical contacts enclosed in an electrically conductive enclosure, comprising means for alternately opening and closing said electrical contacts, a main D.-C. source of supply connected to said contacts for establishing a main arc therebetween upon the opening of said contacts, means controlling the current-time integral of said main arc, and an auxiliary D.-C. source of supply, connected between said conductive enclosure and one of said electrical contacts, for applying between said conductive enclosure and said one contact a voltage sufficiently high to establish

another arc between said main arc and said conductive enclosure.

5. Apparatus according to claim 4, additionally including

means for measuring the voltage between said one contact and said conductive enclosure,

means, having two inputs, for displaying a representation of one voltage supplied to one of said inputs and for simultaneously displaying a representation of another voltage supplied to the other of said inputs,

means connected to said first and second contacts for supplying to said one input a voltage proportional to the voltage between said contacts,

means connected in circuit with said auxiliary source of supply for producing a voltage proportional to the current flowing through said auxiliary source, and

means for supplying the last-named voltage to said other input.

6. Apparatus for testing for parasitic arc susceptibility of separable electrical contacts enclosed in an electrically conductive enclosure comprising a constant current D.-C. source of supply connected to two of said separable contacts, a solid state controlled rectifier including a control element, said rectifier being connected in shunt circuit with said two contacts, an integrating network connected in shunt circuit with said two contacts, means connecting the output of said integrating network to said control element of said rectifier for controlling the operating state of said rectifier, said rectifier providing a short-circuit between said two electrical contacts upon conduction of said rectifier, and an auxiliary D.-C. source of supply connected between said conductive enclosure and one of said two electrical contacts and adjustable to apply between said conductive enclosure and said one contact a voltage sufficiently high to establish another arc between said main arc and said conductive enclosure.

7. Apparatus according to claim 6, additionally including:

means for measuring the voltage between said one contact and said conductive enclosure,

means, having two inputs, for displaying a representation of one voltage supplied to one of said inputs and for simultaneously displaying a representation of another voltage supplied to the other of said inputs, means connected to said two contacts for supplying the voltage between said contacts to said one input,

resistive means, connected in series relationship with said auxiliary source of supply, for producing a voltage proportional to the current flowing through said auxiliary source, and

means for supplying the last-named voltage to said other input.

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