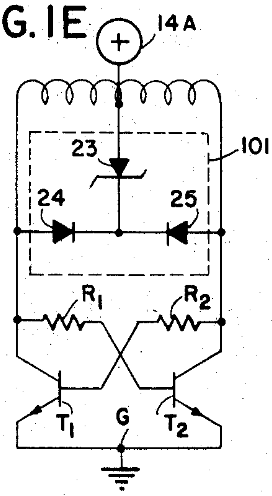
FIG. 1E



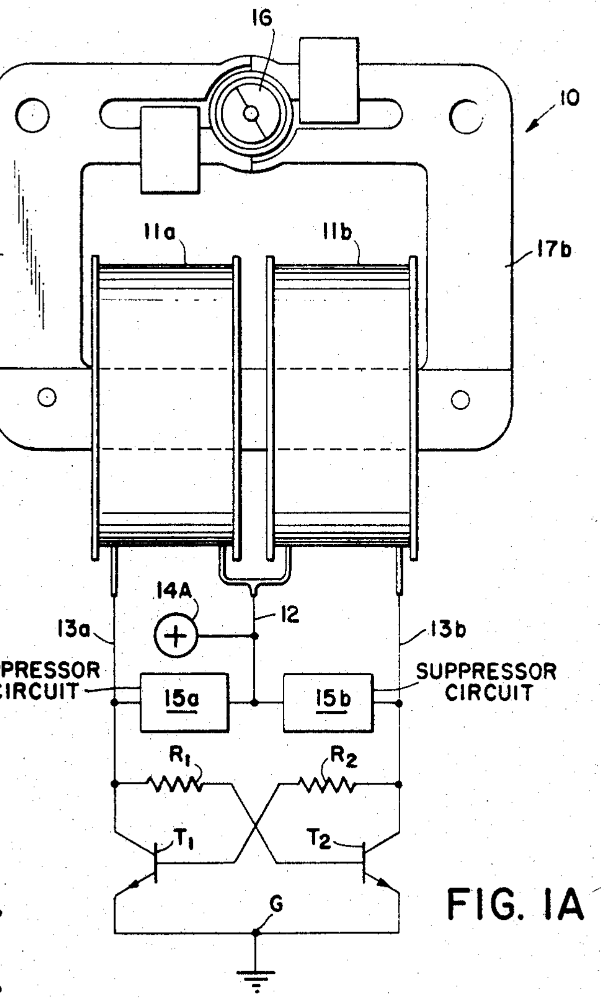
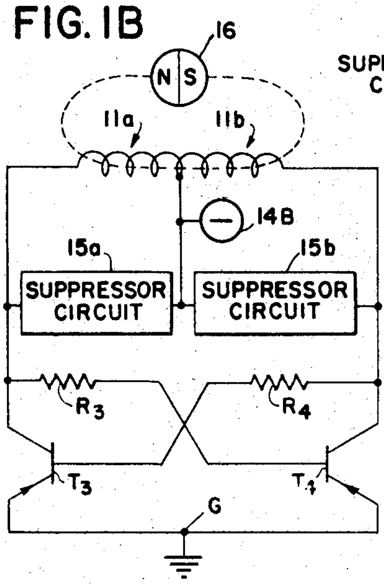


FIG. 1A

FIG. 1B



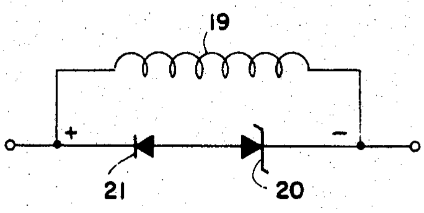


FIG. 1C

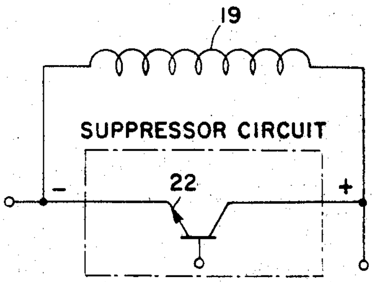


FIG. 1D

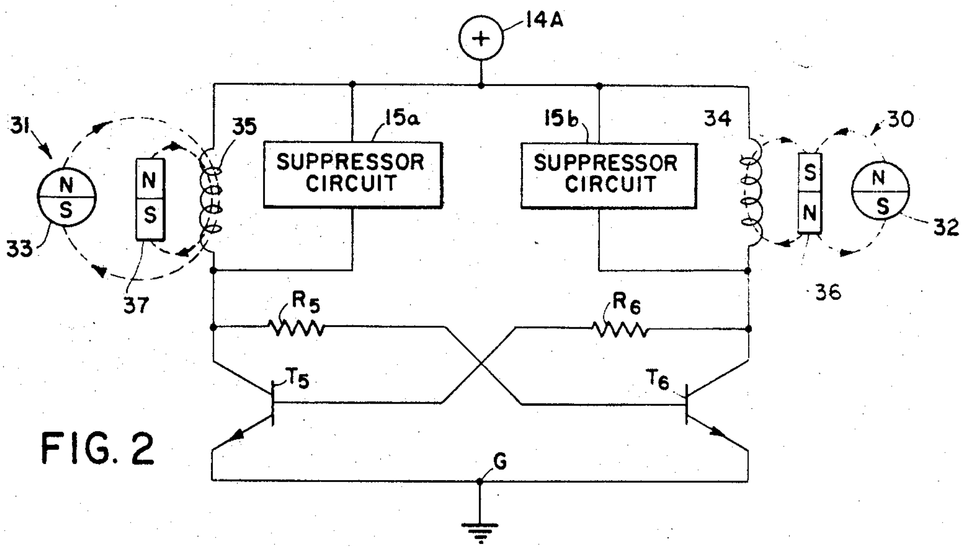


FIG. 2

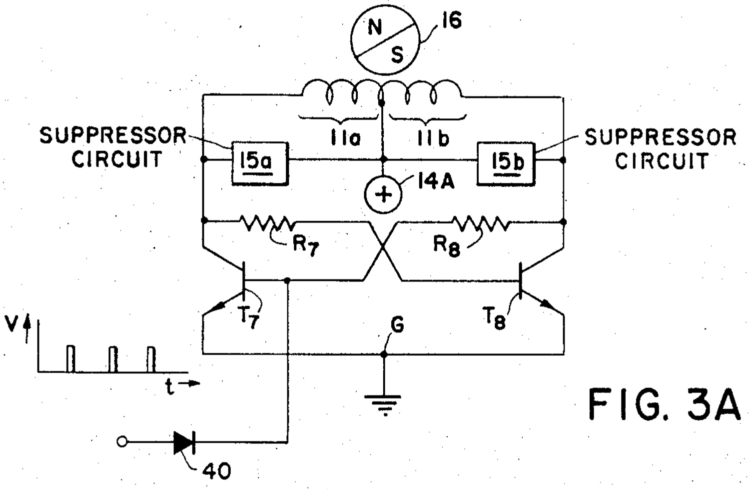


FIG. 3A

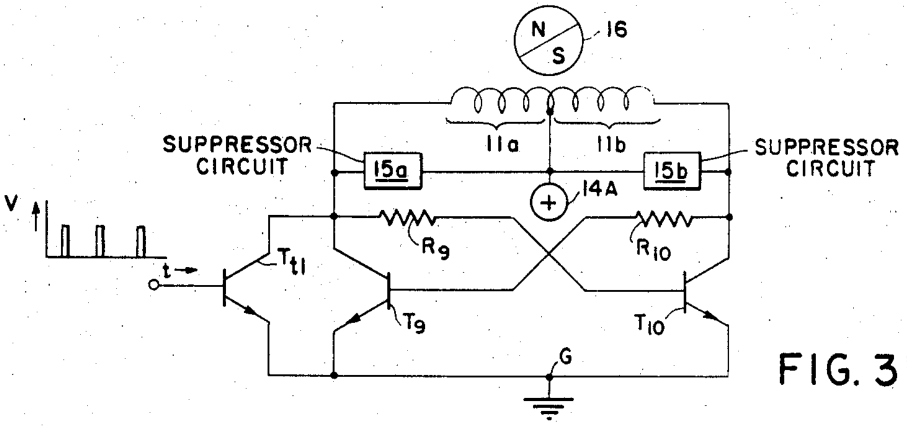


FIG. 3B

Oct. 14, 1969 E. HERBERT III 3,473,069

SYSTEM FOR TRANSLATING ELECTRICAL PULSES
INTO INCREMENTAL MECHANICAL MOTIONS

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FIG. 4A

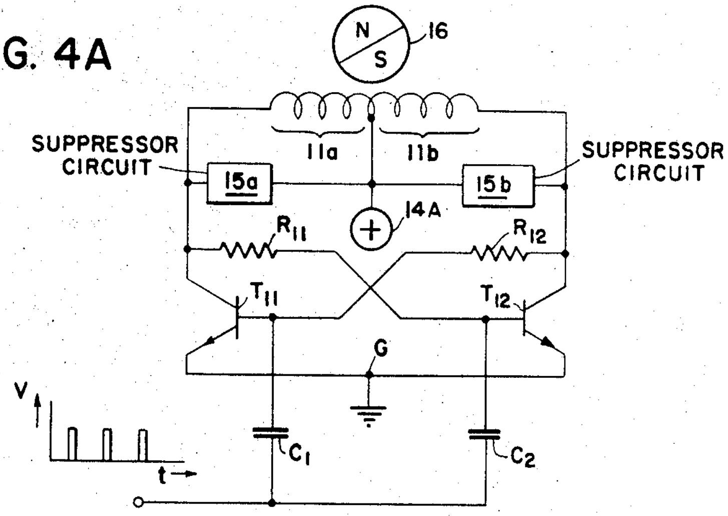
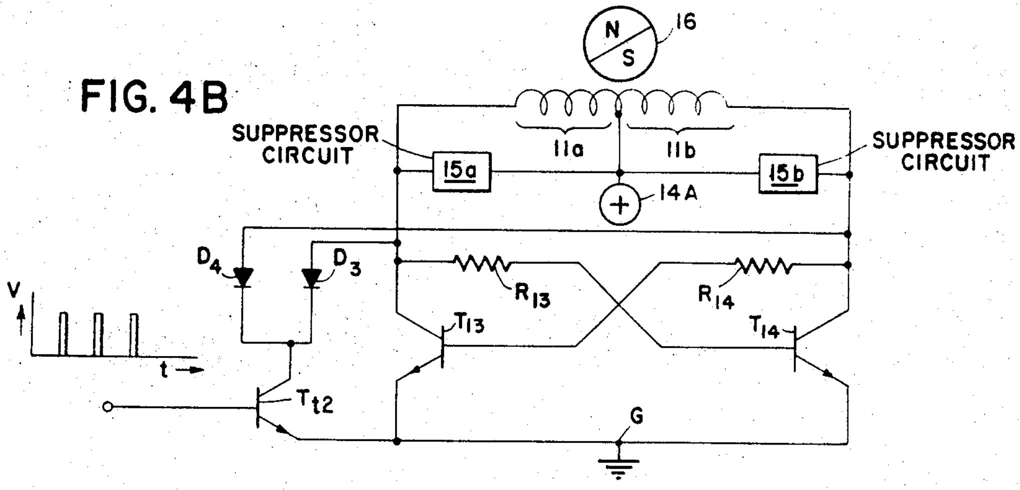


FIG. 4B



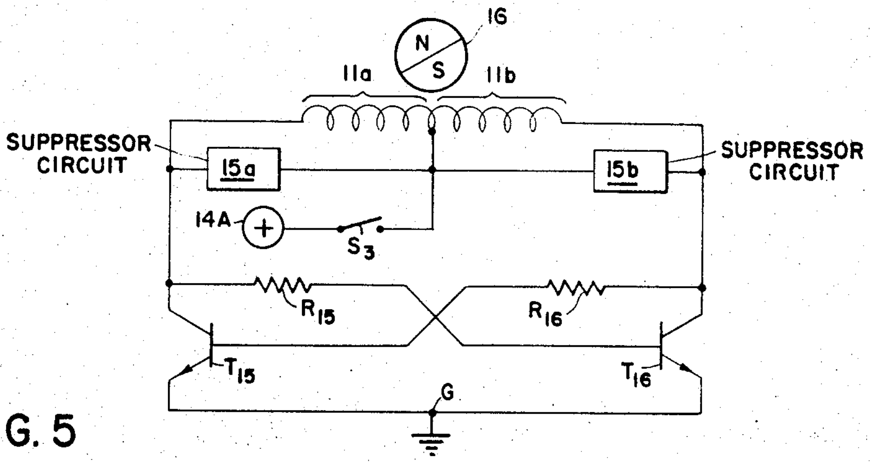


FIG. 5

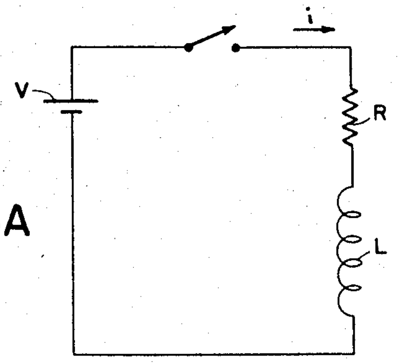


FIG. 6A

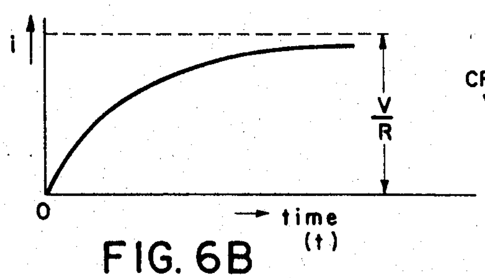


FIG. 6B

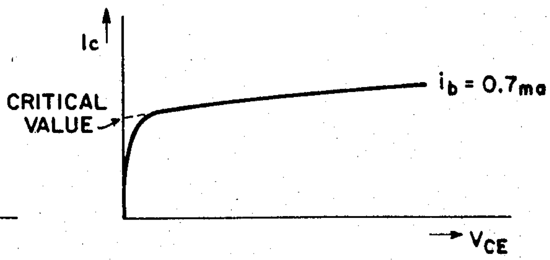


FIG. 6C

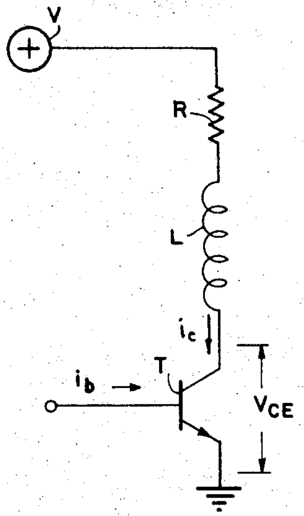


FIG. 6D

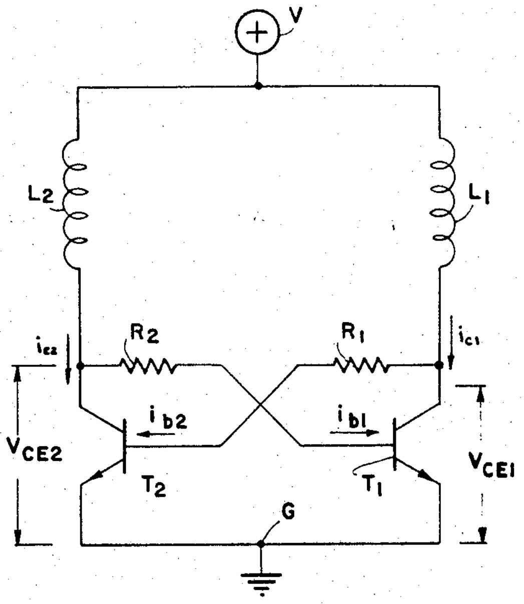


FIG. 6E

3,473,069

SYSTEM FOR TRANSLATING ELECTRICAL PULSES INTO INCREMENTAL MECHANICAL MOTIONS

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Filed June 29, 1966, Ser. No. 561,504
Int. Cl. H02k *29/00, 37/00;* **H03k** *5/08*
U.S. Cl. 318—138 **5 Claims**

ABSTRACT OF THE DISCLOSURE

A motor control circuit utilizing a transistor multivibrator having an astable, a monostable or a bistable state, in which each full cycle of transition between states produces one complete revolution of the motor. The motor includes two stator windings which are each provided with a transient suppressor circuit comprising either a diode-Zener diode arrangement or a transistor with an open base. In some embodiments the stator windings are employed to respectively energize two separate rotors.

This invention relates to systems for translating electrical pulses into incremental mechanical motions, and in particular to a stepper motor arrangement characterized by two or more stable or quasi-stable states in which the rotor member of the motor is advanced by a selected increment of rotation in response to each transition between stable or quasi-stable states.

In stepper motors of conventional design, incremental rotation of a magnetized rotor member is typically accomplished by selectively energizing one or more field coils. In order to energize the field coil or coils and thereby advance the rotor member of conventional stepper motors, it is necessary to provide relatively complex switching or logic circuitry to supply electrical energizing pulses in proper sequence and with correct polarity, amplitude and duration. Also, in conventional stepper motor arrangements, it is necessary to supply a number of energizing pulses in order to advance the rotor member through each complete revolution. One solution to some of the problems resulting from these requirements is provided by the unique stepper motor embodiments shown in the copending application of A. W. Haydon, E. Herbert, and W. D. Riggs, Ser. No. 394,669, filed Sept. 8 1964, now abandoned in favor of continuation application Ser. No. 595,286, filed Oct. 14, 1966, which latter application issued on Feb. 20, 1968, as Patent 3,370,189.

Another solution to the above problems is provided by the extraordinary discovery embodied in the present invention, in which the field coils of a motor or other electric rotating device are also the energy storage elements of a closed loop, self-regenerating system having two or more stable or quasi-stable states, each of these states being maintained without an external control or holding signal. Because of this singular structure, the rotor member in each of the embodiments of the present invention is advanced through a selected increment of rotation each time that the system undergoes a transition between states in which alternate coils are energized.

By appropriate choice of component values, embodiments characterized by different stable or quasi-stable states may be constructed. Thus in the astable embodiment, there are two quasi-stable states so that the system is self-starting and free running as the system switches between the two states and alternate coils are energized. By selecting the increment of rotation to be 180 mechanical degrees, the rotor member may be advanced through a complete revolution in each complete cycle of transition between the two quasi-stables states.

In the monostable and bistable embodiments, in which one and two stable states are respectively provided, the apparatus remains in a stable state indefinitely until an external stepping control signal or trigger pulse is applied to trigger the apparatus out of its stable state. In the case of a monostable embodiment, the external stepping control signal triggers the apparatus out of its one stable state into a quasi-stable state and thereby causes an alternate coil to be energized and the rotor member to advance. The apparatus remains in the quasi-stable state for only a brief interval, after which the apparatus returns to its stable state to await the next trigger pulse.

By constructing the apparatus to have two stable states, a bistable embodiment is formed in which the transitions are between stable states, thereby requiring an external stepping control signal to trigger the apparatus out of either of its stable states and thereby advance the rotor member. Thus, if each increment of rotation is selected to be 180 mechanical degrees for both the monostable and the bistable embodiments, it requires two extermal stepping control signals to advance the rotor member through each complete revolution.

The invention will be fully understood from the following detailed description of illustrative embodiments thereof taken in connection with the appended drawings in which:

FIGS. 1A and 1B are partial schematic diagrams of astable arrangements embodying the principles of this invention;

FIGS. 1C, 1D and 1E are schematic diagrams of alternative suppressor circuit arrangements which are employed in the present invention;

FIG. 2 is a partial schematic diagram of an astable embodiment utilizing the principles of this invention in which two rotor members are employed;

FIGS. 3A and 3B are partial schematic diagrams illustrative of monostable arrangements embodying the principles of this invention;

FIGS. 4A and 4B are partial schematic diagrams of bistable arrangements constructed in accordance with the principles of this invention;

FIG. 5 is a partial schematic diagram illustrating an alternative means for triggering either a monostable or a bistable arrangement; and

FIGS. 6A, 6B, 6C, 6D and 6E are graphs and circuit diagrams of assistance in explaining the principles of this invention.

Referring first to FIG. 1A, this drawing illustrates an astable version of the present invention, in which a rotating member is advanced in step with each internally generated change between two quasi-stable states. Motor

10, which may be of the three wire, brushless, direct current stepper variety disclosed in the copending application referred to above, is provided with a permanently magnetized, two pole ferrite rotor member **16** and two separate field coils or winding **11***a*, **11***b* (or alternatively, a single center-tapped coil) respectively mounted on stators **17***a*, **17***b*. The center tap **12** of the coils **11***a*, **11***b* is connected to a positive D.C. voltage source **14**A, and the other two leads **13***a*, **13***b* are respectively connected to the collector terminals of NPN transistors T_1, T_2, which may be, for example, of any conventional switching variety. The emitter terminals of the transistors T_1, T_2 are connected to a common point of ground potential G. As used herein and in the appended claims, the expressions "common point of ground potential," "common ground point," etc., is intended to include conventional ground points and also other points having a fixed D.C. potential with respect to ground which is different from the potential of the source **14**A. The base of each transistor is respectively cross-coupled via a resistor R_2, R_1, to the collector of the other transistor so that the transistors T_1, T_2 are linked in astable relationship to have two quasi-stable states. In one of these quasi-stable states, transistor T_1 is turned on, that is, becomes conductive, and at the same time transistor T_2 is turned off, that is, becomes non-conductive. In the second quasi-stable state, T_1 is turned off, while T_2 is turned on. Because the relationship between the transistors is quasi-stable, the two transistors automatically alternate between their turned on and turned off conditions without the application of any external control or trigger signal. Also, connected between voltage supply **14A** and the collector terminal of each transistor T_1, T_2 is a so-called suppressor circuit respectively denoted **15***a*, **15***b*, the suppressor circuits and their construction being described in detail below.

The quasi-stable relationship between transistors T_1, T_2 may be understood by referring to FIGS. 6A through 6E in connection with the following explanation.

It is well known that with a resistor of resistance R in series with an inductor of inductance L between two points maintained at a constant voltage V, as shown in FIG. 6A, the current flow *i* in the inductor at a time *t* may be found from the following circuit equation:

$$V=IR+L\frac{di}{dt} \qquad (1)$$

Solving for *i* in Equation 1,

$$i=\frac{V}{R}\left(1-e^{\frac{-Rt}{L}}\right) \qquad (2)$$

that is, *i* increases exponentially from 0 at time $t=0$ to a value approximately equal to V/R, as shown graphically in FIG. 6B.

It is also well known that for a given base current i_b, the collector-emitter voltage V_{CE} across a transistor depends upon the value of the current i_c at the collector terminal of the transistor. However, as shown in typical common emitter collector current characteristic curves, such as that illustrated in FIG. 6C for a type 2N3417 transistor with $i_b=0.7$ ma., the collector-emitter voltage V_{CE} remains small until the collector current I_c reaches a given current level, at which point V_{CE} rises quickly to a relatively high value. This critical current level is determinated by the beta or h_{FE} (D.C. current gain) of the transistor, where $I_c=h_{FE}\times i_b$.

Turning to FIG. 6D, assume that a resistor R, an inductor L, and a transistor T are connected in series between a D.C. voltage source V and ground, with a fixed base current i_b applied to transistor T. Since the current through L and hence the collector current I_c rise slowly from the instant that the potential is applied, the collector voltage V_{CE} remains low until I_c reaches the critical value, at which instant V_{CE} rise quickly.

In the circuit illustrated in FIG. 6E, which represents a portion of an electrical analog of the apparatus shown in the other drawings, transistors, T_1, T_2, are each in series with a corresponding inductor L_1, L_2, between a voltage source V and ground, and the two transistors are coupled together through resistors R_1, R_2 so that the collector-emitter voltage of each transistor determine the current applied to the base of the other transistor.

Conduction by first one transistor and then the other without an external stimulus constitutes the astable version of the circuit, in which temporary conduction by each transistor is defined to be a quasi-stable state or condition for the apparatus. In the astable version, self-regenerating transitions between the two quasi-stable states are initiated by having the collector current of one of the transistors, say I_{c1} of T_1, exceed the product $h_{FE1}\times i_{b1}$. In this manner, assuming that T_1 is turned on initially, when I_{c1} reaches the critical value at which V_{CE1} rises rapidly to say approximately 1 volt, transistor T_2 is turned on and i_{c2} starts to rise. However, as I_{c2} rises, V_{CE2} drops and so does i_{b1} so that T_1 is turned off. When T_1 is turned off, V_{CE1} rises to a value somewhat larger than the potential V due to the inductive transient from inductor L_1. Correspondingly, after T_2 is turned on, when I_{c2} reaches the critical value, the increase in i_{b1} turns on T_1, thereby causing a drop in V_{CE1} and a corresponding drop in i_{b2} to turn off T_2 and completes a cycle of transition from conduction by T_1 to conduction by T_2 and back to the conduction by T_1.

The appartus shown in FIGURE 1A converts internally generated electrical pulses into incremental mechanical rotation of rotor **16** in the following manner. In one half cycle of operation, the apparatus remains briefly in one of its quasi-stable states with transistor T_1 conducting and transistor T_2 cut off, so that a pulse of current flows briefly through field coil **11***a* but not through field coil **11***b*. This brief flow of current through coil **11***a* generates magnetic flux through stator frame pieces **17***a*, **17***b* to cause rotor member **16** to rotate by a selected increment, in accordance with the principles described in the copending application referred to above. Thus, the rotor rotates from a position in which a rotor pole of one polarity is opposite a given stator pole to a position in which an immediately adjacent rotor pole of the opposite polarity is opposite the given stator pole, which is defined to be a rotation through an angle of 180 electrical degrees. In cases in which the rotor includes only a single pair of rotor poles, each increment of rotation of 180 electrical degrees also corresponds to a rotation of 180 mechanical degrees.

When the apparatus changes to its second quasi-stable state in the next half cycle of operation, transistor T_2 conducts and transistor T_1 is cut off so that a brief pulse of current flows through field coil **11***b* but not through field coil **11***a*. This flow of current through coil **11***b* produces magnetic flux in the opposite direction through frame pieces **17***a*, **17***b*, thereby causing rotor member **16** to advance a further increment of 180 mechanical degrees in the same direction as the previous increment of rotation. Therefore each full cycle of transition between both quasi-stable states is accompanied by one complete revolution of rotor member **16**.

Frequency of oscillation and therefore frequency of rotor revolution are controlled by the values selected for the various components. It has been found that the inductance of coils **11***a*, **11***b* has the greatest effect on frequency, with the resistance of the cross-coupling resistors R_1, R_2 and the gain of the transistors T_1, T_2 having somewhat lesser effects. For example, an increase in coil inductance, a decrease in coupling resistance, or an increase in transistor gain tends to lower the frequency. Frequency is only slightly dependent on loading of the rotor member, and any change in frequency with load is due to the change in coil inductance caused by the loading.

Suppressor circuits **15***a*, **15***b* are provided to stabilize operation and to prevent damage to the transistors by suppressing transients which occur at the time that coils

11*a*, **11***b* are turned off, and at the same to provide relatively rapid quenching of the current. A conventional transient suppressing arrangement is shown in FIG. 1C, in which a diode **21** and a Zener diode **20**, both of well-known design, are connected in parallel with an inductive load **19** representative of the winding and storage element component of this invention, with the diodes **20, 21** being connected to one another either anode-to-anode or cathode-to-cathode. In this manner, diode **21** presvents conduction in parallel with inductive load **19** when the load is turned "on," and Zener diode **20** breaks down at some selected voltage when a transient reverse voltage is applied due to interruption of the current through the inductive load, thereby limiting the amplitude of the transient reverse voltage while quenching the current more rapidly than by diode suppression alone.

Turning to FIG. 1D, transient suppressing action similar to that of the diode-Zener diode arrangement shown in FIG. 1C may also be obtained with a single transistor **22** having an open base connection. Transistor **22** is selected to have a collector-base junction with a sufficiently high break-down voltage to act as a blocking diode, and an emitter-base junction which acts as a Zener diode. Polarity between the two junctions is such that the collector to emitter characteristics, with the base connection open, are similar to the diode-Zener diode arrangement shown in FIG. 1C. Although in certain important embodiments of the invention it is desirable to employ a suppressor circuit in parallel with each inductive load in the manner shown in FIG. 1A and described above, in other arrangements having less stringent operating requirements, the apparatus of this invention may be operated without the suppressor circuits.

FIG. 1E is illustrative of another form of suppressor circuit **101** which in some respects is similar to that described above with respect to FIG. 1C. The circuit **101** includes a Zener diode **23** having its anode connected to the center tap of the inductor. Two diodes **24** and **25** are connected across the inductor with their cathodes connected to the cathode of the Zener diode **23**. The Zener diode **23** and the diodes **24** and **25** are effective to suppress transient voltages in a manner similar to the Zener diode **20** and the diode **21** of FIG. 1C and have the additional advantage that only one Zener diode is needed to suppress transients in both of the coils.

The various illustrated embodiments of this invention may employ either NPN transistors, as shown in FIG. 1A, or PNP transistors, as shown in FIG. 1B. With PNP transistors T_3 and T_4 illustrated in FIG. 1B, however, the supply voltage **14B** is of negative polarity, whereas with NPN transistors as shown in FIG. 1A, the supply voltage **14A** is of positive polarity. Also, the suppressor circuits **15***a*, **15***b* in FIG. 1A and the suppressor circuits **18***a*, **18***b* in FIG. 1B are connected with appropriate polarity between the respective voltage supplies **14A**, **14B** and the terminals of the corresponding transistors T_1, T_2 and T_3, T_4, in the manner shown in FIGS. 1C and 1D.

Referring to FIG. 2, this drawing illustrates an arrangement in which electrical pulses are converted into mechanical rotation of two rotors instead of mechanical rotation of a single rotor as in FIGS. 1A and 1B. Two rotor members **32** and **33**, which may be part of motors **30** and **31** of the two wire, magnetically biased, brushless stepper variety also disclosed in the above-mentioned copending application, are respectively associated with a corresponding one of the two quasi-stable states of the arrangement shown in FIG. 1A. Motors **30, 31** are represented symbolically in FIG. 2 by coils **34, 35**, permanent bias magnets **36, 37**, and rotor members **32, 33**, with the dashed lines through each coil, magnet and rotor indicating the magnetic flux therebetween.

In one transition between the two quasi-stable states of the apparatus shown in FIG. 2, for example, the transition between the first and the second quasi-stable states, transistor T_6 is turned on, and a pulse of current energizes coil **34**. The energization of coil **34** produces magnetic flux which advances rotor **32** by a selected increment of rotation. Similarly, in the other transition between quasi-stable states, for example, the transition between the second and the first quasi-stable states, transistor T_7 is turned on, and a pulse of current energizes coil **35**. This energization of coil **35** generates magnetic flux which thereby advances rotor **33** by another selected increment of rotation. Thus, rotor members **32, 33** are advanced in alternate sequence as the apparatus alternates between its two quasi-stable states. In the case where the increment of rotation is selected to be 360 mechanical degrees for each rotor, it therefore requires one full cycle of operation to advance both of the rotors through one complete revolution. Suppressor circuits **15***a*, **15***b* may be identical with the similarly designated circuits in FIG. 1A. It is to be understood that one of the motors **30, 31** may be replaced by an inductor or other suitable impedance, if desired.

In certain situations, it may be desirable to modify the present invention to be either monostable or bistable, that is, to modify the apparatus to have either one stable and one quasi-stable condition, or two stable conditions, instead of two quasi-stable states as exemplified by the apparatus illustrated in FIGS. 1A, 1B, and 2. However, whereas the provision of two quasi-stable states enables the apparatus to be self-starting and free-running, so that the rotor member advances without requiring the application of an external stepping control or trigger signal for each increment of rotation, a monostable or bistable arrangement of the types shown in FIGS. 3A, 3B, 4A, 4B and 5 will remain indefinitely in a stable state, so that stepping of the rotor member is dependent upon the application of an appropriate external stepping control signal to trigger the apparatus out of its stable state and thereby advance the rotor member for each increment of rotation.

Monostable or bistable embodiments are obtained by providing each transistor which is to have a stable state with a base current which is greater than

$$\frac{I_{\mathrm{css}}}{\mathrm{hFE}}$$

or approximately

$$\frac{V/R}{hFE}$$

where I_{css} is the collector current under steady state conditions, V is the applied voltage and R is the resistance of the coil. With this arrangement, the transistor does not come out of saturation, and hence the transition out of a stable state does not occur without an external stimulus. By way of example, if $V=24$ volts and $R=240$ ohms, so that the steady state collector current I_{css} is approximately 100 ma., and if $h_{\mathrm{FE}}=100$, a base current greater than 1 ma. would be sufficient to prevent transfer to another state. In the case of monostable embodiments, it is to be understood that one of the two coupling resistors is provided with a larger resistance than the other, thereby to bias one of the transistors relative to the other so that the apparatus will have one stable state and one quasi-stable state.

FIG. 3A illustrates a monostable version of the present invention, in which it will be assumed that the stable state corresponds to transistor T_8 turned on and transistor T_7 turned off, hence $R_7<R_8$. By applying external stepping control signals or pulses through diode **40** to the base of nonconducting transistor T_7, transistor T_7 is turned on and the apparatus is triggered from its stable state to a quasi-stable state, after which the apparatus automatically returns to its stable state. During the brief interval that T_7 is in its conducting condition, a pulse of current is directed through winding **11***a*, and this ener-

gizing of winding **11***a* causes rotor member **16** to advance by a selected increment of rotation, say 180°. Shortly thereafter, the apparatus automatically returns to its stable state and remains there until the next incoming trigger pulse is applied to the base of transistor T_7, with rotor member **16** advancing one increment of rotation for each incoming trigger pulse.

FIG. 3B illustrates an alternative monostable arrangement in which the stable state corresponds to transistor T_{10} turned on and transistor T_9 turned off, hence $R_9 < R_{10}$, and in which incoming trigger pulses are applied to the base of trigger transistor T_{t1}. An incoming trigger pulse of duration Δt causes transistor T_{t1} to be turned on for a corresponding interval, thereby providing a temporary path to shunt current to ground and turn off T_{10}, followed by the turning on of T_9. When T_9 is turned on, coil **11***a* is energized and rotor member **16** is advanced through a predetermined increment of rotation. At the termination of the trigger pulse, the apparatus remains in its quasi-stable state, in which T_9 is conductive and T_{10} is nonconductive, until the collector current rises sufficiently to bring T_9 out of saturation. The collector voltage for T_9 thereupon rises and initiates transition to the stable state, in which T_9 is nonconductive and T_{10} is conductive. No further rotation of member **16** occurs until the next stepping control signal is applied to transistor T_{t1} after the apparatus of FIG. 3B has returned to its stable state.

FIGS. 4A and 4B are illustrative of alternative bistable arrangements in which the rotor **16** is advanced by a selected increment of rotation during each transition between two stable states. Since there are two stable states in which the apparatus will remain indefinitely, it is necessary to provide a way to trigger the apparatus out of each of its stable states and thereby advance the rotor.

In FIG. 4A there is illustrated one arrangement for triggering the apparatus out of each of its stable states, in which external trigger pulses are applied by way of capacitors C_1 and C_2 to the respective bases of transistors T_{11} and T_{12}.

FIG. 4B shows an alternative arrangement for switching the bistable version of the apparatus of this invention from one stable state to another, in which it will be assumed that T_{14} is in its conductive condition. When a trigger pulse is applied to turn on T_{t2}, current is shunted to ground via both diodes D_3, D_4, thereby to render both T_{13} and T_{14} non-conductive for the duration of the trigger pulse. If the trigger pulse is sufficiently short so that the current through the coil 11*a*, the diode D_3 and the transistor T_{t2} does not build up appreciably, an inductive voltage transient will be present across the coil **11***b* but not across the coil **11***a* when T_{t2} turns off at the end of the trigger pulse. This voltage raises the collector voltage of T_{14} above the supply voltage. Thus, T_{13} will receive the larger base drive and will turn on and complete the transition. The opposite action occurs when transistor T_{13} is in its conductive condition at the time that a trigger pulse is applied to transistor T_{t2}.

Triggering of either a monostable or a bistable version of the apparatus of this invention may also be accomplished by interrupting the supply voltage **14A**. This is illustrated symbolically in FIG. 5 by switch S_3 interposed between supply voltage **14A** and the center tap between coils **11***a* and **11***b*. In practice, switch S_3 may be a transistor which interrupts the supply voltage for an interval sufficiently short so that current through the inductances does not decay appreciably, for example, an interval on the order of 50 to 100 microseconds.

In addition, the means for triggering a bistable version of this invention shown in FIGS. 4A and 4B may be employed to inject a synchronizing signal into one or both transistor bases in the astable versions shown in FIGS. 1A, 1B and 2, thereby locking the free running frequency to a selected submultiple of the synchronizing frequency, provided that the synchronizing frequency is more than twice the free-running frequency of the astable version. In this mode of operation, the transfer between quasi-stable states is initiated slightly sooner than it would have initiated itself, thus speeding up the frequency of revolution of the rotor member and making its speed dependent solely on the frequency of the external source.

Although transistors have been shown in the various alternative arrangements as specific examples of appropriate switching elements, it is to be understood that various other types of switching devices, such as vacuum tubes, for example, may be employed instead, if desired.

The terms and expressions which have been employed are used as terms of description and not of limitation, and there is no intention in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the invention claimed.

What is claimed is:

1. An astable rotating machine characterized by two quasi-stable states so that as said machine alternately changes from one of said quasi-stable states to the other a rotor member is advanced through a predetermined increment of rotation, which comprises

first and second inductive means each having first and second terminals,

a rotor member that advances by a predetermined increment of rotation in response to the energizing of either of said first and second inductive means,

a source of unidirectional electrical power connected to the first one of said terminals of each of said inductive means,

first and second transient suppressor means respectively connected in parallel with a corresponding one of each of said inductive means, each of said transient suppressor means comprising a suppressor transistor having a base terminal free of any connection, a collector terminal connected to the first terminal of the corresponding inductive means and an emitter terminal connected to the second terminal of said corresponding inductive means,

first and second transistors each provided with a collector terminal, an emitter terminal, and a base terminal,

means for connecting the collector terminal of each of said first and second transistors to the second terminal of a corresponding one of said inductive means,

a point of ground potential,

means for connecting the emitter terminals of said first and second transistors to said point of ground potential, and

first and second resistor means for coupling said base terminal of a corresponding one of said first and second transistors to the collector terminal of the other one of said first and second transistors so that said first and second transistors are made conductive in alternating sequence, thereby to energize in alternating sequence said first and second inductive means.

2. A system for converting electrical pulses into incremental mechanical motions which comprises

a first brushless, direct current stepper motor including a stator having winding means, a permanent biasing magnet and a magnetized rotor that is rotatable by a predetermined amount in response to the energizing of said winding, wherein said winding is provided with first and second terminals,

a second brushless, direct current stepper motor including a stator having winding means, a permanent biasing magnet and a magnetized rotor that is rotatable by a predetermined amount in response to the energizing of said winding, wherein said winding is provided with first and second terminals, a source of unidirectional electrical power connected to the first terminal of the winding means of each of said first and second motors,

first and second transient suppressor means respectively connected in parallel with the winding means of said first and second motors,

first and second transistors each provided with a collector terminal, an emitter terminal, and a base terminal,

means for connecting the collector terminal of each of said first and second transistors to the second terminal of the winding means of a separate one of said first and second motors,

a point of ground potential,

means for connecting the emitter terminal of each of said first and second transistors to said point of ground potential, and

first and second resistor means for coupling said base terminal of a corresponding one of said first and second transistors to the collector terminal of the other one of said first and second transistors, wherein said first and second transistors alternately conduct thereby to energize in alternate sequence said windings of said first and second motors with electrical pulses from said source of power.

3. A system for converting electrical input pulses into incremental mechanical motions which comprises

a pair of salient stator poles in spaced relationship with each other,

a source of unidirectional electrical current,

first and second coil means connected to said source of electrical current so that a selected flow of current from said source through said coil means energizes said coil means to generate magnetic flux, said first and second coil means being respectively disposed in magnetizing relationship with said stator poles,

a common point of ground potential,

first and second switching means respectively connected between a corresponding one of said coil means and said common ground point, said first and second switching means being coupled together to conduct current in alternate sequence between said source and said common ground point through said first and second coil means, thereby alternately energizing said first and second coil means,

a rotatable member responsive to said magnetic field generated by said first and second coil means so that a single alternate energizing of each of said coil means causes said rotatable member to rotate through a complete revolution,

first transient suppressing means connected in parallel with said first coil means between said source of current and said first switching means, and

second transient suppressing means connected in parallel with said second coil means between said source of current and said second switching means,

each of said first and second transient suppressing means comprising a transistor provided with a collector terminal, an emitter terminal, and a base terminal, wherein said base terminal is free of any connection, and said collector and emitter terminals are respectively connected with proper polarity to the appropriate one of said source of current and said corresponding switching means.

4. A system for converting electrical pulses into incremental mechanical motions which comprises

first and second inductive means each provided with first and second terminals,

a rotor member that advances one hundred and eighty mechanical degrees in response to the energization of either of said first and second inductive means,

a source of unidirectional electrical power connected to the first one of said terminals of each of said inductive means,

a common ground point,

first and second switching means coupled together in bistable relationship to have two stable states, in which said first switching means is conductive and said second switching means is nonconductive in one of said stable states and in which said first switching means is nonconductive and said second switching means is conductive in the other of said stable states, wherein said first and second switching means are first and second switching means from either one of said terminals of a corresponding one of said inductive means and said common ground point,

said first and second switching means each comprising a transistor,

a source of stepping control signals for triggering said first and second switching means from either one of said stable states to the other of said stable states by making the nonconductive one of said switching means conductive, thereby energizing the corresponding one of said inductive means with a brief electrical pulse from said power source and advancing said rotor member by one hundred and eighty mechanical degrees in response to each pulse, and

means for applying said stepping control signals to said first and second switching means, said means for applying said stepping control signals to said first and second switching means comprising first and second diodes respectively connected to the collector of a corresponding one of said switching means.

5. A system for converting electrical pulses into incremental mechanical motions which comprises

first and second inductive means each provided with first and second terminals,

a rotor member that advances one hundred and eighty mechanical degrees in response to the energization of either of said first and second inductive means,

a source of unidirectional electrical power connected to the first one of said terminals of each of said inductive means,

a common ground point,

first and second switching means coupled together in bistable relationship to have two stable states, in which said first switching means is conductive and said second switching means is nonconductive in one of said stable states and in which said first switching means is nonconductive and said second switching means is conductive in the other of said stable states, wherein said first and second switching means are respectively connected between the second one of said terminals of a corresponding one of said inductive means and said common ground point,

a source of stepping control signals for triggering said first and second switching means from either one of said stable states to the other of said stable states by making the nonconductive one of said switching means conductive, thereby energizing the corresponding one of said inductive means with a brief electrical pulse from said power source and advancing said rotor member by one hundred and eighty mechanical degrees in response to each pulse, and

means for applying said stepping control signals to said first and second switching means, said means for applying said stepping control signals to said first and second switching means comprising

a transistor provided with a base terminal, a collector terminal, and an emitter terminal,

first and second diodes each provided with an input terminal and an output terminal,

means for connecting the base terminal of said transistor to said source of stepping control signals,

means for connecting said collector terminal of said transistor to the input terminals of said first and second diodes, and

means for connecting said emitter terminal of said transistor and said output terminals of said diodes to said first and second switching means in selected circuit relationship so that said first and second switching means are triggered from either one of said stable states to the other one of said stable states.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,473,069 Dated October 14, 1969

Inventor(s) E. Herbert III

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 2, lines 32-33, "extermal" should be --external--.

Col. 3, line 5, "winding" should be --windings--.

Col. 4, line 4, "determine" should be --determines--;
line 24, "completes" should be --complete--.

Col. 5, line 10, "presvents" should be --prevents--.

Col. 10, line 9, "first and second switching means from either" should be --respectively connected between the second--.

SIGNED AND
SEALED
JUN 16 1970

(SEAL)
Attest:

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Attesting Officer

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