

March 19, 1968

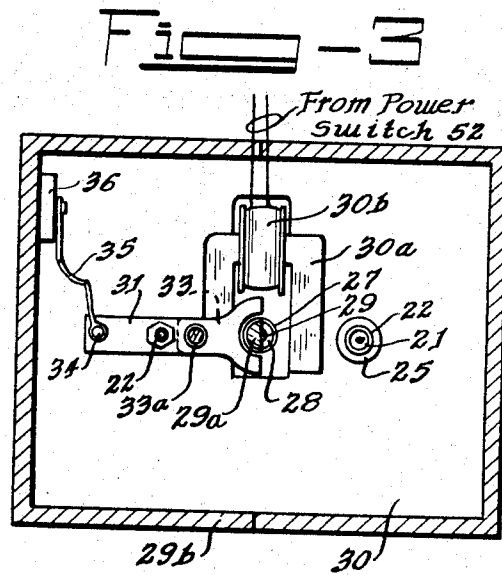
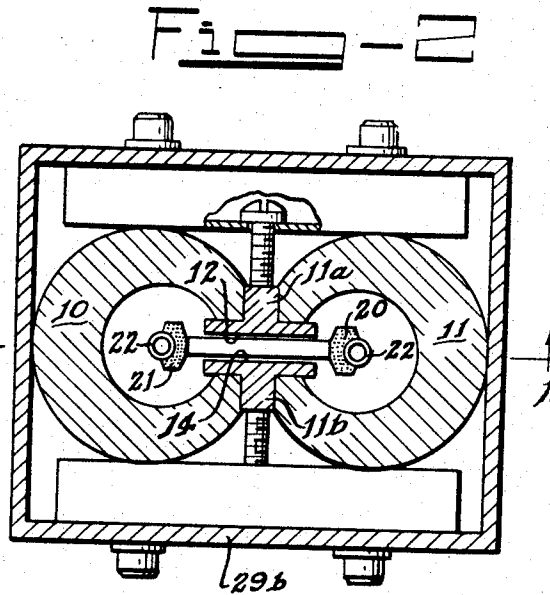
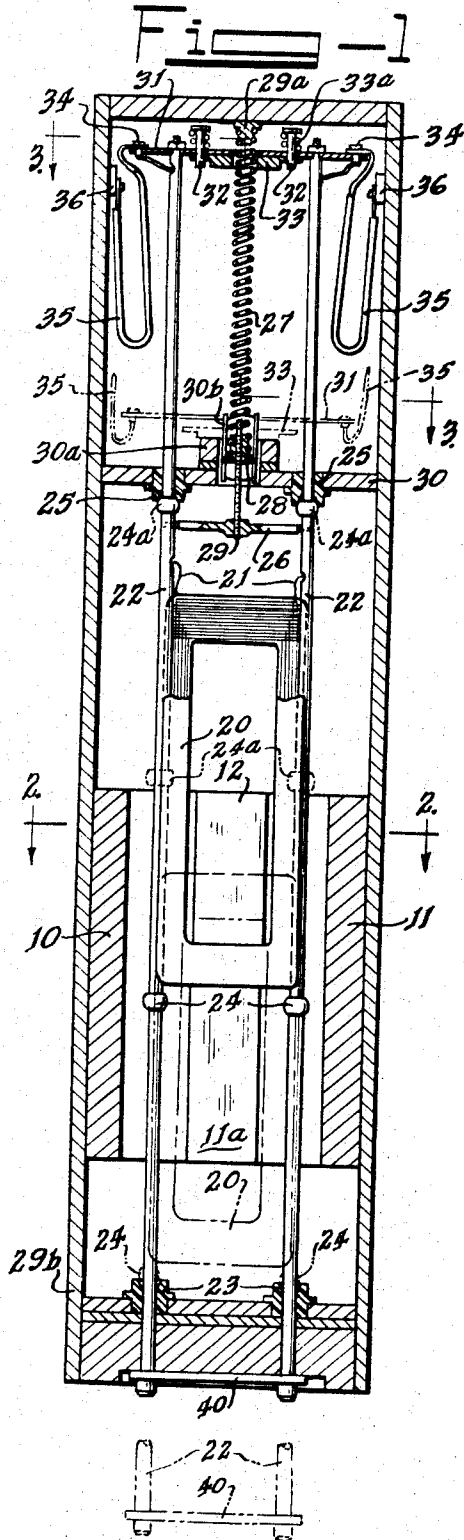
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3,374,409

FAST VERTICAL STROKE MOVING COIL TRANSDUCER

Filed Sept. 28, 1965

2 Sheets-Sheet 1



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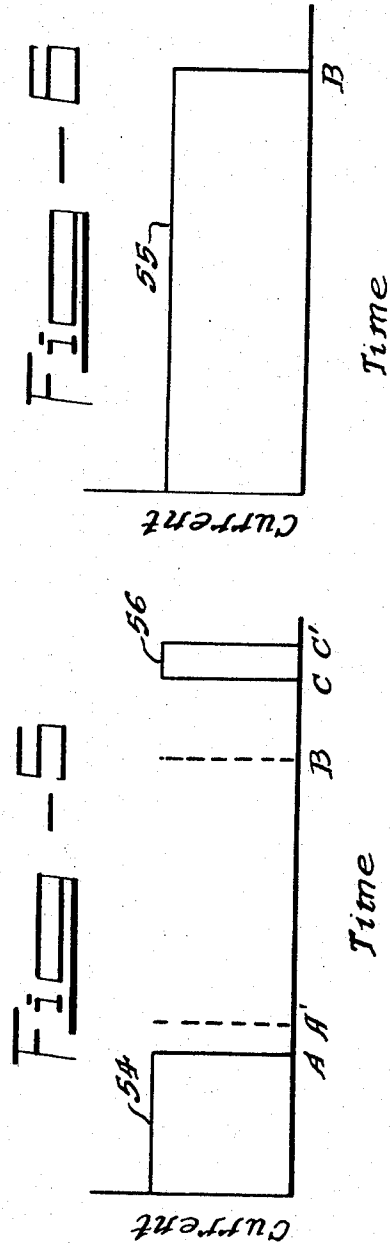
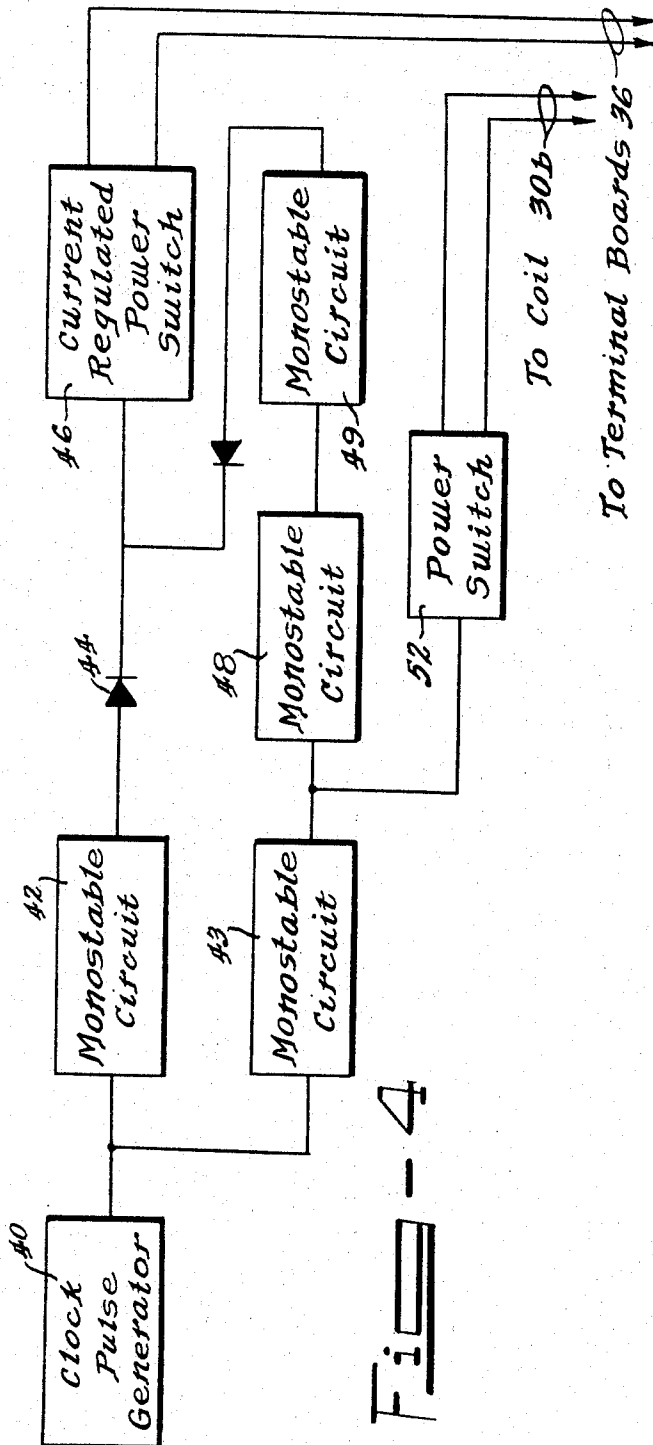
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2 Sheets-Sheet 2



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3,374,409 FAST VERTICAL STROKE MOVING COIL TRANSDUCER

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6 Claims. (Cl. 318—122)

The invention described herein was made in the course of, or under, a contract with the U.S. Atomic Energy Commission.

This invention relates to electromechanical transducers and more particularly to a transducer having an armature located partially in a magnetic field and energized with electrical current.

This device may be used, for example, to place a target in the path of a nuclear particle accelerator beam. Typical requirements for such a target placement mechanism might demand a stroke of approximately four inches from rest position in 100 milliseconds repeated every four seconds. The vertical position of the target at the lowest extremity or bottom of the stroke must be maintained within an accuracy of ± 5 mils for each subsequent cycle of operation. Fast-moving mechanisms of this type are likely to suffer excessive wear when required to operate in a high vacuum because conventional lubrication methods are of little value under vacuum conditions.

It is therefore the main object of the present invention to provide apparatus for producing a very fast, recurrent, vertical stroke mechanism.

It is a further object of the present invention to provide a fast, recurrent stroke mechanism capable of operating in high vacuum without excessive wear or components.

It is still another object of the present invention to provide a fast, recurrent stroke mechanism having a movable armature wherein the vertical position of the armature at the lowest extremity of each stroke is very accurately determined and reproducible within a small tolerance on successive strokes without having the armature undergo severe shock at the stroke extremities.

Briefly, the above objects are accomplished by having an armature held by a spring at the top of the desired stroke. The armature consists of an electrical conductor wound into a number of rectangular loops. The lower portion of the armature is located in a uniform magnetic field which induces a downward motion in the armature when it is pulsed with an electrical current circulating in the proper direction around the conductor loops. The current in the upper portion of the loop reverses direction with respect to the magnetic field, and the armature experiences a decelerating or upward force as its lower portion passes out of the field and its upper portion enters the field. The armature reaches the bottom of its stroke while approaching zero velocity, and it is returned to its rest position under action of the spring.

The nature and objects of the invention will be better understood from the following description of a preferred embodiment with reference to the accompanying drawings, in which:

FIG. 1 is a schematic frontal elevation of an apparatus according to the present invention.

FIG. 2 is a sectional view taken through line 2—2 of FIG. 1.

FIG. 3 is a sectional view through line 3—3 of FIG. 1.

FIG. 4 is a schematic block diagram of the electrical power supply for the apparatus of FIG. 1.

FIG. 5 is a diagrammatic representation of the excitation current for the drive armature.

FIG. 6 is a diagrammatic representation of the excitation current for the holding magnet.

In FIGS. 1 and 2, the driving magnetic field structure is formed by two semi-cylindrical, permanent magnets, indicated by numerals 10 and 11, placed with their axes vertical and parallel to each other. The drive magnets 10 and 11 each have a C-shaped cross-sectional area with the center cavity thereof slightly off-center in the direction of the opening of the C. The drive magnet 11 is turned so that the opening of its C is adjacent to the opening of the C of drive magnet 10. T-shaped, soft-iron members 11a and 11b are fitted between like poles of the drive magnets 10 and 11 thereby forming a uniform magnetic field between the crossbars on the T's. The top surfaces of the crossbars of the T-shaped members 11a and 11b are called pole faces and are indicated by numerals 12 and 14 respectively. Pole faces 12 and 14 extend the full length of the drive magnets 10 and 11.

An armature 20 comprising a conducting wire 21 wound into a series of rectangular loops and embedded in an epoxy potting compound is fixedly attached to two vertical guide bars 22 so as to move therewith. The guide bars 22 are located along the axes of the cavities of the drive magnets 10 and 11. Fixed on each guide bar 22 is a ball stop 24 located below the armature 20, and a ball stop 24a located above the armature 20. The assembly comprising the armature 20 and guide bars 22 is movable in the vertical direction with the upper and lower horizontal legs of armature 20 passing between pole face 12 and pole face 14.

The lower portion of each guide bar 22 is fitted through a Teflon bushing 23 attached to a chassis 29b and counter-bored to form a seat for the ball stop 24. Similarly, the upper portion of each guide bar 22 is fitted through a Teuon bushing 25 attached to a plate 30 which is fixed to the chassis 29b. The bushings 25 are counter-bored to form a seat for the ball stop 24a thereby constraining motion to a vertical plane and defining the stroke of armature 20. A crossbar 26 is attached to both guide bars 22 above the armature 20. Fastened to the center of crossbar 26 is a screw 29 on which is threaded an adapter 28. The adapter 28 also has threads on its outside surface, and one end of a spiral spring 27 is threaded onto the external threaded surface of adapter 28. The other end of the spiral spring 27 is similarly threaded onto a stud 29a which is fastened to the chassis 29b of the device. The tension of spiral spring 27 is adjusted by moving the adapter 28 along the screw 29. The plate 30 also supports a soft-iron holding magnet 30a. The holding magnet 30a is U-shaped and has an energizing coil 30b wound around its middle section (as shown in FIG. 3). Plate 30 contains a hole located to allow spiral spring 27, adapter 28 and screw 29 to pass between the legs forming the U of holding magnet 30a. The coil 30b, energized by a current source described below, activates the holding magnet 30a.

A mounting plate 31 is attached to the top of the guide bars 22 and adapted to move therewith. A soft-iron holding-magnet armature 33 is located directly beneath the mounting plate 31 and circumferential to the spiral spring 27 which passes through the plate 31 to stud 29a. The holding-magnet armature 33 is resiliently held to the bottom of mounting plate 31 by two studs 32 passing through the mounting plate 31. The studs 32 are kept in position by the force exerted by two coil springs, indicated by numeral 33a, located between the upper lip of the studs 32 and the mounting plate 31.

The holding magnet 30a is shimmed above plate 30 so that when the armature 20 is at the bottom of its stroke, the air gap between holding magnet 30a and holding-magnet armature 33 will be 0.020 of an inch. However, since coil 30b will already have been energized when the armature 20 reaches the bottom of its stroke, as will be

described below in detail, the holding-magnet armature 33 will be attracted to and physically engage the holding magnet 30a, and the 0.020 inch air gap will exist between the lower surface of plate 30 and the holding-magnet armature 33. This places the springs 33a under slight tension. In situations in which it is desirable to hold the armature 20 at the bottom of its stroke, the holding-magnet armature 33 will be snapped away from holding magnet 30a under action of the springs 33a when the holding-magnet coil 30b is de-energized. This snapping action is an important feature in overcoming the effect of the unpredictability of the strength of residual magnetism of holding magnet 30a.

Each of the ends of the armature conductor 21 is threaded through one of the guide bars 22 and terminates at connectors 34 located on mounting plate 31. Two flexible cables 35 run from the connectors 34 to two terminal boards 36 located on either side of chassis 29a. The flexible cables 35 are long enough to maintain conductivity between terminal boards 36 and the armature conductor 21 as the armature 20 proceeds through its vertical stroke.

A crossbar 40 to which a target (not shown) may be attached for placement in the path of a particle accelerator beam is secured to the bottom of guide bars 22 and disposed to move therewith.

FIG. 1 illustrates both the top and the bottom of the stroke of the apparatus. The armature 20, the guide bars 22, and the two sets of ball stops 24 and 24a are shown at the top of the stroke by the solid lines and at the bottom of the stroke by the dashed lines. In the upper position, the ball stops 24a are seated on the bushings 25. In the lower position, the ball stops 24 are seated on the bushings 23.

With the uniform flux established between pole face 12 and pole face 14, it can be seen by using the left hand motor rule that if a current circulates counterclockwise in armature conductor 21, a net downward force is induced on the armature 20 when only the lower horizontal leg of armature 20 is within the magnetic field between pole face 12 and pole face 14, as for instance, when the armature 20 is at the top of its stroke. The magnitude of the induced force is proportional to the strength of the magnetic field between pole faces 12 and 14, and the product of the ampere-turns of armature conductor 21.

FIGS. 4-6 illustrate the power supply used to energize the apparatus described above, but it should be noted that the power supply uses components well known in the art and that the same function (that is, timing of drive currents supplied to the apparatus) may be accomplished in a number of equivalent ways by one skilled in the art.

Referring to FIG. 4, the output of a clock pulse generator 40 is connected to the input of monostable circuits 42 and 43. The output of monostable circuit 42 is connected in series with a diode 44 to the input of a current regulated power switch 46. The output of the current regulated power switch 46 is connected to the terminal boards 36 mounted on the chassis 29b (FIG. 1), thus supplying power to the armature conductor 21. The output of monostable circuit 43 is connected in series with monostable circuits 48 and 49, and a diode 50 to the input of the current regulated power switch 46. The output of monostable circuit 43 is also connected to the input of a power switch 52 which supplies current to coil 30b.

The clock pulse generator 40 produces a series of negative-going voltage output pulses which determine the basic time interval at which armature 20 cycles through a stroke. The monostable circuits 42, 43, 48 and 49 are of the type which are triggered on negative-going edges of voltage pulses. A monostable circuit is one which stays "on" (that is, has voltage at its output terminals) for a predetermined time independent of the length of time the input voltage is present. The current regulated power switch 46 and power switch 52 are power amplifiers operated in the switching mode and they generate an output voltage for

the time during which a positive voltage is present at their input.

FIG. 5 shows the output current of current regulated power switch 46. The first output pulse 54 of FIG. 5, which lasts from time zero to the time indicated by letter A, is generated by an output pulse from clock pulse generator 40 triggering monostable circuit 42. The output of monostable circuit 42 is fed through diode 44 to turn on the current regulated power switch 46, thereby supplying the energizing current pulse 54 to armature conductor 21 of FIG. 1, and forcing the armature 20 in a downward motion. The duration of the current pulse 54 is chosen so that it will end (time A) before armature 20 reaches the bottom of its stroke. The time at which the armature 20 actually reaches the bottom of its stroke is indicated by letter A' of FIG. 5.

FIG. 6 shows the duration of the energizing current pulse 55 fed to the coil 30b of holding magnet 30a from power switch 52. Monostable circuit 43 (FIG. 4), triggered by the same pulse from clock pulse generator 40 that triggers monostable circuit 42, turns on power switch 52 which generates pulse 55 (FIG. 6). Power switch 52 need not be current regulated since the holding function performed by energizing coil 30b of holding magnet 30a is not critical to the timing of the apparatus as is the force exerted on armature 20 due to the current circulating in armature 21 supplied from the current regulated power switch 46. When monostable circuit 43 turns off, as shown at time B of FIGS. 5 and 6, the trailing edge of its output pulse triggers monostable circuit 48. When monostable circuit 48 times out, the trailing edge of its output pulse triggers monostable circuit 49 at a time indicated by letter C of FIG. 5. The output of monostable circuit 49 is fed through diode 50 to turn on current regulated power switch 46 thereby energizing armature conductor 21 a second time during the same cycle. Diodes 44 and 50 merely serve to isolate the respective outputs of monostable circuits 42 and 49.

The output of clock pulse generator 40 of FIG. 4 serves only as a basic timing signal which initiates a complete cycle of the apparatus. It is to be noted that this timing signal may be supplied by any command means and the clock pulse generator 40 represents such command means.

One complete cycle of operation of the device will now be described: a pulse from clock pulse generator 40 triggers monostable circuit 42 (FIG. 4) which is pre-set to time out at time A of FIG. 5. The output pulse of monostable circuit 42 is then fed through diode 44 to turn on current regulated power switch 46 which sends a pulse 54 of current to the armature conductor 21 via flexible cables 35 and terminal boards 36. The duration of pulse 54 (FIG. 5) is chosen so that armature 20 will be accelerated downward with its lower horizontal leg passing out of the magnetic field between pole faces 12 and 14, thereby moving the upper horizontal leg of armature 20 into the magnetic field and exerting a decelerating force on armature 20. The current pulse 54 supplied to armature conductor 21 ends before armature 20 reaches the bottom of its stroke so that ball stops 24 seat into bushings 23 while armature 20 is traveling at a relatively low velocity at time A' (FIG. 5). This saves considerable wear on bushings 23 and ball stops 24.

At the beginning of the same cycle and triggered by the same pulse from clock pulse generator 40, monostable circuit 43 activates power switch 52, which supplies current pulse 55 to coil 30b thereby activating holding magnet 30a. Therefore, when armature 20 reaches the bottom of its stroke, holding magnet 30a will already have been activated, and holding-magnet armature 33 will be attracted to holding magnet 30a causing slight tension on springs 33a by attracting holding-magnet armature 33 away from mounting plate 31, and at the same time maintaining armature 20 at the bottom of its stroke until monostable circuit 43 times out at B of FIG. 6 thereby turning off power switch 52. Holding-magnet

armature 33 is then snapped back against mounting plate 31 under action of springs 33a, thereby overcoming the force of residual magnetism in holding magnet 30a, as described above, and allowing armature 20 to proceed to the top of its stroke under action of spiral spring 27. 5

The output of monostable circuit 43 is also used to trigger monostable 48 which times out between times B and C of FIG. 5. The trailing edge of the output pulse of monostable circuit 48 triggers monostable circuit 49 thereby activating current regulated power switch 46 a second time and producing pulse 56. This second current pulse 56, which is supplied to armature conductor 21 as armature 20 is returning to the top of its stroke, exerts a downward force on the lower leg of armature 20 and serves to decelerate armature 20 as it approaches the top of its stroke. 15

It will be noted that the information necessary to initiate pulse 56 of retarding current could be obtained from the trailing edge of pulse 54 of FIG. 5, allowing for the elimination of the holding feature of the device if it were not desired to hold the armature 20 at the bottom of its stroke. 20

While the invention is susceptible of various modifications and alternative constructions other than the preferred embodiment in the drawings and described herein, it is to be understood that I do not intend to thereby limit my invention, but intend to cover all modifications and equivalent constructions falling within the spirit and scope of the invention as expressed in the appended claims. 25

The embodiments of the invention in which the exclusive property or privilege is claimed are defined as follows:

1. Apparatus for producing a fast vertical stroke comprising:

- (a) an armature having current conducting means forming a closed loop and being adapted for linear motion;
- (b) means for confining the motion of said armature within predetermined limits thereby defining its stroke;
- (c) means for producing a constant magnetic field transversely through said armature;
- (d) resilient means for holding said armature at the top of its stroke whereby only the lower portion of said armature conductor lies within said magnetic field; and
- (e) means for supplying a current pulse to said armature conductor to produce a downward motion of said armature thereby causing the upper portion thereof to enter said magnetic field whereby an upward, decelerating force is induced in said armature conductor, said current pulse ending before said armature reaches the bottom of its stroke whereby said armature returns to the top of its stroke under action of said resilient means. 40 45 50 55

2. The apparatus of claim 1 including means for engaging and releasably holding said armature at the bottom of its stroke for a predetermined time.

3. Apparatus for periodically producing a fast vertical stroke comprising: 60

- (a) a drive armature having current conducting means forming at least one closed rectangular loop, said armature being adapted for motion in a vertical plane;
- (b) means for confining the motion of said drive armature within predetermined limits thereby defining its stroke;
- (c) means for producing a magnetic field transversely through said drive armature conductor;
- (d) a spiral spring for resiliently holding said drive armature at the top of its stroke whereby only the lower portion of said drive armature conductor lies within said magnetic field;
- (e) means for periodically supplying pulsed energizing 75

current to said drive armature conductor, said current flowing in the lower portion of said conductor forcing said drive armature downward thereby causing the upper portion of said drive armature conductor to enter the magnetic field and the lower portion of said drive armature to leave said magnetic field whereby said armature experiences an upward force, said current pulse ending before said drive armature reaches the bottom of its stroke;

- (f) a soft iron holding armature connected to said drive armature and adapted to move therewith;
- (g) a magnetizable holding magnet adapted to engage said holding armature at the bottom of the stroke; and

- (h) current supply means for energizing said holding magnet in timed relation to said drive armature current supply means, said holding magnet being energized before said drive armature reaches the bottom of its stroke whereby said holding armature is firmly held, and for de-energizing said holding magnet after a predetermined time, whereby said drive armature is forced to the top of its stroke by said spiral spring.

4. The apparatus of claim 3 including means for centering said drive armature in said magnetic field and for guiding the vertical motion of said drive armature in a linear path.

5. The apparatus of claim 4 in which said guide means comprises two extended rods fixed vertically and fastened to either side of said drive armature; and in which said stroke defining means comprises ball stops attached to said guide rods; and including seat means for receiving said ball stops to determine the position of said drive armature at the extremities of its stroke.

6. Apparatus for periodically producing a fast vertical stroke comprising:

- (a) a drive armature having a conducting wire wound into a number of rectangular loops cemented together to form a rigid structure;
- (b) first and second rods supporting said drive armature on either side thereof, each rod having ball stops affixed thereto above and below said drive armature;
- (c) means adapted to receive said rods for confining the motion of said rods and drive armature to a vertical plane and for engaging said ball stops to define the vertical stroke of said drive armature;
- (d) a north and a south magnetic pole face located opposite one another and adapted to permit the upper and lower horizontal legs of said drive armature to move therebetween;
- (e) a spiral spring resiliently holding said drive armature at the top of its stroke whereby said upper ball stops are seated against said ball-stop engaging means such that only the lower horizontal leg of said drive armature is between said magnetic pole faces;
- (f) a soft iron armature;
- (g) means for resiliently attaching said soft iron armature to said first and second supporting rods whereby said soft iron armature moves therewith;
- (h) a fixed electromagnet located to cause a small air gap to exist between said electromagnet and a surface of said soft iron armature when said drive armature is at the bottom of its stroke;
- (i) means for periodically supplying pulsed energizing current to said drive armature conducting wire; said energizing current flowing in the lower horizontal leg of said drive armature to force it downward thereby causing the upper portion of said drive armature conductor to move between said pole faces and the lower horizontal leg of said drive armature to move below said pole faces, said energizing current ending before said drive armature reaches the bottom of its stroke;
- (j) current supply means for energizing said electro-

magnet, said electromagnet being energized before said drive armature reaches the bottom of its stroke whereby said drive armature is held at the bottom of its stroke by action of said electromagnet engaging and holding said soft iron armature thereby closing said air gap against the resilient force holding said soft iron armature, and for de-energizing said electromagnet after a predetermined time, whereby said drive armature is forced to the top of its stroke by said spiral spring; and

(k) means for supplying a second current pulse to said drive armature conducting wire responsive to the trailing edge of the pulse of said electromagnet cur-

rent supply means to decelerate said drive armature before reaching the top of its stroke.

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