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Everest et al.

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[54] **ELECTROMECHANICAL INTERVALOMETER, AND METHOD OF USING SAME**

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 882,431, Dec. 5, 1969, abandoned.

[52] **U.S. Cl.**.....**317/80,** 89/1.814

[51] **Int. Cl.**.....**F23g 21/00**

[58] **Field of Search**.....317/80; 335/138; 102/91; 89/1.8, 1.807, 1.813, 1.814, 27, 28, 1.5 E; 315/214, 216, 217

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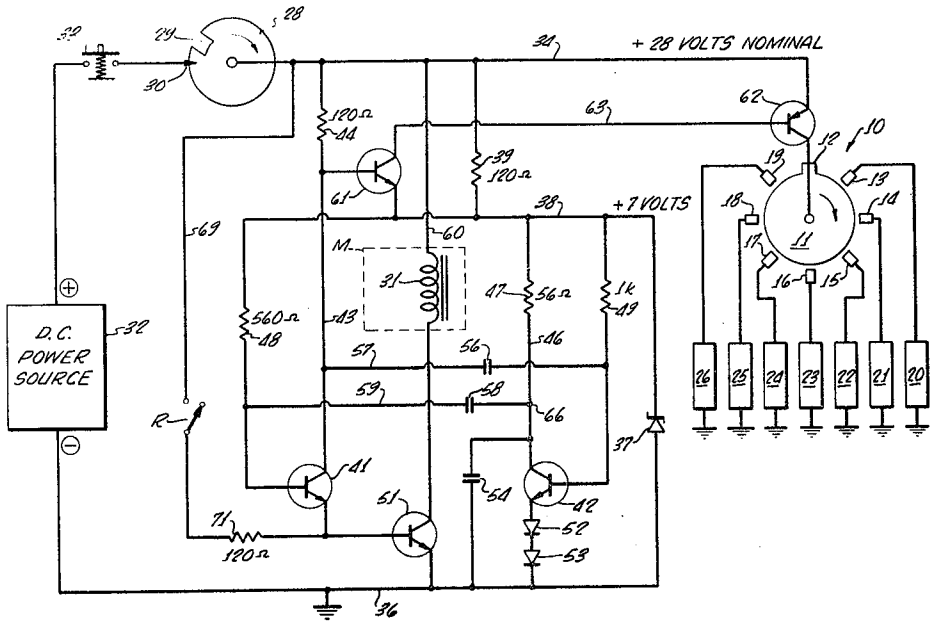
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[57] **ABSTRACT**

Apparatus and method for effecting firing, at predetermined intervals, of rockets, flares or the like. An astable, asymmetrical multivibrator oscillator is adapted to maintain energized, during the major portion of each cycle of oscillation, a solenoid which operates a stepping switch connected to the rockets. The multivibrator is adapted to complete a firing circuit through the stepping switch during the remaining or minor portion of each oscillatory cycle. The relative lengths of the cycle portions are so correlated to the firing times and shock wave-transmission times of the rockets that the solenoid is energized when the shock resulting from any firing reaches the stepping switch. The multivibrator is so constructed that pressing of the pilot-operated start button always effects initiation of operation of the long (major) portion of the cycle, but for only an abbreviated time period adapted to effect initial stepping of the stepping switch. An isolated power storage capacitor maintains operation of the multivibrator during temporary power dropouts.

50 Claims, 7 Drawing Figures



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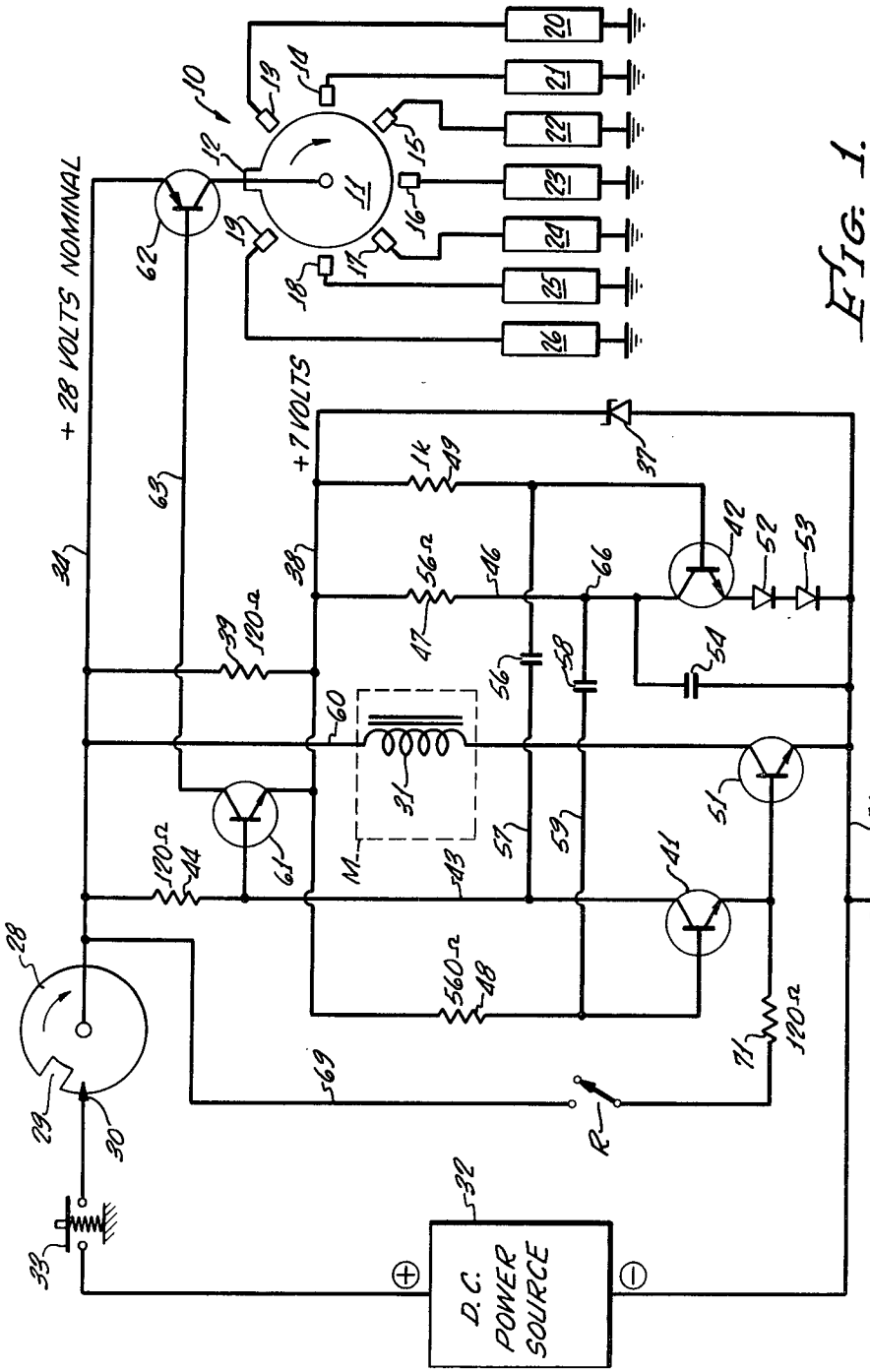
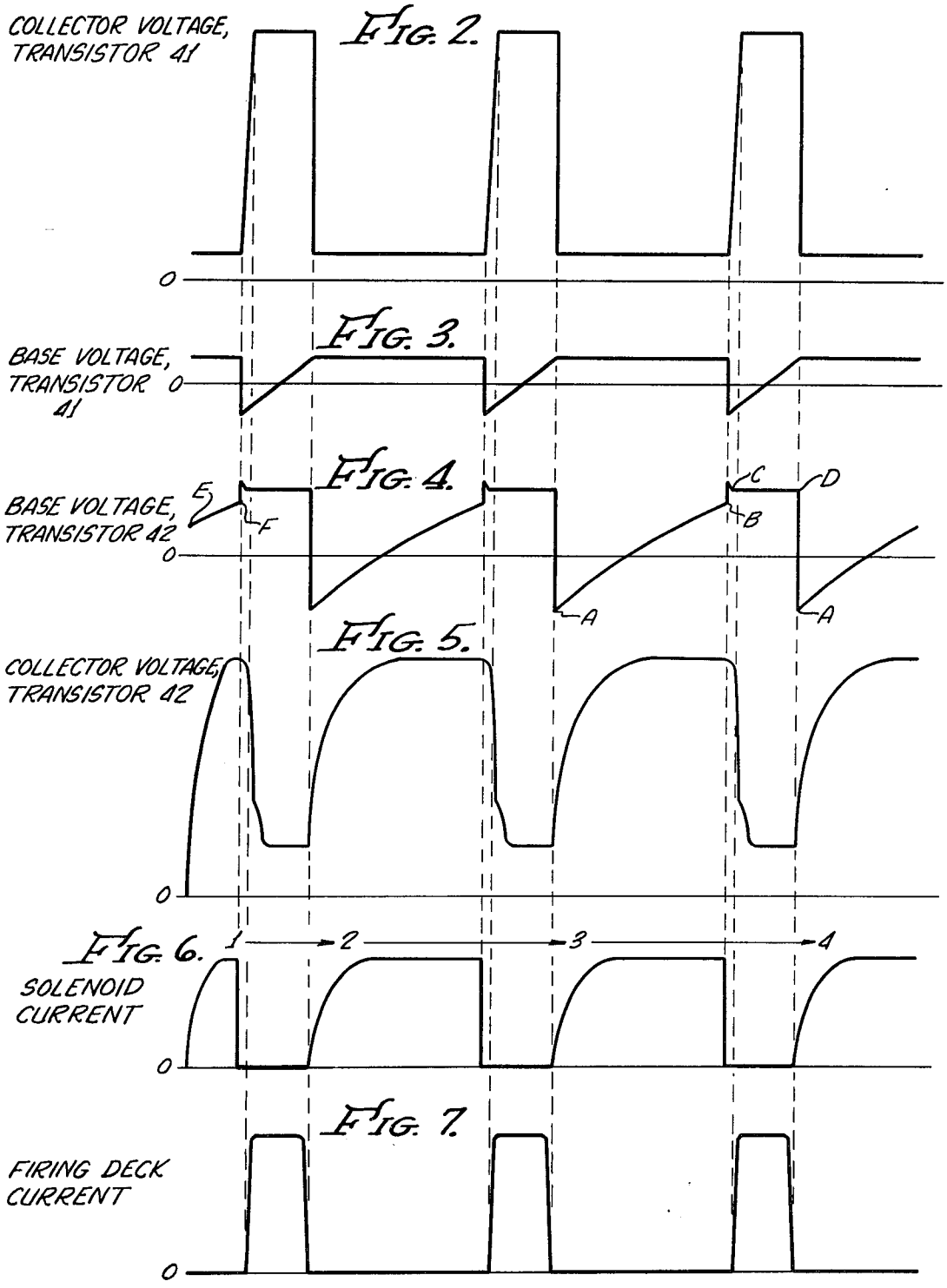


FIG. 1.

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ELECTROMECHANICAL INTERVALOMETER, AND METHOD OF USING SAME

REFERENCE TO RELATED APPLICATION

This is a continuation-in-part of our co-pending application, Ser. No. 882,431, filed Dec. 5, 1969, now abandoned for Electromechanical Intervalometer, and Method of Using the Same.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to the field of electromechanical devices, and associated methods, for controlling the firing of rockets or flares in a predetermined sequence and with predetermined times between firings.

2. Description of the Prior Art

It is known to fire rockets from rocket launchers by means of intervalometers or stepping switches, the purpose being to provide predetermined time intervals between the ignition of various rockets or pairs of rockets. Each rocket (or rocket pair) is ignited by supplying thereto an electric current, the current being derived from the aircraft electrical system or from a military power source on the ground. The current passes through a stepping switch or intervalometer the operation of which is initiated by manual closing of a control switch by the aircraft pilot or vehicle commander, etc.

The firing of the rockets creates great shock, vibration and acoustical effects in the rocket launcher, the result being that all elements in the launcher, including the intervalometer, are subjected to extremely heavy disturbing forces. Such forces are in turn amplified as each additional rocket or pair of rockets is fired. As a result of these extreme forces, prior-art stepping switches or intervalometers have not been able to control the intervals between firings in any consistent manner. The resulting variations cause the rockets to leave the launcher in such closely-spaced relationship that interference and damage to the rockets sometimes occurs, and may even result in the breaking of parts off the rockets. When the rockets are launched from aircraft, the broken and flying parts may be ingested by the turbojet engines, with consequent destruction of the aircraft. In addition, the erratic firing intervals, some of which are short and some long, have caused aerodynamic interferences with consequent reduction in the effectiveness of the fins of the rockets, so that the rockets become unstable and therefore disperse over excessively wide regions.

The above problems are compounded by the fact that the intervalometer must operate under a very wide variety of environmental conditions, including low temperatures ranging to 65° below zero (for aircraft flying at high altitudes or in the Arctic zones), to high temperatures up to 165° above zero. In addition, there are voltage variations, for example in the range of from 20 to 30 volts, which must be contended with.

It will thus be seen that the extreme environmental conditions to which the intervalometer is subjected prior to firing are compounded by the vibratory shocks which result from firing, creating an overall condition which is severe in the extreme. It is therefore desired to provide an apparatus which will produce discrete timed intervals for firing rockets while in the launcher, which is insensitive to the shocks, vibrations and acoustics

developed by the rockets when launched, and which accordingly will continue to provide the necessary control pulses at repeatable, controlled intervals determined by presettings at the factory or in the field.

The military requirements of an electromechanical intervalometer incorporating electronic components are particularly severe since the electronic components must fit into an extremely small space, namely, the space previously required by an intervalometer not incorporating electronic components.

One of the major factors which has heretofore prevented the creation of a practical electromechanical intervalometer, incorporating electronic elements, is that the first firing pulse must be delivered only a very short time period after the pilot or commander presses the button. This is particularly difficult to achieve in conjunction with relaxation oscillators, and without employing excessive numbers of components, since normally the capacitors in such oscillators require substantial charging times which prevent delivery of firing pulses until a rather long time interval after the start button is pressed.

Examples of prior-art intervalometers, and which do not incorporate electronic elements, are described in Davis U.S. Pat. No. 3,384,728 and Giese U.S. Pat. No. 3,405,376. Intervalometers of this and similar types incorporate interrupter switches which may be either single-throw or double-throw in nature. In such intervalometers or stepping switches, the power to the solenoid is only applied during a minor portion of the time, such minor portion being barely sufficient to effect retraction of the armature. Because of the short durations of the periods during which power is applied to the solenoid, and because of various other factors including contact bounce in the interrupter switch, and also including the severe environmental conditions mentioned above, the types of intervalometers shown in these patents were characterized by erratic firing and by other defects and deficiencies.

A prior-art electromechanical intervalometer incorporating electronic elements is described in U.S. Pat. No. 3,453,496 but this circuit relates primarily to counter means whereby the number of rockets fired may be predetermined. An all-electronic intervalometer is shown by U.S. Pat. No. 3,316,451.

Airborne power supplies, particularly those of military aircraft, generally have poor regulation and are susceptible to short period transients including millisecond intervals of total power dropout. Such transients may totally disrupt operation of an electronic timing arrangement or change its phase. Should such disruption or change in phase occur in an electronic timer during the course of firing of a group of devices, the result may be an unacceptably lengthened interval between successive firings or, even worse, the failure to fire one rocket of a group whereby the aircraft may continue its operation without knowledge by the pilot that he still carries a live round.

SUMMARY OF THE INVENTION

The apparatus and method of the invention comprise a means and method for maintaining the solenoid of the stepping switch substantially fully energized throughout substantially the entire time period while it is subjected to shocks resulting from rocket firing. The

apparatus and method provide relatively long-duration pulses of energizing power to the solenoid, followed by short-duration periods of solenoid de-energization. Means are provided to fire the rockets during such periods of solenoid de-energization. The solenoid-energizing pulses are correlated to the rocket-firing times, and to the shock-transmission times, in such manner as to assure the above-indicated solenoid energization while shocks are applied to the intervalometer.

The electronic portion of the present electromechanical intervalometer apparatus comprises an astable (free-running) multivibrator oscillator which is asymmetrical or unbalanced. The manner of unbalance is that each cycle of oscillation has two portions, a long portion and a short portion, and such portions are caused to be of such durations that the solenoid motor of the stepping switch is energized during substantially the entire time period when major shocks and vibrations are transmitted thereto from the rockets. Since the solenoid is thus energized, it is locked and is rendered immune to the shocks and vibrations. Threshold means are provided in the multivibrator to insure that the transistor on the long-period side of the multivibrator turns on before the transistor on the short period side, but the threshold means is also caused to be such that, for this first cycle only, the duration of the pulse generated when the long-period side is on will be relatively short. Such first pulse is caused to be sufficiently short that firing occurs only a very short time period after the pilot or commander pushes the start button. To avoid disruption of timing in the case of temporary power dropout, power storage is provided for the multivibrator and a separate path is provided for negative transients from the solenoid coil that may occur upon power dropout. The circuit is extremely rugged and reliable yet characterized by simplicity and by small numbers of components, the result being that it may be packaged in an extremely small space and thereby meet military requirements for intervalometers having no electronic components.

BRIEF DESCRIPTION OF THE DRAWINGS:

FIG. 1 is a schematic diagram of an electromechanical intervalometer incorporating the present invention;

FIG. 2 shows a wave representing the voltage present at the collector of the transistor on the long-period side of the multivibrator oscillator;

FIG. 3 shows a wave representing the base voltage of such transistor;

FIG. 4 shows a wave representing the base voltage of the transistor on the short-period side of the multivibrator;

FIG. 5 shows a wave representing the collector voltage of the last-mentioned transistor;

FIG. 6 represents the current pulses through the solenoid motor of the stepping switch, and also represents the positions of the stepping switch; and

FIG. 7 represents the pulses of firing current delivered to the firing deck of the stepping switch and thus to the rockets.

The vertical scales of FIGS. 2 through 5 represent voltage, and those of FIGS. 6 and 7 represent current, but the various voltage scales do not necessarily correspond to each other, nor do the current scales correspond to each other. However, the horizontal time scales correspond so that corresponding portions of the six curves shown in FIGS. 2 – 7 are directly above each other as illustrated by dashed vertical lines.

DESCRIPTION OF A PREFERRED EMBODIMENT:

Throughout this specification, the convention is adopted that a capacitor is "charging" when its voltage is changing relatively slowly, and is "discharging" when its voltage is changing rapidly. For convenience, the portion of the multivibrator oscillator which contains a transistor which is "on" for a relatively long period of time is termed the "long-period side" of the multivibrator. Conversely, the portion of the oscillator containing the transistor which is "on" for a relatively short period of time is termed the "short-period side" of the multivibrator.

Referring to FIG. 1, the firing deck of a conventional stepping switch or intervalometer is indicated at **10** and may comprise an electrically-conductive wafer or disc **11** having a lug or ear **12** at one portion thereof and which forms the movable contact. Such movable contact **12** is initially not in engagement with any stationary contact, being instead in a safety position. However, the first time the switch steps the contact **12** is shifted clockwise into engagement with a first stationary contact **13**. Similarly, upon each subsequent step of the switch the contact is shifted clockwise into engagement with subsequent stationary contacts **14 – 19**.

Contacts **13 – 19** have connected therewith, respectively, rocket igniters **20 – 26**. For example, each such igniter may comprise a small-diameter wire adapted to burn (and thus ignite the powder in a rocket) when a current pulse is passed therethrough between a stationary contact (such as **13 – 19**) and ground.

It is to be understood that many more stationary contacts are normally provided than are here illustrated. For example, there may be nineteen contacts associated with the disc **11**, and these contacts may be double so that two rockets are fired after each stepping of the wafer **11**.

The stepping switch further comprises a wafer or disc **28** formed of electrically conductive material and having a single notch **29** therein. Such wafer is mounted on the same shaft as is the wafer **11** of the firing deck **10**, and therefore rotates therewith and in the same direction (clockwise). A contact **30** is in continuous engagement with the electrically conductive wafer **28** at all times except when it has rotated clockwise for almost 360° and the notch **29** becomes registered with the contact **30**. The elements **28 – 30** insure that the entire apparatus may only be operated during one revolution of the wafer **11** of the firing deck **10**.

The solenoid-type actuating motor for the stepping switch is indicated schematically at M, with the solenoid (electromagnet) being illustrated at **31**. Motor M may be of the type described in U.S. Pat. No. 2,496,880, which patent is referred to in the above-cited prior-art U.S. Pat. Nos. 3,384,728 and 3,405,376. Such solenoid motor is so constructed that when the winding thereof is energized the armature will be magnetically maintained clamped or locked close to the winding.

For purposes of the present description, and for no other purpose, the elements described thus far relative to the letter M and to numbers **10 – 31** may (as a matter

of convenience, to shorten the present specification) be regarded as the same as are described in the cited prior-art U.S. Pat. Nos. 3,384,728 and 3,405,376 except, however, that no interrupter switch is employed. Such patents, and also U.S. Pat. No. 2,496,880, are therefore incorporated by reference herein as though set forth in full.

The characteristics of the mechanisms described in the patents cited in the preceding paragraph are such that the wafer **10** (and also wafer **28**) shift through one step each tine solenoid **31** is energized. However, such wafers do not step (but instead remain stationary) upon each de-energization of solenoid **31**. The wafers remain stationary, when the solenoid is de-energized, despite the fact that after each deenergization of solenoid **31** a return spring shifts the armature back to a new position setting up the mechanism for an additional power stroke. Such operation is accomplished by ratchet or equivalent means.

For convenience, in the present specification and claims, the entire combination of the deck **10** and the solenoid-type rotary stepping motor M are sometimes denoted the "stepping switch." Also, the wafers and associated contacts are sometimes termed the "stepping switch" or the "rotary switch." Such interchangeability of nomenclature is occasioned by the fact that the switch disc **11**, wafer **28** and motor M are normally (but not necessarily) incorporated in a single mechanism in the same small space. The term "solenoid" is not intended to imply a limitation (for example, to the type of construction where the armature extends into the coil), but instead encompasses all forms of electromagnetic windings and associated armatures.

A.D.C. power source is schematically represented at **32**, the positive side of such source being connected through a push-button start switch **33** to contact **30**. Such start switch **33** is in the pilot's compartment of an airplane, or is operated by a commander on the ground. The disc or wafer **28** is electrically connected to a positive lead **34** so that such lead may have a nominal voltage of, for example, 28 volts. It is to be understood, however, that this voltage actually varies relatively widely, as indicated above. The negative side of power source **32** is connected to a negative lead **36** which is grounded.

In order to eliminate the effects of the voltage fluctuations, the negative lead **36** is connected to the anode of a zener diode **37**. The cathode of such diode is connected to a regulated-voltage lead **38** which, in turn, is connected through a biasing resistor **39** and an isolating diode **75** to the unregulated positive lead **34**. The relationships are, in the present specific example, caused to be such that the voltage of the regulated-voltage lead **38** is plus 7 volts. As in all examples and illustrations stated in this patent application, the values are only specified by way of illustration and are not to be regarded as limitations.

THE ASTABLE, ASYMMETRICAL MULTIVIBRATOR OSCILLATOR

The transistor on the long-period side of the multivibrator is indicated at **41**, whereas the transistor on the short-period side thereof is indicated at **42**. Each such transistor is illustrated as being an NPN, and is preferably a silicon transistor. A lead **43** connects the collector of transistor **41** to a collector resistor **44** and thence via diode **75** to the unregulated (nominal 28 volts) positive lead **34**. A lead **46** connects the collector of transistor **42** to a collector resistor **47** and thence to the regulated (7 volts) positive lead **38**. The base of transistor **41** is connected through a timing resistor **48** to regulated lead **38**, whereas the base of transistor **42** is connected through a timing resistor **49** to such regulated lead.

The emitter of transistor **41** is connected to the base of an NPN power transistor **51**, whereas the collector of such power transistor **51** is connected to the solenoid **31** and thence directly to unregulated lead **34**. The emitter of transistor **51** is connected to ground.

The emitter of transistor **42** is connected to a threshold means and thence to ground lead **36**. The illustrated threshold means comprises two diodes **52** and **53** (a double diode).

A capacitor **54** is connected between the collector of transistor **42** and ground lead **36**, and serves the purpose of insuring against cessation of oscillations despite extremely short interruptions in the power supply from source **32** as will be more particularly described below. The size of capacitor **54** is sufficiently small to prevent substantial interference with the multivibrator operation, but sufficiently large to insure continuity of operation despite momentary (micro-second or less) power lapses.

A capacitor **56** is provided in a lead **57** which extends between lead **43** (at a point between collector resistor **44** and the collector of transistor **41**) and the base of transistor **42** (that is to say, the lead which extends from such base to resistor **49**). Correspondingly, a capacitor **58** is connected in a lead **59** which extends between lead **46** (at a point between the collector of transistor **42** and the collector resistor **47**) and the base of transistor **41** (that is to say, the lead which extends between such base and resistor **48**).

The threshold means **52–53** plays an important part in the transient operation of the circuit, occurring immediately after pressing of the start button **33**. This is described in detail below. The transistor **51** is an output means related to the solenoid **31** and thus to other elements which respond to the multivibrator (and also to the opening transient) operation.

There will next be described the normal or steady-state multivibrator operation of the multivibrator oscillator (this to be distinguished from the beginning or transient operation thereof).

In the exemplary form of the present circuit, capacitor **56** has a value which is the same as that of capacitor **58**. Accordingly, and since the multivibrator is to be asymmetrical or unbalanced, the value of timing resistor **48** is caused to be smaller than that of timing resistor **49**. The resistor **48** and capacitor **58** combine to form the time constant for transistor **41** on the long-period side of the multivibrator. Correspondingly, resistor **49** and capacitor **56** combine to form the time constant for transistor **42** on the short-period side. It is to be noted that the relative lengths of the turn-on times of transistors **41** and **42** are not determined solely by such time constants, this being because one side of the multivibrator is connected to the 7-volt lead **38**, whereas the other side is connected to the 28-volt lead **34**. As stated below, however, the voltage supplied by

the 28-volt lead is clipped by a transistor which clamps the voltage of lead 43 to a value only approximately 1 volt above the 7-volt voltage of regulated lead 38 (when transistor 41 is in off condition).

Let it be assumed that, at a particular instant in the steady-state operation, the base voltage of transistor 42 is at point A indicated in FIG. 4. At this particular instant of time, the base voltage of transistor 42 has just been pulled down (due to turn-on of transistor 41), so that transistor 42 is turned off. Stated otherwise, the turn-on of transistor 41 connects the collector of such transistor to ground via transistor 51, causing the collector voltage of transistor 41 to drop to only one diode drop (the base-emitter junction of transistor 51) above ground. This negative voltage step is transmitted through lead 57 and capacitor 56 to the base of transistor 42, thoroughly turning off the latter.

At this same time (point A in FIG. 4), the voltage at the collector of transistor 42 is starting to rise exponentially (as shown in FIG. 5) toward the plus seven voltage of lead 38. The rise in exponential because current through resistor 47 is now diverted (due to turn-off of transistor 42) through capacitor 58 to transistor 41 and thence to ground lead 36. Also, some current flows through resistor 47 to capacitor 54 and thence to ground.

Also at this instant of time, point A, current is flowing through capacitor 56, namely, through a circuit which starts a plus lead 38 and continues through resistor 49, lead 57, capacitor 56, transistor 41, transistor 51 and ground lead 36. Current flow through such circuit produces a relatively slowly varying change in the voltage of capacitor 56, and is therefore (in accordance with the convention stated at the beginning of this specification) referred to as a charging current. Such charging current effects charging of capacitor 56 as indicated in FIG. 4 (the base of transistor 42 being directly connected to such capacitor).

At the end of the period A–B (FIG. 4) which is the charging period for capacitor 56, as stated above, the base of transistor 42 rises to turn-on voltage and causes such transistor 42 to commence to turn on. Referring to FIG. 5, such initiation of turn-on of transistor 42 cause the voltage of the collector of such transistor to commence a negative transition (the collector voltage dropping in response to initiation of current flow through transistor 42, due to the presence of resistor 47). The resulting negative rate of change of voltage at the collector of transistor 42, and thus in the connected capacitor 58, results in a current flow through such capacitor 58. The rate of change at the collector of transistor 42 being negative, the current flow through capacitor 58 is from left to right and causes draining of the current which previously passed from lead 38 through resistor 48 to the base of transistor 41.

The base current of transistor 41 is therefore diverted, and (when the rate of change of voltage at the collector of transistor 42 becomes sufficiently high) a sufficient amount of base current is diverted from transistor 41 to cause such transistor 41 to go out of saturation. At that time, the collector voltage of transistor 41 commences to rise, thereby resulting in a discharging current through lead 57 and capacitor 56 (left to right) to reinforce the base current of transistor 42 and cause the latter to turn on fully. Transistor 41 thus turns off rapidly, and transistor 42 turns on rapidly, all in a matter of microseconds or less.

The preceding description thus covers the time period between points B and C, FIG. 4, point C being the point where transistor 42 is saturated and transistor 41 is fully turned off.

After point C in FIG. 4, capacitor 56 continues to discharge. The discharge circuit may be traced from lead 34 through resistor 44, lead 43, lead 57, capacitor 56, transistor 42 and ground lead 36. At the same time, capacitor 58 is charging due to current flow from plus lead 38 through resistor 48, lead 59, capacitor 58, transistor 42 and ground. The charging of capacitor 58 is indicated in FIG. 3 since capacitor 58 is directly connected to the base of transistor 41. At point D, the base voltage of transistor 41 has risen to the point where such transistor starts to turn on.

As described above relative to transistor 42, the initiation of turn-on of transistor 41 creates a negative rate of change of voltage at the collector of such transistor 41, resulting in current flow from lead 38 through resistor 49 and capacitor 56 to transistor 41 and thence to transistor 51 and ground. This diverts base current from transistor 42 and causes the latter transistor to come out of saturation. Thereupon, the collector voltage of transistor 42 starts to rise, causing current to flow through capacitor 58 and to the base of transistor 41, turning such latter transistor on hard. The collector voltage of transistor 41 therefore drops to a small amount above ground voltage, as shown in FIG. 2, thereby resulting in transmission of a negative step voltage through capacitor 56 to the base of transistor 42, thoroughly turning off the latter transistor. The initial point A of the cycle (FIG. 4) is therefore reached.

OUTPUT ELEMENTS WHICH RELATE THE MULTIVIBRATOR TO THE STEPPING SWITCH

One of the main elements which relate the multivibrator to the stepping switch (including the firing deck 10) is the above-indicated power transistor 51, and which forms a first output means. Such transistor is connected in a lead 60 which extends from the unregulated positive voltage line 34 to ground lead 36 via solenoid 31. The solenoid is therefore energized throughout the time period when the transistor 51 is on, the solenoid current being indicated in FIG. 6. Transistor 51 is on at all times when multivibrator transistor 41 is on, since the emitter current of the latter transistor is transmitted through the base of power transistor 51.

Two additional transistors are provided to associate the multivibrator with the stepping switch, namely, transistors 61 and 62 which form a second output means. Transistor 61 is an NPN transistor the base of which is connected to lead 43 (between resistor 44 and transistor 41) and the emitter of which is connected to regulated lead 38. The collector of transistor 61 is connected to a lead 63 which extends to the base of transistor 62, the latter being a PNP power transistor. The emitter of transistor 62 is connected to the unregulated positive lead 34, whereas the collector thereof is connected to the wafer 11.

Each time when transistor 41 saturates, during the above-described multivibrator operation, the voltage of the lower end of resistor 44 is pulled down to a low

voltage near ground. As soon as transistor **41** turns off, during the multivibrator cycle, the collector voltage of such transistor tries to fly up to the plus 28 voltage of lead **34**. However, such voltage of lead **43** (collector of transistor **41**) never reaches 28 volts because it is clipped by operation of the base-emitter junction of transistor **61**. The base of transistor **61** is thus clamped (when transistor **41** is off) at a value above that of the 7-volt lead **38**.

When transistor **41** turns off, the current which previously passed therethrough from lead **34** via resistor **44** passes instead to the base of transistor **61**, thence through the emitter of such transistor to lead **38** and down through zener diode **37** to ground. This effects turn-on of the transistor **61** and, accordingly, effects turn-on of power transistor **62** (because the base of the latter transistor is in the collector circuit of transistor **61**). Turn-on of power transistor **62** completes a firing circuit through which firing current (FIG. **7**) is supplied from plus lead **34** to wafer **11** and thus to the rocket igniters **20–26**.

It will thus be seen that transistor **51** constitutes a first electronic switching means controlled by the multivibrator, and that transistors **61** and **62** constitute second electronic switching means controlled thereby.

IMPORTANT TIMING AND DUTY CYCLE RELATIONSHIPS

As indicated above, current is supplied to the firing deck **10** when transistor **41** of the multivibrator is off, whereas, conversely, current is supplied to the solenoid **31** when the same transistor **41** is on. The current through solenoid **31**, and the deck current through transistor **62**, are therefore out of phase relative to each other as shown in FIGS. **6** and **7**. The deck current may be referred to as "firing pulses" (FIG. **7**), whereas the pulses through the solenoid **31** may be referred to as "holding pulses" (FIG. **6**) since these pulses cause the armature of the solenoid motor M to be held down and thereby effectively resist the effects of shock.

Thus, in accordance with the apparatus and method of the present invention, each firing pulse is delivered during a time when there is no solenoid current, and thus no holding of the armature in its retracted condition. Also in accordance with the present invention, a holding pulse is supplied to the solenoid sufficiently soon after each firing pulse that the armature of the solenoid-operated stepping motor is shifted to retracted condition before the shock wave resulting from the firing pulse is received by the intervalometer. Stated otherwise, the relationships between the firing pulses and the holding pulses are caused to be such that the delay which occurs after each firing pulse (FIG. **7**), and prior to the time the shock reaches the intervalometer, is sufficiently long that no substantial shock is felt before the next solenoid pulse is delivered to thereby shift the armature to retracted position.

The intervalometer is normally mounted in a recess adjacent the outer surface of a pod containing numerous rockets. When a firing pulse is received by one of the igniters (such as **20–26**) in the pod, a certain amount of time is required for the igniter to burn and therefore commence ignition of the rocket. In addition, a certain amount of time is required for burning of the powder in the rocket. Furthermore, time is required for transmission of the shock wave through the pod to the intervalometer. In accordance with the present method and apparatus, the time interval between each firing pulse and each holding pulse is caused to be shorter than the elapsed time resulting from all of the factors enumerated in the present paragraph, the result being that the armature is effectively restrained (solenoid current on) by the time the shock wave is felt.

In accordance with another major aspect of the present method and apparatus, the solenoid pulse is not only supplied sufficiently soon after firing to insure that the armature will be restrained before the shock wave is felt, but each solenoid pulse (after the first one, as stated under the following subheading) is caused to be sufficiently long to insure that all substantial shocks and vibrations will dissipate before the application of the power to the solenoid is discontinued. Thus, the duty cycle of the solenoid is caused to be high, much higher than in prior-art apparatus and methods. The duty cycle of the solenoid **31** is at least 50 percent and should be much higher. Preferably, the duty cycle is in the range of 60 percent to 90 percent. An exemplary duty cycle for the solenoid **31** is on the order of 75 percent. The desired duty cycle is achieved by varying the above-indicated time constants, and applied voltages, in the multivibrator.

The specified duty cycles relate to the time when power is applied to the solenoid **31** as compared to the time when the supply of power to the solenoid **31** is discontinued. Thus, the duty cycle illustrated in FIG. **6** is approximately 70 percent.

Stated in another manner, the aggregate time that power is applied to the solenoid **31** is equal to or greater than, and is preferably several times greater than, the aggregate time that no power is applied thereto. Thus, the solenoid **31** is substantially fully energized the majority of the time during each cycle of operation.

In summary, therefore, the holding pulses are delivered to solenoid **31** sufficiently soon after rocket ignition, and are caused to be sufficiently long, that substantially all shock is dissipated while the armature is magnetically restrained. The armature is only permitted to move during intervals when there is no substantial shock, so that the entire intervalometer is under predetermined electrical control and is substantially immune to shock effects. For similar reasons, the adverse effects of extreme temperatures, and other environmental conditions, are rendered unimportant.

TRANSIENT CONDITIONS FOLLOWING PRESSING OF START BUTTON 33

There will next be discussed the conditions which occur immediately following pressing of the button **33** by the pilot or field commander. It is critically important that the first rocket fire a very short time interval following pressing of such button, it being unsatisfactory to delay for a time period represented, for example, by one of the long pulses shown at the right side of the wave shown in FIG. **5**.

In accordance with a major aspect of the present invention, the above-indicated threshold means, for example the two diodes **52** and **53**, are provided in order to achieve two important results, namely:

a. Making sure that multivibrator operation always starts with turn-on of the transistor 41 on the long-period side instead of the transistor 42 on the short-period side, and

b. Causing the first pulse generated by the "long-period" side to be abbreviated, as shown at the left end of FIG. 5.

It is pointed out that the base of transistor 41 on the long-period side of the multivibrator is two diode drops above ground, namely, the base-emitter junction of transistor 41 and the base-emitter junction of transistor 51. Because of the presence of the two diodes 52 and 53, the base of transistor 42 is initially three diode drops above ground, namely, the base-emitter junction of transistor 42 and the double diode 52–53. This additional diode drop between the base of transistor 42 and ground is what insures that the transistor 41 will be the first to fire upon pressing of start button 33. Furthermore, and very importantly, the number of diode drops between the base of transistor 42 and ground is so correlated to other parameters in the circuit that transistor 42 will turn on a relatively short period of time after turning on of transistor 41, so that the first pulse generated by the long-period side of the multivibrator will be abbreviated.

Prior to pressing of start button 33, all of the capacitors 56, 58 and 54 are fully discharged. Upon pressing of start button 33 by the pilot, the unregulated positive lead 34 comes up to its 28-volt voltage within a fraction of a microsecond. It may be noted parenthetically at this point that a storage capacitor 76, the function which will be described in detail below, is coupled between ground and the diode 75. Capacitor 76 has no appreciable effect upon the rise time of voltage on unregulated positive lead 34 since the resistance between this capacitor and the power source 32 is very small. However, the node or junction point 66 (junction between leads 59 and 46) in the multivibrator remains at zero volts instantaneously. Since the base of transistor 41 is connected to such node 66 through capacitor 58, such base of transistor 41 also remains at zero volts instantaneously. Because, at the very beginning of operation following pressing of button 33, the base of transistor 41 is thus at zero volts, such transistor 41 is in off condition.

After start button 33 is pressed, both sides of capacitor 56 start to rise rapidly toward the 28-volt voltage of line 34. The voltage rise on the right side of capacitor 56 causes the base-collector (not the base-emitter) junction of transistor 42 to become forward biased, whereupon such base-collector junction starts to conduct.

A path for flow of substantial current is thus created from the unregulated lead or line 34 through diode 75, resistor 44, capacitor 56, the base-collector junction of transistor 42, capacitor 54 and ground. In addition, there is a substantial current flow from line 34 through diode 75, the relatively small resistor 39, the relatively small resistor 47, capacitor 54 to ground. There is an additional small current flow, namely, one from lead 34 through diode 75, resistor 39 and the large resistor 49 to the base-collector junction of transistor 42 and thence through capacitor 54 to ground, but this latter flow is so small in comparison to the others that it may be disregarded.

The above-described current rapidly charge capacitor 54, causing the voltage at the collector of transistor 42, and also at the connected node 66, to rise rapidly. Such rapid rise is transmitted through capacitor 58 to the base of transistor 41. This causes turn-on of transistor 41 and thus of the associated power transistor 51, so that solenoid 31 becomes energized as shown at the left end of FIG. 6.

It is important to note that the two diodes 52 and 53 prevent transistor 42 from turning on at this time, there being insufficient voltage at the base of such transistor to overcome the three diode drops indicated above. Thus, it is only the base-collector junction of transistor 42 which goes into conduction.

All of the above occurs in a very short time period, for example 50 microseconds.

The described turn-on of transistor 41 assimilates or draws to transistor 41 current which previously flowed through the first-mentioned one of the above-indicated paths (through resistor 44, capacitor 56, and the base-collector junction of transistor 42), causing such base-collector junction of transistor 42 to cease conduction. The current which previously flowed in the second-mentioned one of the above-indicated paths (through resistor 47) now passes into capacitor 58 as well as into capacitor 54. Such current flow from line 38 through resistor 47 and capacitor 58 to the base of transistor 41 causes the latter transistor to turn on hard, and such transistor goes into saturation. Accordingly, the collector voltage of transistor 41 drops by a predetermined amount down to only one diode drop (the base-emitter junction of transistor 51) above ground. Such predetermined drop in the voltage at the collector of transistor 41 is felt (through capacitor 56) by the base of transistor 42, and causes multivibrator operation to start with a predetermined desired charge on capacitor 56.

As multivibrator operation thus commences, the base voltage of transistor 42 (charge on capacitor 56) is approximately at point E shown at the extreme left end of FIG. 4. It will be noted that such point E is at a much higher voltage level than is the point A which was described above relative to the normal or steady-state operation of the multivibrator, which means that the time period elapsing between point E and point F (when transistor 42 turns on due to a sufficient amount of charging of capacitor 58 via a circuit from line 38 through resistor 47) is much shorter than the time period elapsing between point A and point B.

Because of the selection of the proper threshold means between the emitter of transistor 42 and ground, and also because of the use of capacitors having the necessary values, the time which elapses between point E and point F of FIG. 4 is approximately equal to the time required to effect initial stepping of the solenoid-operated stepping motor M. Stated otherwise, the duration of the resulting solenoid current pulse (shown at the extreme left of FIG. 6) is sufficiently great to cause the solenoid switch or deck to step to its first position.

If there were three diodes between transistor 42 and ground, instead of two, the portion E–F of the curve of FIG. 4 would be much longer, and the delay between pressing of button 33 and the first firing pulse to the firing deck 10 would be longer. It is only desired to cause the first pulse of solenoid current to be sufficiently long

to insure that the switch deck is shifted from safety position to its first firing position (ear 12 resting on the first stationary contact 13), so that immediately thereafter a current pulse may be transmitted through the deck to fire the first rocket. The short-pulse operation thus causes firing of the first rocket a short time after start button 33 is pressed.

Although the above description has been given relative to a circuit including capacitor 54, it is emphasized that such capacitor 54 is not essential to this initial turn-on operation. Instead, as previously stated, such capacitor is primarily intended to maintain the multivibrator in operation despite short lapses in the power supplied from source 32. Nevertheless, in the presence of some transients or unsteadiness in the power supply, capacitor 54 does assist the steering diodes 52, 53 in ensuring that transistor 41 is the one that turns on first.

If there were no capacitor 54, the above-described initial transient operation would be substantially the same except there would be no 50-microsecond delay. Current through the base-collector junction of transistor 42 would then pass through capacitor 58 to the base of transistor 41. There being nothing to ground the node 66, the voltage at such node would fly up instantaneously upon pressing of button 33.

SUMMARY OF INTERVALOMETER OPERATION

There will next be set forth a brief summary of the ripple or intervalometer operation, this being distinguished from the single-shot operation described under the next subheading.

Prior to the time the pilot or field commander presses the start button 33, all of the elements are in the positions shown in FIG. 1. The ear 12 of the wafer 11 on firing deck 10 is therefore not engaged with any of the stationary contacts 13–19, being instead in safety position. Upon pressing of button 33, and as described in detail in the previous subheading, the transistor 41 on the long-period side of the multivibrator is the first to turn on. Such turn-on of transistor 41 causes turn-on of transistor 51 and consequent energization of solenoid 31 of the stepping switch, as shown by the left pulse in FIG. 6. Also as stated under the previous subheading, the solenoid current flows for a time period barely sufficient to cause the firing wafer 11 to step to its first firing position, ear 12 then being engaged with the first stationary contact 13. Such first firing position is represented by the numeral "1" in FIG. 6.

As soon as transistor 41 turns off and transistor 42 turns on, as a result of the above-described multivibrator operation, the voltage in lead 43 flies up until transistor 61 turns on, with consequent turn-on of transistor 62 to deliver a firing pulse from the unregulated lead 34 through transistor 62 and through the deck 10 to the contact 13 and thence to the first rocket igniter 20 and ground. The first rocket thus fires during a time when the solenoid 31 is de-energized. Although the solenoid is de-energized, there is no motion of the deck since, as stated above, the mechanical elements in the stepping switch are such that stepping only occurs upon energization of the solenoid and not upon de-energization thereof. Thus, as shown by the leftmost arrow in FIG. 6, the switch remains in its first firing position.

The firing of the first rocket (or pair of rockets) creates the very powerful shock indicated above but, because of the factors previously stated, such shock does not reach the intervalometer until the solenoid 34 is again energized as indicated by the second pulse in FIG. 6 (which results from the subsequent turn-on of transistor 41 on the long-period side of the multivibrator) and as a result of the normal multivibrator operation. It is emphasized that such second pulse transmitted through the solenoid and all subsequent solenoid pulses are long. Such pulses are sufficiently long that the solenoid will be energized throughout the entire period when substantial shocks and vibratory forces are transmitted to the intervalometer. The consequent magnetic clamping down of the armature of the solenoid motor M therefore prevents the erratic firing which is characteristic of prior-art apparatus.

The second pulse (FIG. 6) transmitted through solenoid 31 not only clamped down the armature of the stepping switch motor but also caused stepping of the ear 12 of the firing deck 10 into engagement with the second stationary contact 14. This is represented by the numeral "2" in FIG. 6. Accordingly, as soon as transistors 41 and 51 turn off during normal multivibrator operation, transistors 61 and 62 turn on to cause transmission of a firing pulse through the above-described circuit to the contact 14 and thus to the second rocket igniter 21.

The operation then proceeds as described above until the stepping switch has stepped to all contacts 13–19, and all of the rockets have been fired. The third and fourth firing positions are indicated by numerals "3" and "4" in FIG. 6, and such positions are maintained as indicated by the arrows. The above-described disc 28 having notch 29 therein insures that there will be no recycling despite any continued pressing of the button 33.

All of the rockets are thus fired (a firing sequence or ripple) in a very short period, such as 600 milliseconds (it being remembered that there are normally more contacts than are shown in the illustrated deck 10). The ripple time may be varied, for example to 400 milliseconds, by adjusting the time constants in the multivibrator. In a typical intervalometer incorporating the present invention, each cycle may require 60 milliseconds, during which the solenoid current is on for about 45 milliseconds. In another application, each cycle requires 40 milliseconds, during which the solenoid current is on for 25 milliseconds.

The rockets fire in such manner, without erratic operation, that there are no aerodynamic disturbances, misfiring, excessive spreading, or other adverse characteristics of prior-art apparatus.

SINGLE-SHOT OPERATION

All of the above description relates to the ripple or multiple firing of the rockets. This occurs when a ripple switch R, FIG. 1, is in the illustrated position connected to a blind contact.

When single-shot operation is desired, the ripple switch is shifted to its other position in order to permit closing of a circuit which extends from the plus voltage lead 34 through a lead 69 and a current-limiting resistor 71 to the junction between the emitter of transistor 41 and the base of transistor 51.

When the ripple switch R is thus shifted away from the illustrated ripple position, the pressing of start switch 33 causes transistor **51** to turn on hard, and thus completes a circuit through solenoid **31**. The firing deck wafer **11** therefore immediately steps, causing the ear **12** to engage the first stationary contact **13** (firing position 1).

Although the lead **69** from the 28-volt supply lead **34** is also connected to the emitter of transistor **41**, there is not much change in the emitter voltage of such transistor since the lead **69** is only one diode drop above ground (the base emitter junction of transistor **51**). The multivibrator therefore operates substantially the same as described above, and starts with the short first pulse just as is the case when the switch R is in the illustrated ripple position. It follows that, as soon as the solenoid **31** effects stepping of the deck **10**, a firing pulse will be delivered to the deck and thus to the first rocket igniter **20**. Thus, the rocket fires very shortly after pressing of button **33** as desired.

Since the solenoid remains energized during the entire time that the pilot or field commander maintains his finger on button **33**, there will be no stepping of the switch while such button is maintained pressed. Subsequent firing pulses may be delivered to the rocket igniter **20**, but they will be ineffectual since the rocket has already fired.

In order to fire the second rocket, the pilot releases the button **33** and then presses it again, thus repeating the described cycle.

POWER DROPOUT PROTECTION

The airborne power supply is subject to various irregularities of which two may be classified as (a) very short firing transients and (b) longer contact dropouts. The very short firing transients are micro or nanosecond duration transients, largely due to rocket firing. To enhance reliability, the pulse to the rocket firing squib is of 15 milliseconds duration although the squib itself requires only four milliseconds for complete burnout. When the firing pulse is applied, it is supplied as a 4 ampere pulse through a 5 ohm resistor to thereby create a 20 volt drop in the voltage on the power line as seen at the input to the intervalometer. This is an exceedingly sharply rising wave front of the indicated short duration. Nevertheless, it may be sufficiently long and sufficiently large to toggle the multivibrator at a point in its cycle that is not in phase with its normal toggling (changing of state). This short but sharp wave front is a voltage function that also occurs when burning of the firing squib has been completed. At such time the voltage on the power line rapidly returns to its 28 volt nominal level and again the circuit is subjected to a sharp, short transient which may toggle the multivibrator out of phase.

Capacitor **54** is sufficiently large to eliminate the adverse effects of these very sharp transients. By preventing such sharp changes in the collector of transistor **42**, both sides of the multivibrator are effectively protected against these transients. Capacitor **54**, connected between the collector of transistor **42** and ground, also helps to steer the turn-on to the long side of the multivibrator, transistor **41** in the presence of unsteady power supply as described above. The additional function of capacitor **54** is to prevent relatively fast firing transients (on the order of microseconds or even nanoseconds) from commutating or toggling the multivibrator.

Other transients occur in the power supply such as the contact dropouts referred to above. These are due to faulty wiring connections between the power supply and the intervalometer. The latter is normally positioned in or about the rocket launching mechanism, carried in a pod or other structure externally of the aircraft. In the usual arrangement, in addition to the pilot's firing button, there are many switches, wiring connectors, plugs, safety devices, and the like, interposed in the electrical line between the power supply and the intervalometer. These devices are all subject to chattering or intermittent contact. In particular, as the structure and circuitry become older and have been subjected to the harsh and continuously vibrating environment of a flying aircraft, the various connections become loose, worn and frayed. Thus, it is common in a conventional aircraft to accept a power supply that is frequently subjected to partial power dropouts having a duration of as much as 1 millisecond.

Such power dropouts may have serious adverse effects upon circuit operation. They may result in completion of a full ripple firing cycle in which the interval between a pair of successive rocket firings has been unacceptably enlarged. Consider for example, an instant of time that follows by 2 milliseconds the initiation of a rocket firing pulse. Assume that at such instant there is a 1 millisecond, more or less, power dropout. Note that the rocket squib has not yet fired since the latter requires approximately 4 milliseconds to complete its burn. The firing pulse is applied for 15 milliseconds to ensure the full 4 millisecond squib burnout. It is possible that during and because of the 1 millisecond power dropout, the multivibrator will be toggled (change state). Thus, when the power comes back on after the 1 millisecond dropout, a holding pulse would be applied to the solenoid coil, the firing deck would switch to the next firing squib, and that rocket of which the firing squib was receiving a firing pulse at the time of dropout would remain unfired. In such a situation, it is entirely possible that the aircraft would return to its base or continue its operation without the knowledge by the pilot that he was carrying a live, unfired rocket.

Again consider a 1 millisecond, more or less, power dropout that occurs shortly after the holding pulse is supplied to the solenoid coil, but before the solenoid armature had been fully actuated and locked. If upon subsequent power return, the multivibrator had been toggled, an additional time would be required before the multivibrator returned to that point in its cycle at which the firing deck **11** would step to the next rocket. Thus, the interval between rocket firings has been enlarged by a time significantly greater than the duration of the firing pulse. An intervalometer exhibiting firing intervals greater than specified amounts is not considered to be acceptable to the military organizations.

The aborting of the solenoid operation upon power dropout may be due in part to the back electric motive force developed by the solenoid. Thus, upon temporary power dropout, this back EMF could discharge the solenoid so that upon return of power, application of the holding pulse might not be of sufficient remaining

duration to ensure a full throw and locking of the armature.

In order to eliminate the adverse effects of such relatively longer power line dropouts, the unregulated power supply line **34** is connected via diode **75** to provide power to the multivibrator. The multivibrator power is supplied from diode **75** via resistor **44** to the collector of transistor **41** and via resistor **39**, regulated voltage lead **38** and resistors **47** and **49** to transistor **42**.

Also connected to diode **75** is a capacitor **76** having its other side connected to ground. Capacitor **76** is a large capacitor, on the order of fifteen microfarads or more, having a size limited only by available physical space. Capacitor **76** is charged to the nominal 28 volts during normal operation by current flowing from switch deck **28** and through diode **75**. In the event of dropout of power on the power line **34**, the charge on capacitor **76** is isolated from the power supply, from the solenoid coil, and from the power transistor **62** by means of diode **75**. Accordingly, the charge on the capacitor **76** cannot be drained by the power supply nor by the solenoid, nor by power transistor **62**, all of which are connected directly to the unregulated power line **34**. Thus, the stepping switch and rocket firing may be momentarily disabled during the power line dropout but capacitor **76** will continue to supply power to the multivibrator. Accordingly, the multivibrator will remain in phase and its timing will be entirely unaffected by such 1 millisecond, more or less, power line dropout.

Where the capacitor **76** and diode **75** are connected as shown, a momentary loss of power that occurs during the firing pulse, cannot and will not change the multivibrator phase, and, thus, when power is returned the remainder of the 15 millisecond firing pulse will be applied to the same rocket squib which will fire just as if no power dropout had occurred. Similarly, if a power dropout had occurred during a holding pulse, upon return of power the holding pulse continues to ensure completion of the armature stroke and locking of the armature in place without any change of cycling phase of the apparatus.

In a copending application for Intervalometer and Timing Oscillator by Charles E. Everest, Ser. No. 62,948, filed Aug. 11, 1970, and assigned to the assignee of the present application, there is described an analogous power dropout storage arrangement. However, the power dropout storage of said copending application is connected in a different manner to ensure continued operation of a unijunction transistor oscillator. Such oscillator drives a silicon control rectifier that initiates energization of a solenoid coil having a set of self-interrupting contacts. In the arrangement of the copending application, power dropout effects are considerably different, particularly because of the use of the self-interrupting solenoid coil.

Power loss in a circuit having a coil such as the solenoid coil **31** introduces still other problems due to the back EMF generated by an inductance. Thus, upon loss of power, the upper end of the solenoid as illustrated in FIG. **1** may go sharply negative by an amount sufficient to toggle the multivibrator and change its phase. Change of phase of the multivibrator can result in the several problems detailed above.

Such adverse effect of the coil EMF upon the multivibrator timing may occur through a negative current path from the solenoid through power line **34** through the emitter base junction of transistor **62**, and thence from the collector to the emitter of transistor **61** to the regulated voltage line **38**. This path may produce a sharp negative-going voltage step on line **38** that could be sufficient to turn off transistor **41** if it happens to be conducting.

In order to eliminate or at least significantly minimize any current in the above-described path, a diode **77** is connected between the upper end of coil **31** and ground. Diode **77** is poled so as to provide a low impedance path to ground for such a negative-going signal that may occur at the upper end of coil **31** upon temporary power loss.

SPECIFIC EXAMPLE

As previously stated, the values of resistance, capacitance, etc., are given by way of illustration only and not limitation. Certain values are placed in FIG. **1** for purposes of convenience, because the relative magnitudes of resistors aid the reader in determining what is occurring, particularly during transient conditions.

Each of resistors **39**, **44** and **71** has a value of 120 ohms. Resistor **47** has a value of 56 ohms, whereas resistor **49** has a nominal value of 1 kilohm. Resistor **48** has a value of 560 ohms.

Each of capacitors **56** and **58** has a value of 47 microfarads, whereas capacitor **54** has a value of 12 microfarads.

Zener diode **37** is a 1N5341. Diodes **52**, **53**, **75** and **77** are all type 1N4001. Each of transistors **41** and **42** is a 2N4401, whereas transistor **51** is a TIP35. Transistor **61** is an MJE340, whereas transistor **62** is a TIP32.

It is to be understood that the appended claims are to be interpreted as applying to equivalent circuits wherein complementary transistors are employed, since the transistors **41** and **42** could readily be replaced by PNP transistors. In the latter event, the diodes **52** and **53** would be reversed so that the anodes thereof would be adjacent ground lead **36** and the cathodes adjacent the PNP transistor which replaces transistor **42**. It is also to be understood that phase inversion may be employed relative to the various outputs, such as the first and second output means specified above, without avoiding the appended claims. Means may be provided to discontinue the ripple at any point in the firing cycle, so that not all of the rockets in the bank need be fired after the pilot or ground commander pushes the start button **33**. The power transistors **51** and **62** may be replaced by thyristors.

The foregoing detailed description is to be clearly understood as given by way of illustration and example only, the spirit and scope of this invention being limited solely by the appended claims.

We claim:

1. An intervalometer for supplying firing pulses in timed relationship to a bank of rockets or the like, which comprises:

a stepping switch operated by a solenoid,

means to apply actuating power to said solenoid at predetermined intervals,

said stepping switch stepping from one station to the next upon each of said power applications to said solenoid, and

means associated with said stepping switch to supply firing current to different rockets in the rocket bank connected to said stepping switch, thus firing such rockets and generating shock forces that are applied to said intervalometer during a predetermined period following such firing,

said means for applying power to said solenoid including timing means correlated to the firing times and firing characteristics of said rockets, and also to the distance between said rockets and said solenoid, for maintaining said solenoid in energized condition throughout said predetermined period when the shocks and vibrations incident to the firings of said rockets are applied to said solenoid, whereby to prevent erratic firings of said rockets.

2. The invention as claimed in claim **1**, in which said means to supply firing current to said rockets includes means for supplying such firing current during periods when there is no power applied to said solenoid.

3. The invention as claimed in claim **2**, in which said means to apply said power to said solenoid includes means for applying such power sufficiently soon after said supplying of firing current to said rockets that said solenoid is substantially fully energized when said shocks and vibrations reach said solenoid, and in which said means to apply said power to said solenoid includes means for applying the same for time periods sufficiently long to maintain said solenoid substantially fully energized until said shocks and vibrations are dissipated.

4. The invention as claimed in claim **45** including

unidirectional means for isolating said storage means from said solenoid and from said rocket firing current.

5. The invention as claimed in claim **1**, in which said means to apply power to said solenoid for predetermined time periods and at predetermined intervals includes means for energizing said solenoid with a duty cycle of at least **50** percent.

6. The invention as claimed in claim **5**, in which said duty cycle is in the range of 60 to 90 percent.

7. The invention as claimed in claim **1**, in which said means to apply power to said solenoid includes means for effecting application of such power thereto for an aggregate time longer than the aggregate time during which application of such power is discontinued, during each firing sequence of the intervalometer.

8. The invention as claimed in claim **7**, in which said aggregate time during which such power is applied to said solenoid is at least several times longer than said aggregate time during which application of such power is discontinued.

9. The invention as claimed in claim **1**, in which said means to apply power to said solenoid includes means for maintaining the same substantially fully energized for a first period of time, means for discontinuing application of power to said solenoid for a second period of time shorter than said first period of time, means for applying power to said solenoid for said first period of time, means for discontinuing application of power to said solenoid for said second period of time shorter than said first period of time, and means for repeating said long-short relationship until completion of firing of said bank of rockets.

10. The invention as claimed in claim **9**, in which said second period of time has a duration which is much smaller than said first period of time.

11. The invention as claimed in claim **1**, in which said means to apply power to said solenoid includes means for applying thereto a first pulse of current which is relatively short but still sufficiently long to effect retraction of the armature of said solenoid, means for thereafter discontinuing application of power to said solenoid for a relatively short time period, means for thereafter applying to said solenoid a second pulse of current which is much longer than said first pulse, means for thereafter discontinuing application of power to said solenoid for said relatively short time period, means for thereafter applying to said solenoid a third pulse of current which is much longer than said first pulse, and means for thereafter continuing to supply relatively long pulses of current followed by relatively short periods of discontinuation of application of power to said solenoid.

12. The invention as claimed in claim **11**, in which said means to supply firing current to said rockets includes means for supplying such firing current during periods when there is no power applied to said solenoid.

13. The invention as claimed in claim **1**, in which said means to supply firing current to said rockets is a source of current pulses including electronic switching means external to said stepping switch.

14. An intervalometer for supplying firing pulses in timed relationship to a bank of rockets or the like, which comprises:

a stepping switch having numerous stationary contacts adapted to be engaged sequentially by a movable contact,

each of said stationary contacts being connected to the firing means for at least one rocket in said bank thereof,

said movable contact being initially in a safety position out of engagement with any of said stationary contacts,

a solenoid motor mechanism connected to said stepping switch and so related thereto that the first energization of the solenoid in said mechanism effects shifting of said movable contact from said safety position to a first position in engagement with the first of said stationary contacts; the second energization of said solenoid effects shifting of said movable contact from said first position into a second position in engagement with the second of said stationary contacts, and subsequent energizations of said solenoid effect successive shifting of said movable contact into successive positions in engagement with others of said stationary contacts, and

means associated with said stepping switch and with said solenoid motor mechanism to first supply to said solenoid a first current pulse sufficiently long to shift said movable contact from said safety position to said first position, to then send firing current through said then-engaged movable contact and first stationary contact, to then supply to said solenoid a second current pulse sufficiently long to shift said movable contact to said second position and also sufficiently long to maintain said solenoid substantially fully energized throughout the time when the shocks and vibrations incident to firing of the rocket connected to said first stationary contact are received by said stepping switch and

by said mechanism, to then send firing current through said then-engaged movable contact and second stationary contact, and to then repeat in alternation all of such steps of supplying current pulses to said solenoid and sending firing current through the engaged contacts, excepting the first-mentioned step of shifting said movable contact from said safety position to said first position,

whereby the rocket in said bank are fired sequentially in a non-erratic manner.

15. The invention as claimed in claim 14, in which said last-named means effects discontinuation of application of power to said solenoid for a substantial time period after the end of each of said current pulses thereto, during which time period said firing current is supplied through the then-engaged contacts.

16. The invention as claimed in claim 15, in which said last-named means is so constructed that the duration of each of said second and subsequent pulses of current to said solenoid is substantially longer than the duration of the period during which application of power to said solenoid is discontinued.

17. The invention as claimed in claim 16, in which said means to apply said pulses to said solenoid includes,

an electrical power supply,

a timing circuit energized from said power supply for applying said pulses for the aforesaid periods, and

storage means responsive to said power supply for receiving and storing electrical energy therefrom and for supplying such stored energy to said timing circuit to maintain the energization thereof during periods of loss of power from said power supply.

18. The invention as claimed in claim 16, in which the duration of each of said second and subsequent pulses is on the order of several times longer than the duration of each period of discontinuation of application of power to said solenoid.

19. The invention as claimed in claim 14, in which said last-named means effects discontinuation of said first current pulse to said solenoid a relatively short time period after commencement thereof, said short time period being barely sufficient to insure stepping of said movable contact from said safety position to said first position, said short time period having a duration much shorter than that of said second and subsequent current pulses to said solenoid.

20. The invention as claimed in claim 14, in which said last-named means supplies said current pulses to said solenoid sufficiently soon after sending of said firing current to insure that said solenoid is substantially fully energized when said shocks and vibrations reach said solenoid, and in which said last-named means delivers said current pulses to said solenoid throughout time periods sufficiently long to insure that said shocks and vibrations are dissipated before said solenoid is de-energized.

21. The invention as claimed in claim 14, in which said last-named means is an electronic circuit incorporating electronic switching means to supply said current pulses to said solenoid, and also incorporating electronic switching means to supply firing current to said rocket bank through the engaged contacts of said stepping switch, said first-mentioned and second-mentioned electronic switching means operating in alternation to supply said current pulses to said solenoid and to supply said firing current to said rocket bank.

22. The invention as claimed in claim 14, in which said last-named means is an astable, asymmetrical multivibrator adapted to supply current to said solenoid during the long-period portion of each oscillatory cycle, and adapted to supply current to the engaged contacts of said stepping switch during the short-period portion of each oscillatory cycle.

23. The invention as claimed in claim 22, in which said means to supply current to said solenoid includes,

an electrical power supply connected to energize said multivibrator, and

storage means responsive to said power supply for receiving and storing electrical energy therefrom and for supplying such stored energy to said multivibrator to maintain the energization thereof during periods of loss of power from said power supply.

24. The invention as claimed in claim 23 including means for providing a unidirectional low impedance path to ground for voltage steps that are caused by said solenoid upon loss of power from said power supply.

25. The invention as claimed in claim 22, in which start-switch means are provided for said multivibrator, and in which means are provided to insure that said multivibrator starts to oscillate at the long-period portion of the first cycle upon closing of said start-switch means, and also to abbreviate greatly the duration of such long-period portion of the first cycle.

26. A method of operating an intervalometer apparatus for firing a bank of rockets, such apparatus comprising a rotary switch driven by a solenoid-type stepping motor, said stepping motor effecting shifting of said switch from one switching position to the next switching position upon each energization of said motor, said switch remaining stationary upon each de-energization of said motor, which method comprises:

applying power to the solenoid of said motor for a time period longer than that which is required to effect shifting of said switch from one position to the next,

said time period being sufficiently long to insure that the shocks and vibrations incident to the firing of the rockets in said bank will dissipate while said solenoid is substantially fully energized,

thereafter discontinuing the application of power to said solenoid for a time period shorter than said time period of power application thereto, and

thereafter repeating in alternation said steps of applying power and discontinuing the same.

27. The invention as claimed in claim 26, in which said method further comprises supplying rocket-firing current through said switch to one of said rockets during said time period when supply of power to said solenoid is discontinued, but a sufficiently short time before application of power to said solenoid that said solenoid will be energized before said shocks and vibrations reach said solenoid.

28. The invention as claimed in claim 27, in which each of said periods during which power is applied to said solenoid is on the order of several times longer than each of said periods when no power is applied thereto.

29. The invention as claimed in claim 28, in which each of said periods of power application is about three times longer than each of said periods of no power application.

30. The invention as claimed in claim 26, in which said method additionally comprises employing a switch which is initially in a safety position at which none of the operative switch contacts are engaged with each other, and in which said method further comprises supplying to said solenoid, in advance of the first-mentioned one of the specified applications of power to said solenoid, a relatively short pulse of power adapted to rotate said switch from said safety position to the first operative position.

31. An intervalometer, which comprises:
a stepping switch,
a solenoid-type stepping motor connected to said switch to drive the same,
a free-running multivibrator,
means responsive to the "on" condition of one side of said multivibrator to supply energizing pulses of current to the solenoid of said stepping motor, and
means responsive to the "on" condition of the other side of said multivibrator to supply firing pulses of current to said switch and thus to the devices connected thereto.

32. The invention as claimed in claim 31, in which said switch is connected to the firing devices in a rocket launcher, in which said multivibrator is an asymmetrical or unbalanced multivibrator, in which said multivibrator and said means responsive to the "on" condition of said one side supply relatively long-period pulses to said solenoid, and in which said means responsive to the "on" condition of said other side supply relatively short-period pulses to said switch.

33. The invention as claimed in claim 32, in which said multivibrator is highly unbalanced, the degree of unbalance being such that said one side thereof is in "on" condition at least several times as long as said other side thereof.

34. The invention as claimed in claim 31, in which said multivibrator further incorporates means to perform both of the following functions:
a. cause said one side of said multivibrator to achieve the "on" condition prior to the other side thereof, upon initiation of multivibrator action, and
b. abbreviate the duration of the first "on" condition of said one side, upon initiation of multivibrator action, while leaving unabbreviated the durations of subsequent "on" conditions of said one side.

35. The invention as claimed in claim 34 including
an electrical power supply connected to energize said multivibrator, and
storage means responsive to said power supply for receiving and storing electrical energy therefrom and for supplying such stored energy to said multivibrator to maintain the energization thereof during periods of loss of power from said power supply.

36. The invention as claimed in claim 27, wherein said motor includes
a solenoid, and
means for providing a unidirectional low impedance path to ground for voltage steps that are caused by said solenoid upon loss of power from said power supply.

37. The invention as claimed in claim 34, in which said means is a threshold means, and in which said multivibrator is unbalanced, the unbalance being such that the durations of the second and subsequent "on" conditions of said one side are substantially longer than the durations of the "on" conditions of said other side.

38. The invention as claimed in claim 31, in which the time constants in said multivibrator are such that the time required for each full cycle of operation, during the steady-state operation thereof, is in the range of about 40 milliseconds to about 60 milliseconds.

39. The invention as claimed in claim 38, in which said time constants are such that said other side of said multivibrator is in "on" condition for about 15 milliseconds.

40. An electromechanical intervalometer adapted to effect firing of a bank of rockets, which comprises:
an unregulated D.C. lead connected to the positive terminal of a D.C. power source through a pilot-operated switch, a ground lead connected to the negative terminal of such power source,
a regulated D.C. lead connected to said unregulated D.C. lead through a biasing resistor,
a zener diode connected between said regulated D.C. lead and said ground lead,
a first NPN transistor the base of which is connected through a second resistor to said regulated D.C. lead,
the collector of said first transistor being connected through a third resistor to said unregulated D.C. lead,
a second NPN transistor the base of which is connected to said regulated D.C. lead through a fourth resistor,
the emitter of said second transistor being connected through two series-related diodes to said ground lead,
the anodes of said diodes being relatively adjacent said emitter of said second transistor,
the collector of said second transistor being connected
through a fifth resistor to said regulated D.C. lead,
a first capacitor connected between the base of said first transistor and the collector of said second transistor,
a second capacitor connected between the collector of said first transistor and the base of said second transistor,
a solenoid-operated stepping motor,
a rotary switch connected mechanically to said motor for driving thereby,
a third NPN transistor the base of which is connected to the emitter of said first transistor, and the emitter of which is connected to said ground lead,
the collector of said third transistor being connected through the solenoid of said stepping motor to said unregulated D.C. lead, and
a fourth NPN transistor the base of which is connected to the junction between said third resistor and the collector of said first transistor,
the emitter of said fourth transistor being connected to said regulated D.C. lead,
the collector of said fourth transistor being connected to the base of a fifth and PNP transistor,
the emitter of said fifth transistor being connected to said unregulated D.C. lead,

the collector of said fifth transistor being connected to the movable contact of said rotary switch,

the stationary contacts of said switch being respectively connected to rockets in said bank of rockets.

41. The invention as claimed in claim 40, in which a ripple switch is connected between said unregulated D.C. lead and the junction between the emitter of said first transistor and the base of said third transistor.

42. The invention as claimed in claim 40, in which a capacitor is connected between said ground lead and the collector of said second transistor.

43. The invention as claimed in claim 40, in which the time constant formed by the combination of said fourth resistor and said second capacitor is substantially larger than the time constant formed by the combination of said second resistor and said first capacitor, whereby said first transistor is on for a relatively long portion of each oscillatory cycle.

44. The invention as claimed in claim 40 in which an isolating diode is connected between said power source and said biasing and third resistors, in which a first storage capacitor is connected between said ground lead and the side of said isolating diode that is connected to said resistors, in which a second storage capacitor is connected between said ground lead and the collector of said second transistor, in which said motor includes a solenoid coil, and in which a coil EMF shunting diode is connected between said ground lead and said solenoid coil.

45. An intervalometer for supplying firing pulses in timed relationship to a bank of rockets or the like, which comprises:

a stepping switch operated by a solenoid,

means to apply actuating power to said solenoid for predetermined time periods and at predetermined intervals,

said stepping switch stepping from one station to the next upon each of said power applications to said solenoid, and

means associated with said stepping switch to supply firing current to different rockets in the rocket bank connected to said stepping switch, thus firing such rockets,

the timing of said means for applying power to said solenoid being correlated to the firing times and firing characteristics of said rockets, and also to the distance between said rockets and said solenoid, in such manner that said solenoid is energized when the shocks and vibrations incident to the firings of said rockets are applied to said solenoid, whereby to prevent erratic firings of said rockets,

said means to apply said power to said solenoid including

an electrical power supply,

a timing circuit energized from said power supply for applying said power for the aforesaid periods, and

storage means responsive to said power supply for receiving and storing electrical energy therefrom and for supplying such stored energy to said timing circuit to maintain the energization thereof during periods of loss of power from said power supply.

46. An intervalometer for supplying firing pulses in timed relationship to a bank of rockets or the like, which comprises: a stepping switch operated by a solenoid, means to apply actuating power to said solenoid for predetermined time periods and at predetermined intervals, said stepping switch stepping from one station to the next upon each of said power applications to said solenoid, and means associated with said stepping switch to supply firing current to different rockets in the rocket bank connected to said stepping switch, thus firing such rockets, the timing of said means for applying power to said solenoid being correlated to the firing times and firing characteristics of said rockets, and also to the distance between said rockets and said solenoid, in such manner that said solenoid is energized when the shocks and vibrations incident to the firings of said rockets are applied to said solenoid, whereby to prevent erratic firings of said rockets, said means to apply said power to said solenoid operating to apply such power sufficiently soon after said supplying of firing current to said rockets that said solenoid is substantially fully energized when said shocks and vibrations reach said solenoid, said means to apply said power to said solenoid applying the same for time periods sufficiently long to maintain said solenoid substantially fully energized until said shocks and vibrations are dissipated, and means for providing a unidirectional low impedance path to ground for voltage steps that are caused by said solenoid upon loss of power from said power supply.

47. An intervalometer for supplying firing pulses in timed relationship to a bank of rockets or the like, which comprises:

a stepping switch operated by a solenoid,

means to apply actuating power to said solenoid for

predetermined time periods and at predetermined intervals,

said stepping switch stepping from one station to the next upon each of said power applications to said solenoid, and

means associated with said stepping switch to supply firing current to different rockets in the rocket bank connected to said stepping switch, thus firing such rockets,

the timing of said means for applying power to said solenoid being correlated to the firing times and firing characteristics of said rockets, and also to the distance between said rockets and said solenoid, in such manner that said solenoid is energized when the shocks and vibrations incident to the firings of said rockets are applied to said solenoid,

whereby to prevent erratic firings of said rockets, said means to apply power to said solenoid applying thereto a first pulse of current which is relatively short but still sufficiently long to effect retraction of the armature of said solenoid, thereafter discontinuing application of power to said solenoid for a relatively short time period, thereafter applying to said solenoid a second pulse of current which is much longer than said first pulse, thereafter discontinuing application of power to said solenoid for said relatively short time period, thereafter applying to said solenoid a third pulse of current which is much longer

than said first pulse, and thereafter continuing to supply relatively long pulses of current followed by relatively short periods of discontinuation of application of power to said solenoid,

said means to apply said power to said solenoid including

an electrical power supply,

a timing circuit energized from said power supply for applying said power for the aforesaid periods, and

storage means responsive to said power supply for receiving and storing electrical energy therefrom and for supplying such stored energy to said timing circuit to maintain the energization thereof during periods of loss of power from said power supply.

48. In an intervalometer for supplying firing pulses in timed relation to a bank of explosive devices, said intervalometer having a stepping switch adapted to step from one position to another to successively apply firing pulses to different ones of said devices, singly or in groups, thus firing said devices and producing shock and vibration forces that are transmitted to said intervalometer during a known period following each such firing, a stepping switch drive motor armature, and a coil capable of being energized to shift the motor armature to a given position from which it is released when the coil is de-energized, the improvement comprising timing means for repetitively and alternately energizing said coil and feeding firing pulses to said devices through said stepping switch, said timing means comprising:

means for delivering a relatively brief firing pulse to said stepping switch,

means for delivering to said motor coil an energizing pulse

that initiates energization of said coil at a time following said firing pulse that is less than the time required for said shock forces produced by said firing to be transmitted to said intervalometer, said last mentioned means including means for maintaining said coil energizing pulse for a time at least equal to said known period whereby all substantial shocks and vibrations will dissipate before the coil is de-energized,

each said brief firing pulse being initiated during a time when said coil energizing pulse is absent, whereby said motor coil is energized and said armature is held in position by energization of said coil during the occurrence of shock and vibration resulting from said firing.

49. The intervalometer of claim **48** wherein the duration of said energizing pulse to said motor coil is considerably greater than the intervening time in which no pulse is supplied thereto whereby the motor coil is fully energized and the armature is held the majority of the time during each cycle of operation.

50. In an intervalometer for supplying firing pulses in timed relation to a bank of explosive devices, said intervalometer having a stepping switch adapted to step from one position to another to successively apply firing pulses to different ones of said devices, singly or in groups, thus firing said devices and producing shock and vibration forces that are transmitted to said intervalometer during a known period following such firing, a stepping switch drive motor armature, and a coil capable of being energized to shift and hold the motor armature in a given position from which it is released when the coil is de-energized, the improvement comprising:

means for energizing said motor coil to hold said armature against movement immediately after each firing and before said shock and vibration forces are transmitted to said intervalometer, said means including means for retaining energization of said coil and thereby retaining said armature in said held condition for a time substantially equal to said known period and sufficient to insure substantial dissipation of shock and vibration forces produced by said firing, and

means for initiating firing and releasing the energization of said motor coil, only after said shock and vibration forces having substantially dissipated to thereby permit said armature to be moved.

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