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[54] **LINEAR MOTOR POSITIONING DEVICE WITH POSITION DETENT MEANS**

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Related U.S. Application Data

[63] Continuation of Ser. No. 178,155, Sept. 7, 1971, abandoned.

[30] **Foreign Application Priority Data**

Sept. 16, 1970 Switzerland 13717/70

[52] **U.S. Cl.** **318/687**; 318/135

[51] **Int. Cl.** **G05b 11/00**

[58] **Field of Search** 318/561, 687, 576, 135; 310/12

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[57] **ABSTRACT**

A positioning device for shifting a load into any one of a series of predetermined positions comprises a plurality of coaxial annular electromagnets acting upon a common armature through a like number of cores whose relative axial spacing is different from the axial separation of the electromagnets; thus, selective energization of any single electromagnet, or of a pair of adjoining electromagnets, attracts the associated core or cores into a relatively centered position corresponding to a desired operating position of the load entrained by the armature. The armature is indexed in any operating position by a bidirectionally effective detent which is electromagnetically controlled through a timing circuit in response to a selection signal for the actuation of any of the positioning electromagnets, such a signal being stored in an associated flip-flop and causing the resetting of all other flip-flops set by a prior signal. The timing circuit comprises delay means, including a pair of monostable multivibrators tripped in staggered relationship by a pulse generator, which result in overlapping periods for the deactivation of the detent and the energization of the selected positioning magnet or magnets.

6 Claims, 8 Drawing Figures

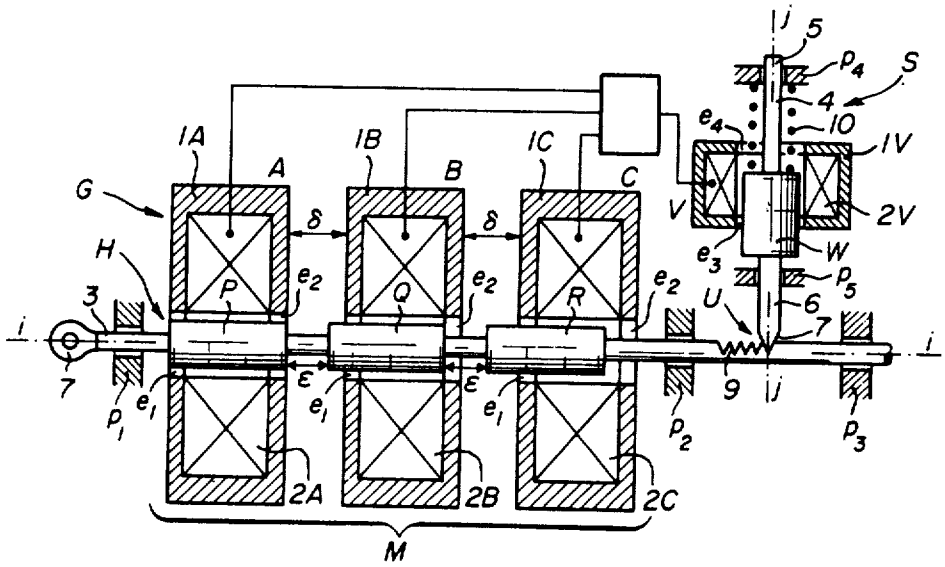
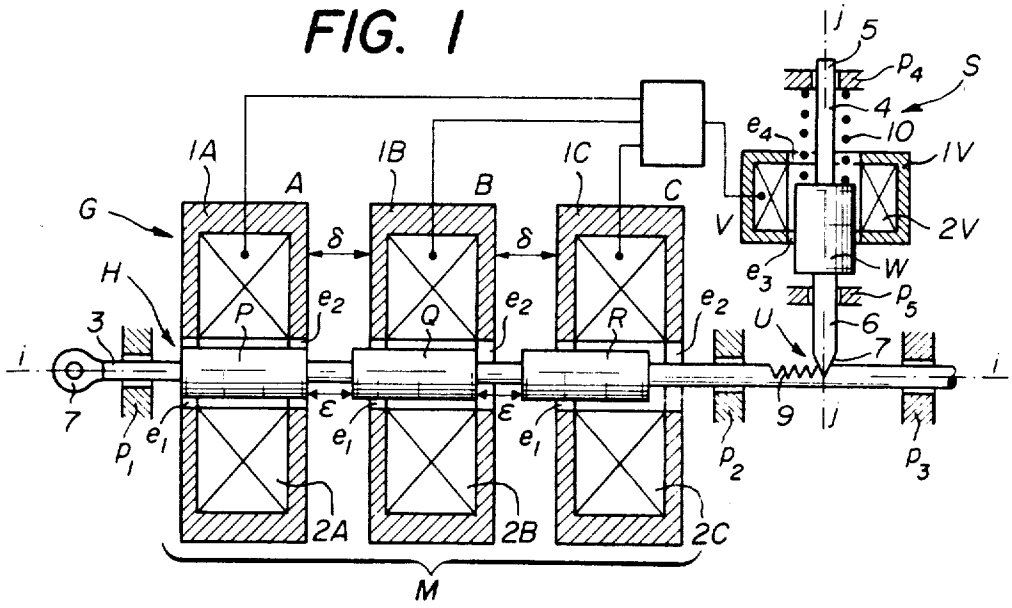


FIG. 1



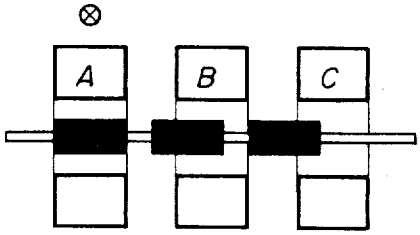


FIG. 2a

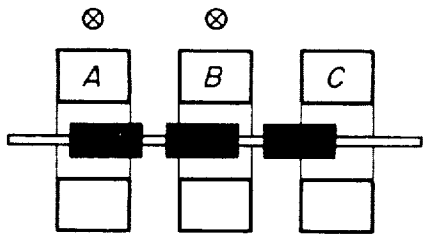


FIG. 2b

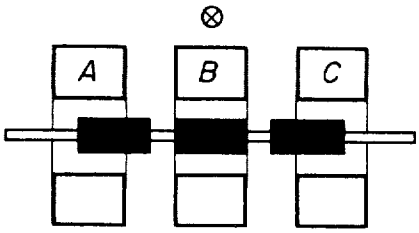


FIG. 2c

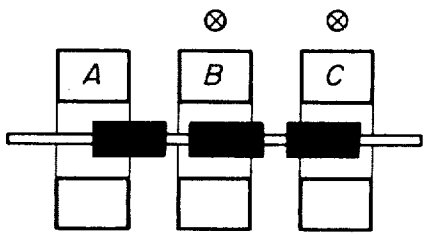


FIG. 2d

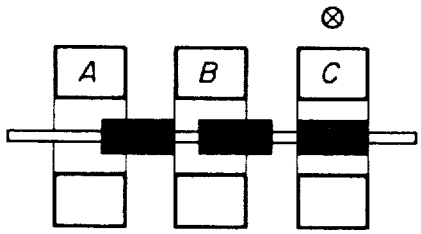


FIG. 2e

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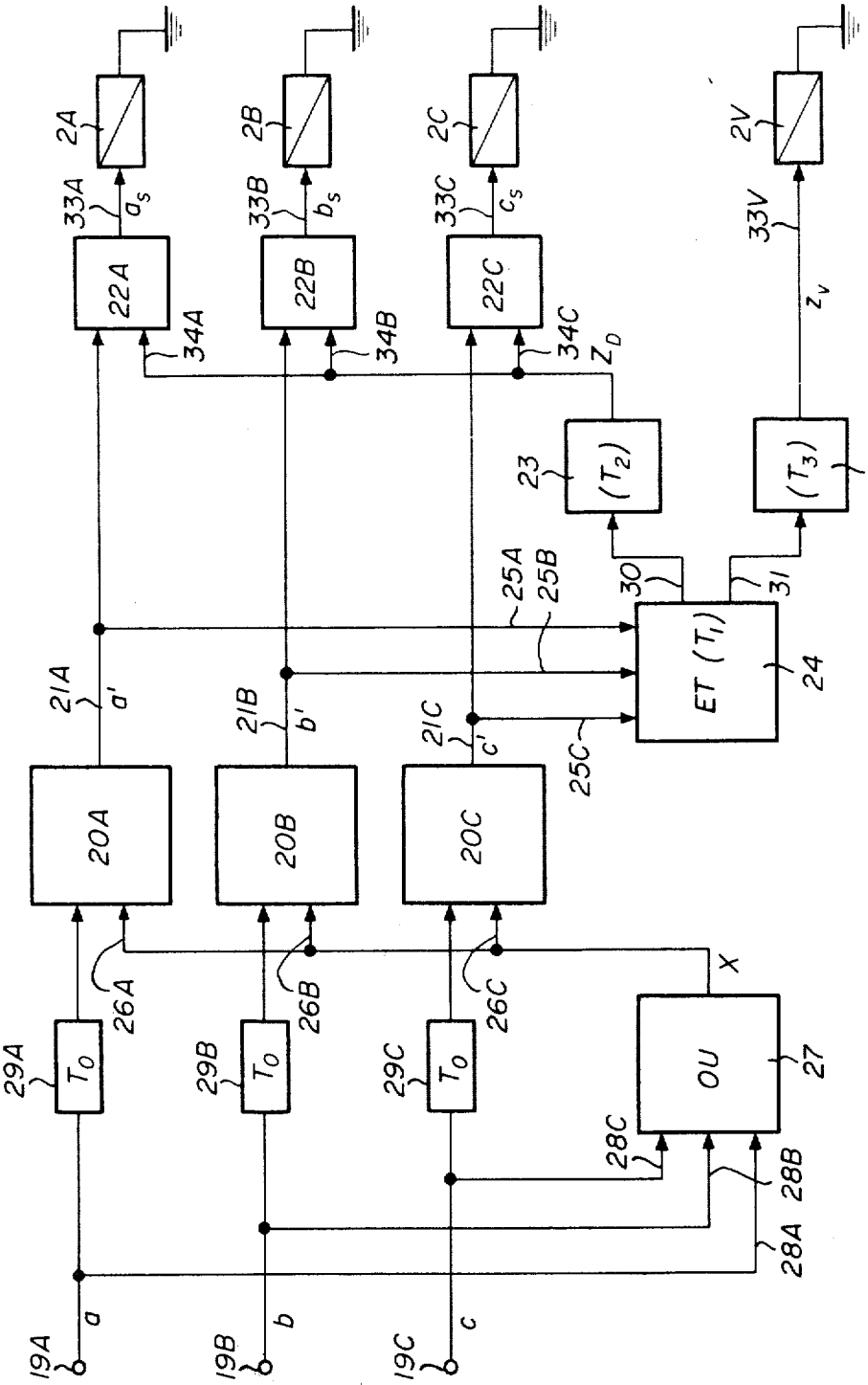


FIG. 3

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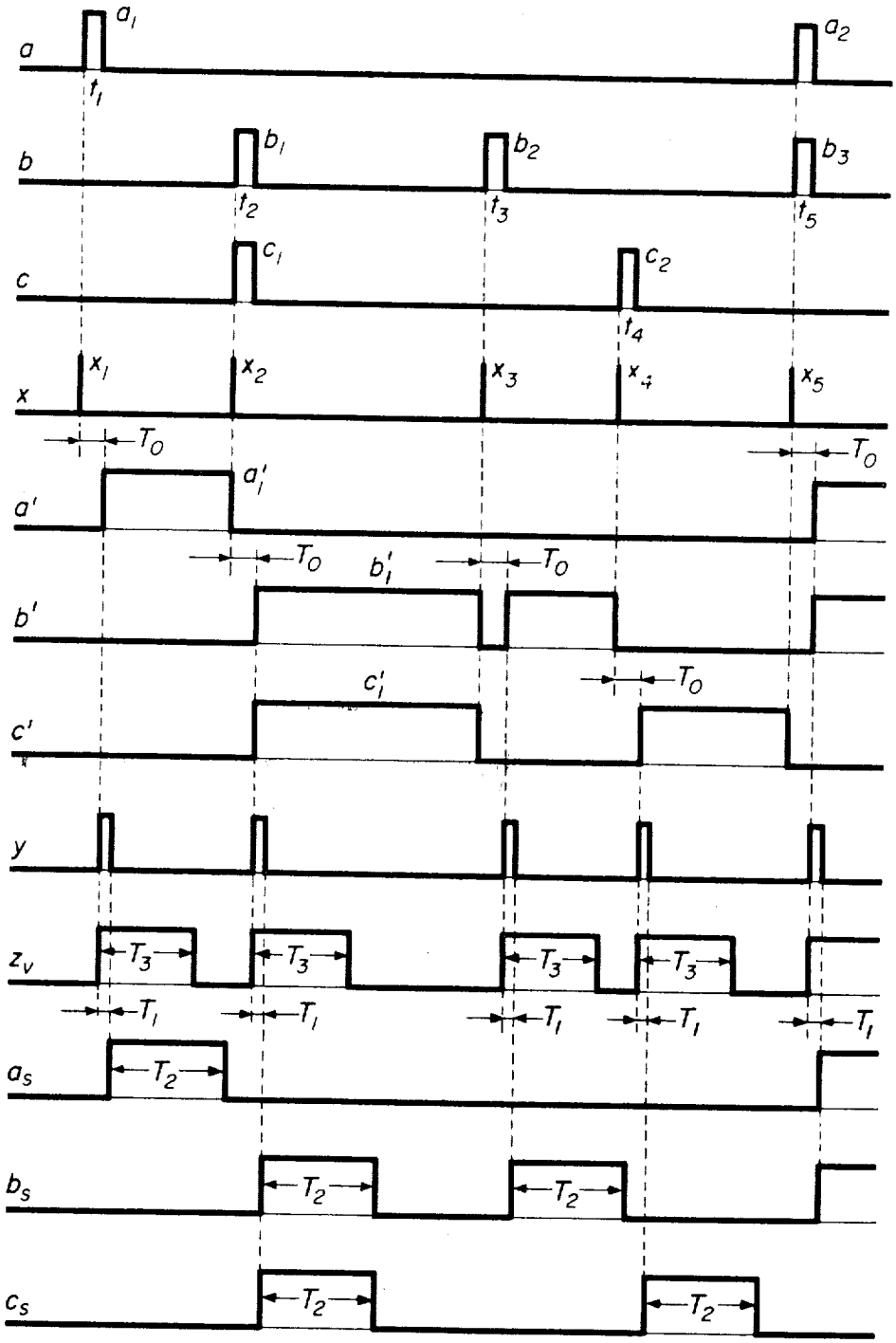


FIG. 4

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LINEAR MOTOR POSITIONING DEVICE WITH POSITION DETENT MEANS

This invention relates to a positioning device of the kind having a stepping linear electric motor, designed to move a mechanical element or load from one position to another within a group of set positions arranged in a straight line.

Positioning devices of this kind are known. They are essentially used to move a mechanical element from one position to another. They are for instance used to actuate hydraulic or pneumatic valves, to actuate at a distance semaphore signals, to control machine parts, to position machine-tool cams, etc. In all of these cases, it is endeavored rapidly to change over from one position to another, the mechanical elements positioned by these devices being required to remain in the attained position for a length of time which is large in relation to the time of transition from one position to the other. In these known devices, however, the mechanical element is held in any one of these positions by keeping the linear electric motor permanently energized. Since this linear motor is required to move the mechanical element very rapidly, it must be supplied with a large amount of electric power. The need for permanently supplying it to hold the mechanical element in its position means that the windings must be made sufficiently large if they are not to become excessively heated by this constant current supply. As a result, the linear motor becomes bulky and heavy.

Further, the axial force exerted by a stepping linear motor drops to zero as soon as the position set by its state of energization has been reached; it is only when the mechanical element moves away from this position, e.g. under the action of a mechanical disturbance, that a countering force is generated tending to return it to the set position. Consequently, the known devices are not capable of ensuring complete immobilization of the mechanical element in the position set by the state of energization. If, moreover, the mechanical element is subjected to frictional forces, the accuracy of the positioning becomes affected and the ensuing inaccuracies cannot be tolerated when the device is to be fitted in precision machine tools. In particular, the known devices are not suitable for positioning the cams of some textile machines, for instance the lifting cams which control the upward motion of the hooks in knitting machines.

An object of the invention is to devise a positioning device of the kind set forth which does not suffer from these drawbacks and which is quick-acting, energetic, accurate and of small bulk.

The device provided in accordance with my invention comprises a linear electric motor having a stator fitted with at least two coaxial annular electromagnets, in alignment with an axis coinciding with the line of load motion, and a movable armature adapted to be connected to the load and fitted with a plurality of coaxial plunger-type cores equal in number to the electromagnets, the armature being arranged to move axially, within the electromagnets. The length of the cores is substantially equal to that of the electromagnets associated therewith, the axial spacing between consecutive cores being different from the axial spacing between the associated electromagnets whereby the axial position of the armature is determined by the state of energization of the electromagnets. The device also includes a locking member or detent, acting as a two-way indexing means capable of immobilizing the armature in any one of several operating positions, and a controller capable of temporarily rendering the locking member inoperative each time the armature is required to change position; I further provide selector means for energizing, individually or in combination, each of the electromagnets for an operating period at least equal to the time taken by the armature to change over from one position to another corresponding to a new state of energization and for actuating the controller whereby the locking member may be deteriorate each time a new state of energization is generated and may be reactivated before the end of that operating period.

In the accompanying diagrammatic drawing:

FIG. **1** is a longitudinal section through emodiment of a device according to the invention;

FIG. **2***a*, *2b*, *2c*, *2d* and **2***e* illustrate the operation of the device shown in FIG. **1**;

FIG. **3** is a diagram of a possible supply circuit for the device; and

FIG. **4** shows a number of graphs illustrating the operation of the circuit illustrated in FIG. **3**.

The device shown in FIG. **1** comprises a linear electric motor M operating stepwise. This linear motor includes a stator G and a movable armature H which is connected by a coupling **7** to the mechanical element or load to be positioned, this element not being shown. The stator G comprises three annular electromagnets A, B and C, each of which includes a magnetic yoke **1** shaped like a cylindrical casing whose two plane faces are centrally formed with circular openings e_1 and e_2, respectively, and further includes a winding **2A**, **2B**, **2C** having a central opening of the same diameter as the openings e_1 and e_2 to define therewith a throughgoing axial bore.

These three electromagnets are aligned along a common axis *i—i*, coinciding with their longitudinal axis of symmetry, this axis being moreover that along which are aligned the various positions to be taken up by the load coupled with the device; the electromagnets are spaced apart from one another by a gap δ. Two guide bearings p_1 and p_2, centered on the axis *i—i*, are arranged at opposite ends of the electromagnets A, B and C; they support a shaft **3** which extends through the axial bore of each electromagnet and carries three ferromagnetic cores P, Q and R. Each of these cores is a body of cylindrical shape, e.g. of soft iron or ferrite, having a diameter somewhat less than that of that bore, so as to be capable of sliding therein, and having a length substantially eequal to that of the bore. The cores P, Q and R are spaced apart from one another by fixed gaps ϵ that are smaller than the fixed gaps δ between two adjacent electromagnets.

If desired, the gaps ϵ between the cores P, Q and R could also be larger than the gaps δ.

If the shaft **3** has a diameter considerably smaller than that of the cores P, Q and R, it could possibly be made of a ferromagnetic metal, e.g. steel. If, however, the diameter of the shaft **3** approaches that of the cores P, Q and R, it is essential that it be made of an nonmagnetic material. The main requirement is that the common armature formed by the cores P, Q and R, connected by the shaft **3**, should include clearly localized zones having a very small magnetic reluctance in relation to that of the gaps ϵ between them; the particular structure of this armature (such as the length of the

cores in relation to that of the electromagnets, the diameter of the latter in relation to that of the passages e_1 and e_2, the size of the gaps ϵ between the cores in relation to the size of the gaps δ between the electromagnets, and the nature of the material making up the shaft 3) is essentially governed by the manner of operation of this stepping linear motor and by the degree of accuracy that it is desired to achieve for the axial displacements imparted to its armature.

The axial movement of this armature is produced by feeding electriccurrent to one or other of the windings 2 of the electromagnets A, B and C. Under the action of a magnetic field set up by an electromagnet, a ferromagnetic core subjected to this field tends to occupy, in relation to the electromagnet, a position corresponding to the minimum value of the magnetic-circuit reluctance.

In, for example, the case of the core P, the position in which this reluctance is at a minimum is that shown in FIG. 1, i.e. that where the core is fully inserted in the passage extending through the electromagnet A.

Since the length of the cores P, Q and R is here the same as that of the axial bores of the electromagnets A, B and C, there is only one axial position in which the reluctance of the corresponding magnetic circuit is at a minimum. This would not be the case if the cores were shorter or longer.

This particular dimensioning of the cores P, Q and R in relation to the electromagnets A, B and C consequently enables the shaft 3 to be positioned in a particularly accurate manner, the accuracy of the positioning being the same whichever electromagnet electromagnets are energized and regardless of the selected energization pattern.

The number of differrent axial operating positions which can be taken up by the armature of the linear motor is equal to the number of said "patterns" i.e. the total number of individual electromagnets and pairs of adjoining magnets in the set A, B and C. FIGS. 2*a* to 2*e* show these various positions, the energized electromagnets being identified by a circled cross.

In FIG. 2*a* only the electromagnet A is energized. In FIG. 2*b* the electromagnets A and B are energized. In FIG. 2*c* only the electromagnet B is energized. In FIG. 2*d* the electromagnets B and C are energized. And in FIG. 2*e* only the electromagnet C is energized.

In practice, these energization patterns can of course be performed in any order, either using them all or omitting some of them.

The axial position taken up by the armature H of the linear motor M is that which corresponds to the minimum value of the sum of the reluctances of the electromagnets energized. To keep the armature in this position, it would be necessary permanently to energize the corresponding electromagnet(s). This would be a prohibitive solution for two reasons: (a) it would involve considerable energy consumption and (b) this consumption would produce a heat dissipitation which could only be coped with by the device at the expense of an excessive enlargement of its component parts. Further, the electromagnetic force tends to drop to zero when the minimum-reluctance position is reached, so that a position being maintained electromagnetically would suffer from inaccuracy. That is why I have resorted to other means for holding its armature in any one of the minimum-reluctance positions.

These means comprise a locking member or detent U actuated by a controller S. This control member includes an annular electromagnet V which is structurally similar to the electromagnets A, B and C but whose axis *j—j* lies at right angles to and intersects the axis *i—i*.

The electromagnet V comprises a magnetic yoke 1V shaped like a cylindrical casing with its plane faces formed with circular openings e_3 and e_4 defining an axial passage or bore. The yoke 1V contains a winding 2V.

In the axial bore travers the electromagnet V there is slidably mounted a pluger-type core W having a length equal to that of this bore.

The core W is fixed to a rod 4 whose upper end 5 extends slidably through a guide bearing p_4 and whose lower extremity 6 extends through a guide bearing p_5 and which is formed with beveled tip 7 adapted to cooperate with any one of five serrated notches 9 cut in the shaft 3 of the armature H of motor M. A spring 10 normally keeps the beveled tip 7 engaged in one or other of the notches 9. The electromagnet V is so arranged that when the armature formed by the rod 4 and the core W is in this engaged position, the core W is downwardly offset in relation to the electromagnet V, the extent of this offsetting being slightly greater than the depth of the notches 9: consequently, when the electromagnet V is energized the core W centers itself in relation to the yoke 1V, thereby extracting the tip 7 from the notches and releasing the armature H armature is then free to move.

Further, the distance between the notches 9 is equal to the axial distance between the various positions of equilibrium that can be occupied by the armature H of the linear motor M, these positions being shown in FIGS. 2*a* to 2*e*.

The lower end of the rod 4 thus forms a bolt which can immobilize the armature H mechanically in any one of the positions corresponding to the notches 9.

The electric supply circuit of the above-described device, whose linear motor m comprises three electromagnets providing five different operating positions for the common armature H, is shown in FIG. 3. Signals a, b and c, for energizing the windings 2A, 2B and 2C of the electromagnets A, B and C, are applied to input terminals 19A, 19B and 19C and are fed into setting inputs of respective flip-flops 20A, 20B and 20C where they are stored. The outputs 21A, 21B and 21C of these flip-flops have leads connected to the windings 2A, 2B and 2C via gates 22A, 22B and 22C whose outputs 33A, 33B and 33C are connected to these windings. These gates are simultaneously controlled by a signal Z applied to their control inputs 34A, 34B and 34C, this signal being generated by a common monostable or monoflop 23 having a time constant of value T_2. This time constant is at least equal to the time taken by the armature H and its load to move from one position to another. The input of the multivibrator 23 is connected to an output 30 of a pulse generator 24 having several inputs 25A, 25B and 25C and having a time constant of value T_1. This output 30 carries a delayed signal derived from the trailing edge of a pulse *y*, as shown in FIG. 4, whose leading edge energizes another thereat output 31. The inputs 25A, 25B and 25C of pulse generators 24 are connected to the outputs 21A, 21B and 21C of the flip-flops 20A, 20B and 20C.

These flip-flops have resetting inputs **26A**, **26B** and **26C** which are connected to the output of an or circuit **277** having inputs **28A**, **28B** and constant, o **28C** which are connected to the input terminals **19A**, **19B** and **19C**. Delaying elements **29A**, **29B** and **29C** are inserted in the leads between these input terminals and the flip-flops **20A**, **20B** and **20C** to ensure the latter are reset before storing the signals *a*, *b* and *c*. These delaying elements all have a common time constanat, of value T_0.

The winding **2V** of the electromagnet of the control member S for the locking member U is connected to the output of a second monostable multivibrator or monoflop **32** having an input which is connected to the undelayed output **31** of the pulse generator **24.** This second monostable multivibrator **32** has a time constant of value T_3.

Of course, each of the gates **22A**, **22B** and **22C** and the monostable multivibrator **32** includes amplifying stages as required for them to ensure, besides the above-described logic functions, the supply of power on the one hand to the windings **2A**, **2B** and **2C** and on the other hand to the winding **2V**.

The electrical operation of this supply circuit is as follows. Selection signals *a*, *b* and *c*, serving to control the energization of the electromagnets A, B and C in the motor M, are shown as pulses in the top three graphs of FIG. **4.** The instants at which these signals appear depend on the program that has been set for moving the armature H of the motor M : some of the signals appear singly, like signals a_1, b_2 and c_2, whereas others appear simultaneously, like signals b_1 and c_1 and signals a_2 and b_3. The first correspond to the occupation by the armature H of the positions shown in FIGS. **2***a*, 2*c* and **2***e*, respectively; the others correspond to the occupation by the armature H of the positions shown in FIGS. **2***d* and **2***b*, respectively. Each of these signals causes the OR circuit **27** to emit a resetting signal x, represented by the spikes visible in the fourth graph of FIG. **4**: spike x_1 is brought about by pulses a_1; spike x_2 by pulses b_1 and c_1; spikes x_3 and x_4 by pulses b_2 and c_2, respectively; and spike x_5 by pulses a_2 and b_3. With a delay T_0, set by the delaying elements **29A**, **29B** and **29C**, these signals respectively cause the flip-flops **20A**, **20B** and **20C** to switched. This changed over state is maintained until the appearance of a subsequent signal *a*, *b* or *c*. Thus, the switched state *a'* of the flip-flop **20***a*, caused with a delay T_0;, by the signal a_1 that appeared at instant t_1, is maintained until instant t_2 making the appearence of signals b_1 and c_1, these latter signals generating the resetting signal x_2 and resulting in a restoration of that flip-flop to its normal contition as indicated at a'_1; the signals b_1 and c_1 bring about, with a delay T_0, the switched states b'_1 and c'_1 of the flip-flops **20B** and **20C** respectively, these latter states being maintained until instant t_3 when the signal b_2 appears, this signal generating the resetting signal x_3. And so on, each switching operation being preceded by a resetting operation brought about by the signal *x* generated by the OR circuit **27.** It can therefore be said that the flip-flops **20A**, **20B** and **20C** serve to storage the signals appearing at the corresponding inputs **19A**, **19B** and **19C**, such storage lasting for as long as no subsequent signal comes to modify the position of the armature H. As soon as they appear at the outputs **21A**, **21B** and **21C**, the signals *a'*, *b'* and *c'* actuate the pulse gererator **24.** The leading edges of the generated pulses *y* trigger the monostable multivibrator **32** which as a result causes the energization by a voltage z_r of the winding **2V** in the electromagnet V actuating the locking member, thereby extracting the tip **7** of the rod **4** from the engaged notch **9** and releasing the armature H of the linear motor M. The trailing edges of the pulses *y* generated element **24,** Which follow the leading edges with a delay T_1, trigger the monostable multivibrator **23** thereby opening the gates **22A**, **22B** and **22C** and enabling the stored signals *a'*, *b'* and *c'* generate operating voltages a_s, b_s and c_s for the windings **2A**, **2B** and **2C**, respectively, in the electromagnets of the linear motor M. The time constants T_1, T_2 and T_3 of the elements **24, 23** and **32,** respectively, are so chosen as to ensure, in the indicated order, the following operations: unlocking, movement of the armature H, and relocking the latter, while taking into account the inertia of the elements to be moved, in particular of the mechanical element or load which is to be positioned by the device and which is attached to the end **7** of the movable armature H of the motor M.

Thus, owing to the staggered operation of monoflops **23** and **32** apparent from graphs z_r, a_s, b_s and c_s of FIG. **4,** the actuation period of the unlocking magnet V starts and ends earlier than the period of energization of any winding **2A**, **2B** 2C of the positioning magnets, these two periods overlapping for a length of time sufficient to let the armature H find its new stable position in which it is then indexed by the tip **7** of detent **4.**

As will have been observed, the distance between the various positions to which the armature H can move depends on the gaps δ and ϵ. In the embodiment shown in FIG. **1** these gaps are invariable. It is however envisaged to have, a modified arrangement in which one and/or the other of these sets of gaps may be modified at will. This can be done, for example, by mounting the electromagnets A and c on slideways along which they can be selectively moved on opposite sides of the electromagnet B and then anchored at distances δ of any magnitude. It is also envisaged to mount the cores P and R slidably on the shaft **3** whereby they can both be moved in relation to the core Q, suitable means being provided to secure these cores, once moved, to the shaft **3.**

In the illustrated embodiment, the device comprises a linear motor having three electromagnets, thus making it possible to have five different positions for the mobile armature. It will of course be appreciated that this number of electromagnets is not the only possible number. Indeed, the device may have any number of electromagnets, greater than one. If the linear motor has two electromagnets and its armature has two cores, the device is able to move the armature into three different positions, corresponding to the energization of one or the other of the electromagnets and to their simultaneous energization. If, as in the illustrated embodiment the linear motor is fitted with three equidistant electromagnets, spaced by gaps δ, and its armature includes three equidistant cores, spaced by gaps ϵ, there are then, as already indicated, five possible positions of which three correspond to the separate energization of the three electromagnets while the other two correspond to the joint energization of the two adjacent pairs; the cases where all three electromagnets or the two outermost electromagnets are simultaneously energized can be ignored if the electromagnets, and likewise the cores, are equidistant from one another; in view of the symmetry, in either of these arrangements,

of the outermost elements in relation to the central one, these cases would in fact correspond to the case where only the central electromagnet B is energized.

It should be noted that neither the equidistance between electromagnets nor the equidistance between cores are mandatory conditions. Since the distance traveled during a displacement step depends on the difference between the gap δ between two electromagnets and the gap ϵ between the corresponding cores, the equidistance of the electromagnets and the equidistance of the cores leads to identical steps. It steps of different size are to be achieved, this state of equidistance must be abandoned either between the electromagnets (whilst maintaining the state of equidistance between the cores) or between the cores (while maintaining the state of equidistance between the electromagnets), or else between both the electromagnets and the cores.

There is thus available to the designer a very large range of possibilities as regards the number of positions to which the armature can be made to move and as regards the distances separating these positions.

Naturally, the positions of the locking notches **9** along the shaft **3** will be determined by the group of stable positions afforded to the movable armature by the design selected for the device, in particular by the size of the steps bo be taken by the armature.

The illustrated locking arrangement is not the only one that can be resorted to. The beveled shape given to the lower end **6** of the rod **4** has the advantage of improving the accuracy of the resultant positioning by not only locking but also indexing the armature in the desired load position.

I claim:

1. A positioning device for the shifting of a load into any one of a series of predetermined positions, comprising:

a plurality of coaxial annular electromagnets;

an armature mechanically coupled with the load, said armature being provided with core means attractable by said electromagnets upon selective energization thereof into any one of several operating positions corresponding to a desired load position;

bidirectionally effective electromagnetic detent means for positively retaining said armature in any selected operating position against displacement in either direction; and

electronic control means for said electromagnets and said detent means including switch means for selectively energizing said electromagnets and timing means in circuit with said switch means for temporarily deactivating said detent means just prior to energization of any electromagnet, the deactivation period of said detent means starting prior to the energization period of the electromagnet and continuing for a portion of the latter period sufficient to enable a displacement of the armature and the load to a new operating position prior to reactivation of said detent means.

2. A device as defined in claim **1** wherein said armature is provided with a plurality of serrated notches, said detent means comprising a member with a symmetrically beveled extremity engageable in any one of said notches for indexing said armature in a selected operating position.

3. A device as defined in claim **1** wherein said switch means comprises a plurality of flip-flops, one for each electromagnet, settable by respective selection signals, and logical circuitry responsive to any such selection signal for resetting any of said flip-flops previously set, said timing means being responsive to the setting of any of said flip-flops for temporarily deactivating said detent means and energizing the respective electromagnet in staggered relationship.

4. A device as defined in claim **3** wherein said control means comprises a plurality of input leads for said selection signals connected to respective setting inputs of the corresponding flip-flops, and delay means in said input leads, said logical circuitry including OR circuit connected to said leads ahead of said delay means and working into respective resetting inputs of said flip-flops.

5. A device as defined in claim **4** wherein said flip-flops are provided with output leads for the energization of the respective electromagnets and with gate means in said output leads normally blocking such energization, said timing means including first pulsing means connected to said detent means and second pulsing means connected to said gate means.

6. A device as defined in claim **5** wherein said timing means comprises a pulse generator connected to said output leads for triggering upon the setting of any of said flip-flops, said first and second pulsing means including a pair of monostable multivibrators respectively trippable by a leading edge and a trailing edge of an output pulse of said pulse generator.

* * * * *