May 5, 1964 H. KUMPF 3,132,290

ELECTROMAGNETIC APPARATUS FOR TRANSMITTING MOTION FROM THE OUTSIDE TO A ROD-SHAPED MEMBER WITHIN A TUBULAR HOUSING

Filed July 18, 1961

4 Sheets-Sheet 1

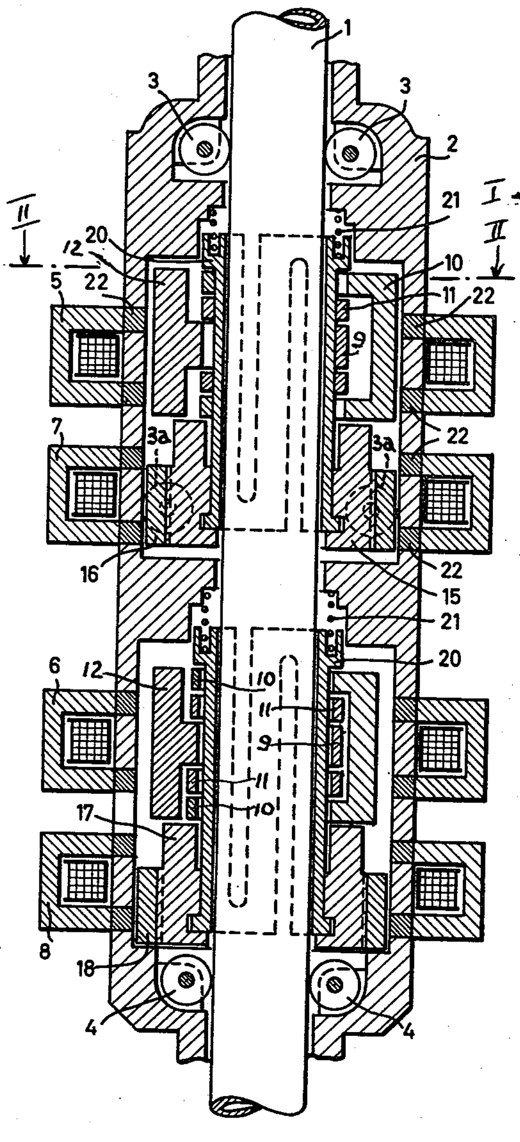

Fig. 1

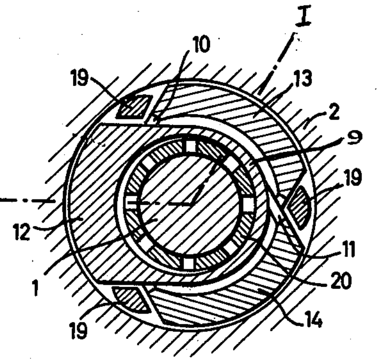

Fig. 2

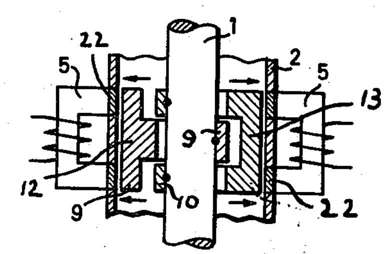

Fig. 3

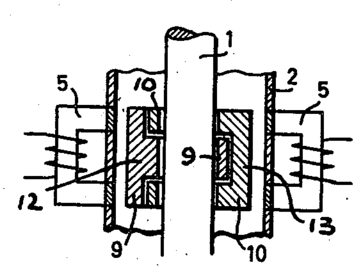

Fig. 4

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ELECTROMAGNETIC APPARATUS FOR TRANSMITTING MOTION FROM THE OUTSIDE TO A ROD-SHAPED MEMBER WITHIN A TUBULAR HOUSING

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4 Sheets-Sheet 2

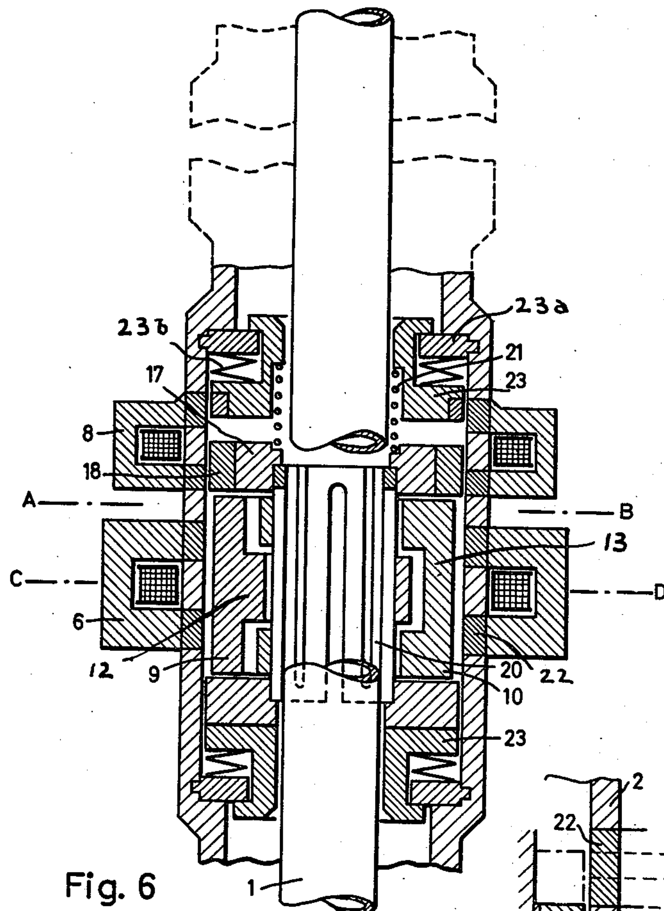

Fig. 6

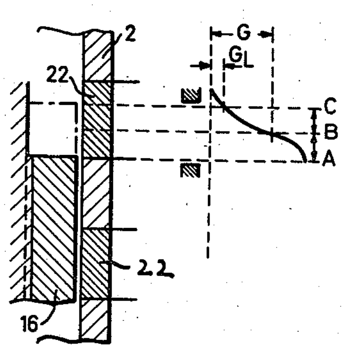

Fig. 5

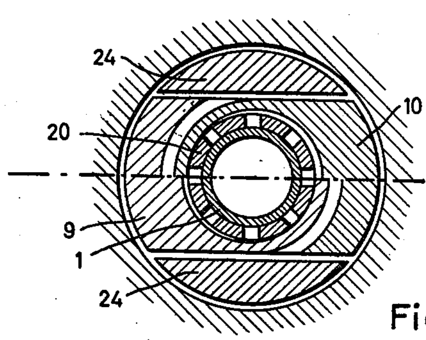

Fig. 7

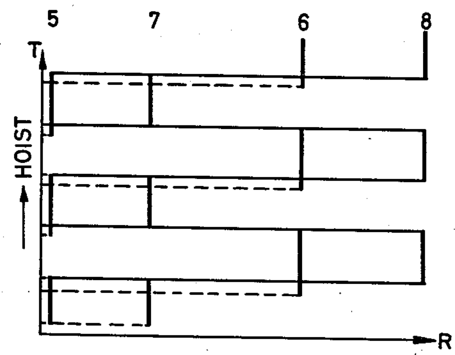

Fig. 8

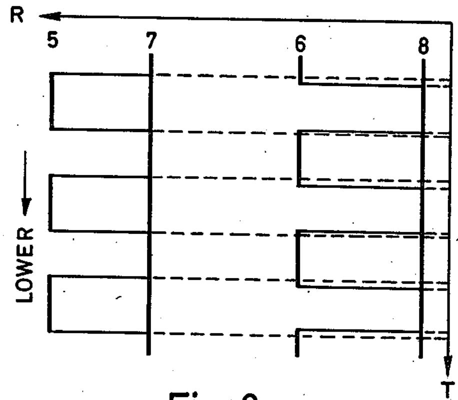

Fig. 9

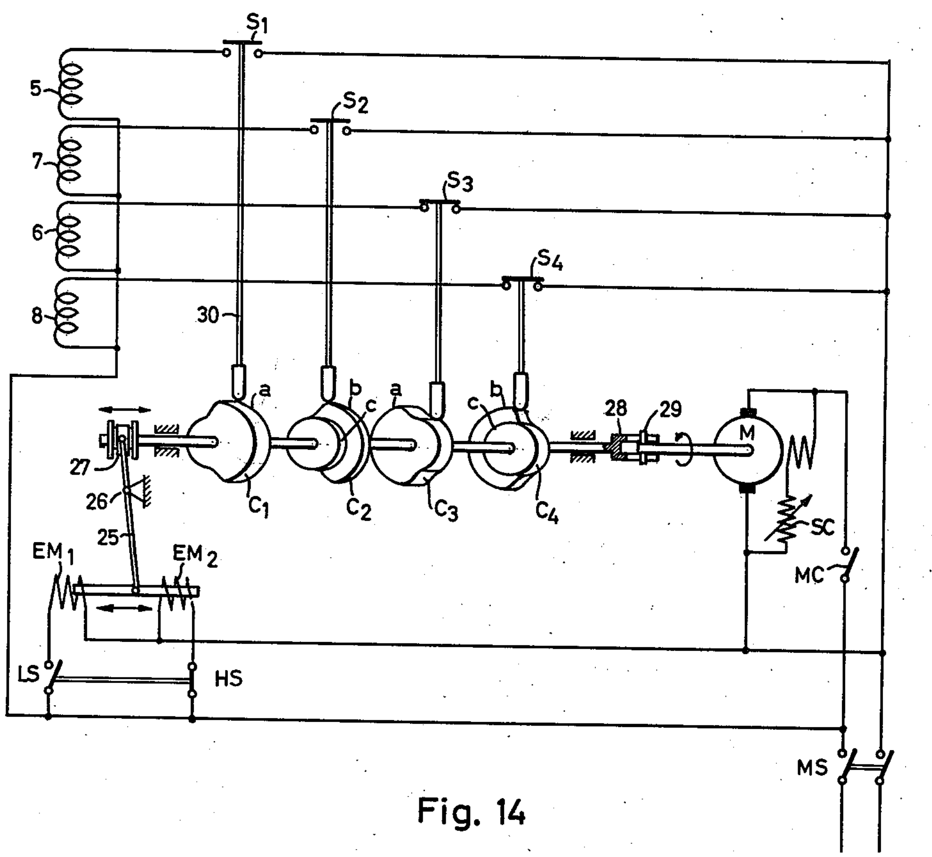

Fig. 14

May 5, 1964 H. KUMPF 3,132,290
ELECTROMAGNETIC APPARATUS FOR TRANSMITTING MOTION FROM THE OUTSIDE TO A ROD-SHAPED MEMBER WITHIN A TUBULAR HOUSING
Filed July 18, 1961 4 Sheets-Sheet 4

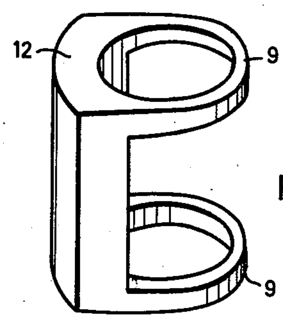

Fig. 10

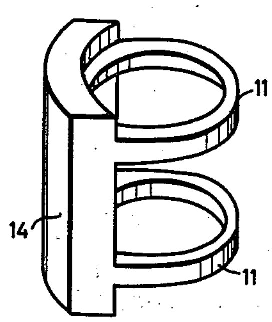

Fig. 11

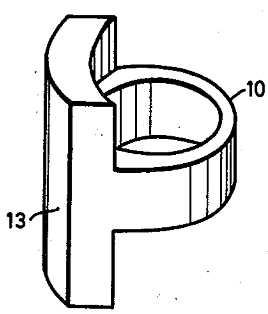

Fig. 12

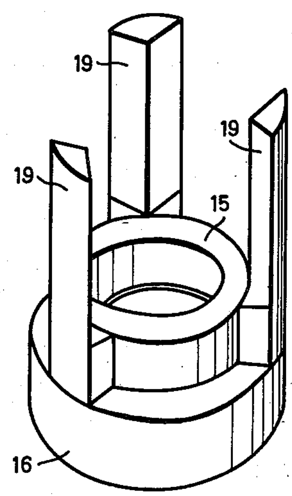

Fig. 13

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3,132,290
Patented May 5, 1964

3,132,290

ELECTROMAGNETIC APPARATUS FOR TRANSMITTING MOTION FROM THE OUTSIDE TO A ROD-SHAPED MEMBER WITHIN A TUBULAR HOUSING

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Claims priority, application Germany July 23, 1960
9 Claims. (Cl. 317—123)

My invention relates to electromagnetic apparatus for transmitting motion from the outside of a tubular housing to a rod-shaped member within the housing. Such apparatus, generally known as "magnetic jack" are applicable, for example, in nuclear techniques, preferably for controlling the lifting and lowering motion of regulating and shut-off rods in nuclear reactors. Apparatus of this type are illustrated and described in my copending applications Serial No. 859,803, filed December 15, 1959, and Serial No. 8,405, filed February 12, 1960, both assigned to the assignee of the present invention.

In a magnetic jack of the known type, the member to be displaced within the housing is fastened to a bunch of bendingly elastic rods of magnetizable material. An axially displaceable armature sleeve of ferromagnetic material surrounds the bunch with clearance and forms part of a magnetic system that comprises a holding coil, a lifting coil and a lowering coil. The system is further provided with an auxiliary holding coil. When the holding coil or the auxiliary holding coil is electrically excited, the rods within the tubular housing are radially pulled apart from one another at the height of the excited coil and are forced against the armature sleeve or the inner wall of the tubular housing, so that they are frictionally held in position. By alternately exciting the holding coils on the one hand, and either the lifting coil or lowering coil on the other hand, the bunch of rods is axially moved step by step. For obtaining a more uniform travel motion, the above-mentioned auxiliary holding coil can be substituted by a second complete set of holding, lifting and lowering coils. It has also been proposed to arrest rod-shaped bodies within a tubular housing by means of clamping or knee-action mechanisms by respective armatures that reciprocate with relatively short strokes, to obtain in this manner a stepwise progressive motion of the rod-shaped bodies.

It is an object of my invention to improve magnetic-jack devices and to increase their field of useful application by doing away with the necessity of giving the movable member a fixed full-bodied cross section and making it of ferromagnetic material. Another object is to permit greatly reducing the weight of the structural component that is to perform the controlled motion within the sealed tubular housing.

According to my invention, the structural component to be moved is no longer traversed by the operating magnetic flux and can therefore be given any desired cross section as well as a much lower weight than needed in the magnetic-jack devices as heretofore known.

More specifically, according to my invention, the length of the above-mentioned armature sleeve is reduced so as to be limited to the action range of the motion-producing magnet coil, the armature for the holding coil is composed of a plurality of radially movable parts that jointly operate as a clamp, and the armature sleeve is coupled with the composite armature in contour-constrained fashion.

In such apparatus, lifting the displaceable structure is effected by alternately exciting the lifting coils and the holding coils in a given sequence. For lowering the structure the holding coils are alternately excited with con-

tinuous excitation of the lifting coils. In each case, the motion is without impact or jarring because the armatures are no longer pulled against rigid and fixed stops but have their motion limited only by magnetic forces.

The foregoing and more specific objects, advantages, and features of my invention, said features being set forth with particularity in the claims annexed hereto, will be apparent from, and will be described in, the following with reference to the embodiments of apparatus according to the invention illustrated by way of example on the accomyanying drawings in which:

FIG. 1 is a longitudinal section through a first electromagnetic apparatus along the line I—I in FIG. 2.

FIG. 2 is a cross section through the tubular housing portion of the apparatus along the line II—II in FIG. 1.

FIG. 3 shows separately the composite armature with the appertaining holding coil, the coil being in excited condition.

FIG. 4 shows the same composite armature in non-excited condition of the holding coil.

FIG. 5 is an explanatory schematic diagram relating to the lifting and lowering operation.

FIG. 6 is a longitudianl section of a second embodiment of apparatus according to the invention.

FIG. 7 shows in its upper portion a cross section along the line A—B in FIG. 6 and shows in its lower portion a cross section along the line C—D in FIG. 6.

FIG. 8 is a graph explanatory of a switching program for a lifting operation.

FIG. 9 is a corresponding switching program for lowering operation.

FIGS. 10, 11 and 12 are perspective views of the three components that jointly form the holding armature assembly in the device according to FIGS. 1 to 4.

FIG. 13 is a perspective view of the lifting armature **15** in the device according to FIGS. 1 to 4; and

FIG. 14 shows a control device for energizing the magnet coils of apparatus according to the invention as required by the switching programs exemplified in FIGS. 8 and 9.

According to FIG. 1, a rod-shaped elongated member **1**, for example a regulating rod for a nuclear reactor, is surrounded on all sides by a pressure-sealed tubular housing **2** generally of non-magnetic metal, and is guided by rollers **3** and **4** for vertical axial motion at low friction. The tubular housing **2** is concentrically surrounded by annular electromagnets, namely two holding magnets **5**, **6** and two lifting magnets **7**, **8** which alternate with each other longitudinally along the housing.

Correlated to each of the four electromagnets is a magnetizable armature assembly which surrounds the rod **1** within the housing **2**. The armature assembly of each holding magnet **5** and **6** consists of three individual clamping parts **9**, **10**, **11** (FIGS. 2, 10, 11, 12) each of which forms a ring with clearance around the rod **1**. The respective magnetizable head pieces **12**, **13** and **14** of the three clamping members are displaced 120° (FIG. 2) from each other. The lifting armatures **15** and **17** which coact with the respective electromagnets **7** and **8** comprise each a magnetizable sleeve **16** or **18** (FIGS. 1, 13). The friction between the lifting armature **15**, **17** and the wall of housing **2** can be minimized by the provision of glide shoes or guide rollers such as the one shown by broken lines at *3a* in FIG. 1. These rollers are journalled on the housing wall in the same manner as shown for rollers **3**, **4** and are in rolling engagement with the armature **15**.

Each of the two lifting armatures **15** and **17** has three upwardly protruding projections **19** (FIGS. 2, 13) 120° spaced from each other which couple the three components **9**/**12**, **10**/**13**, **11**/**14** (FIGS.10, 11, 12) of the holding armature assembly with the lifting armature (FIG.

13) and which guide the three holding-armature components so that each of them can move only in a radial direction. As shown in FIG. 2 the three upward projections 19 of the lifting armatures 15 or 17 do not touch the inner wall of the tubular housing 2.

It is preferable to provide slitted sleeves 20 (FIG. 1) between the three clamping components 9, 10, 11 on the one hand and the rod 1 on the other hand. Such slitted sleeves 20 reduce the peak pressure exerted at any particular locality and thus render the action of the clamping components 9, 10, 11 more uniform. The sleeves 20 are fastened to the respective lifting armatures 15 and 17. A spring 21 seated in the tubular housing 2 and pressing against the top of the sleeve 20 acts cumulatively with respect to the weight of the armature and pushes it reliably to the lowermost position when the lifting magnet 7 or 8 is not electrically excited. The wall of vessel 2, consisting of non-magnetic, austenitic material is provided with magnetizable rings 22 consisting preferably of ferrite and being welded between the adjacent components of the housing structure. The rings 22 form continuations of the respective magnetic field structures of the four electromagnets and hence act as pole shoes, or pole rings.

The operation of the clamping components will be explained with reference to FIGS. 3 and 4. For simplicity, the clamping sleeve 20 is omitted and only the components 9, 12 and 10, 13 of the holding armature assembly are shown. In FIG. 3 the holding magnet 5 is assumed to be electrically excited so that the head pieces 12 and 13 of the illustrated armature components are attracted to the pole rings 22 and clamp the rod structure 1 between the clamping components 9 and 10. At the points identified by black dots, the components 9 and 10 firmly rest against the rod 1 and hold it in position by friction. It will be understood that the third armature component 11, 14 not shown in FIG. 3 performs the same action in a cumulative sense and, due to the uniform distribution of the three components over the periphery, contributes to a more uniform clamping action. It will also be understood that for some purposes the holding armature need be given only two clamping components, whereas for other purposes more than three such components may be uniformly distributed about the structure to be moved and held. In FIG. 4 it is assumed that the holding magnet 5 is deenergized so that the armature head pieces 12 and 13 are no longer attracted toward the wall of the tubular housing 2. The rod structure 1 is now free to move in the upward or downward direction.

The operation of the lifting magnets 7, 8 will be explained with reference to FIG. 5. When the coil of the lifting magnet 7 is excited, the magnetic ring 16 is subjected to the pulling forces schematically represented in the right-hand portion of the diagram. G_L denotes the weight of the idle lifting armature and of the idle clamping components 9, 10, 11, inclusive of the sleeve 20 and the force of the spring 21. G denotes the weight of the armature inclusive of that of the rod structure 1. The same forces are active upon the magnetizable ring 18 of the lifting armature 17 appertaining to the lifting magnet 8. By alternately exciting the lifting magnets 7 and 8 and the holding magnets 5 and 6, a lifting motion is imparted to the rod 1. For explaining this, assume that the lifting magnet 8 and the holding magnet 6 are switched on and that their respective armatures hold the rod in position, while the magnets 5 and 7 are switched off and the lifting armature 15 is in its lowermost position as identified by point A in the diagram of FIG. 5. Now the holding magnet 5 is excited, so that the rod 1 becomes coupled to the armature 15. Then the lifting magnet 7 is excited and lifts the armature 15 with the rod 1 to the midposition B in which the lifting force of magnet 7 is in equilibrium with the weight of the rod. At the same time the magnets 6 and 8 are switched off, and the armature 17 moves to the lowermost position.

The same cycle of operation is repeated with the armature 17, and so forth. During such performance a certain amount of excessive swing motion, preferably beyond the point B (FIG. 5), may occur. Generally, however, the lifting operation takes place between the points A and B.

For lowering the rod 1, the two lifting magnets 7 and 8 are kept continuously switched on. The drive functions only when the rod 1 is continuously subjected to a downward force, for example gravity when the rod is in vertical or inclined position, or hydraulic force or spring force when the rod is in horizontal position. For explanation, assume that the armature 17 in coaction with the holding magnet 6 is maintaining the rod in position and that the armature 15 occupies a position corresponding to the highest point C in FIG. 5 where the magnet 7 is in equilibrium with the weight G_L of the idle armatures inclusive of the forces of spring 21. When now the holding magnet 5 is switched on, the rod 1 becomes tied to the armature 15. Thereafter the holding magnet 6 is switched off so that the armature sleeve 18 glides into the position corresponding to point C, and the loaded armature 15 glides to the position corresponding to point B at which the forces are in equilibrium. The just-mentioned movement of armature 15 occurs because the lifting magnet 17 cannot hold its armature inclusive of the rod in the position C. In practice, the rod 1 with the armature 15 drops to the position B or, for reasons of inertia, somewhat below this point. The same cycle is repeated with the other armature, and so forth. The lowering operation therefore takes place substantially between the points C and B according to FIG. 5.

It will be understood from the foregoing, that only the unloaded armatures can abut against rigid structure when reaching their respective end positions. Such abutting of the idle armatures in the limit positions can be effectively damped by resilient stops as shown at 23 in FIG. 6. In some cases the fluid damping effective between the piston-like stop 23 and a fixed counter-abutment *23a* is sufficient. In other cases, however, a spring *23b* may be inserted. In the embodiment of FIG. 6, the lifting magnets are located above the holding magnets, and the holding armature is composed of only two clamping parts 9 and 10 and is inserted between two lateral portions 24 to form a downwardly protruding neck of the holding armature 17 (FIG. 7).

While in FIG. 6 only one pair of magnets is shown, it is assumed that the apparatus is provided with two identical pairs of such magnets in the same manner as illustrated in FIG. 1 and described above. However, in both embodiments, one of the two pairs can be substituted by an auxiliary holding magnet which is to be provided with a multiple-part armature in the interior of the tubular housing, the armature cooperating with a stop that limits the armature travel in the vertical direction. Furthermore, in lieu of a motion control magnet that effects lifting and lowering, a lifting coil and a lowering coil may be used which are directly located beside each other and which act upon a common armature sleeve whose length is limited to the action range of the two coacting coils.

For increasing the lowering speed, the motion control coils and the holding coils can be alternately switched on and off in the same manner as during the above-described lifting operation. In this case, the lifting armatures loaded with the weight of the rod, do not drop to the mid-position corresponding to point B in FIG. 5, but drop down to the lowermost limiting stops. This, however, involves the disadvantage that the apparatus no longer operates free of impact and that appreciable frictional wear at the rod may occur.

In apparatus according to the invention, as exemplified by the embodiments described above, the rod structure to be moved is tied by frictional connection to the holding armature and the latter in turn is suspended by means of the lifting armature only by the action of magnetic lines of force. For that reason, a frictional gliding of the rod **1** in the sleeve **20** or in the clamping components of the holding armature does not occur to an appreciable extent when the magnet components are given a suitable dimensioning. The cross section of the rod structure can be given any desired design. Most advantageous are circular or ring-shaped cross sections. Thus, the component may consist of a tubular member as shown in FIG. 1, which permits greatly reducing the mass and weight of the member. Since the magnetic flux does not pass through the rod member, the dimension of the cross section is determined only by the desired mechanical strength. This affords giving the rod a considerably smaller weight than with the conventional magnetic jack devices. As a result the overall dimensions of the entire apparatus can also be reduced and the required forces are correspondingly small. When the holding magnets or all magnets are deenergized, the rod **1** drops without hindrance as is desirable for shut-off or scram performance in nuclear reactor plants. Diagrammatically illustrated in FIGS. 8 and 9 are the switching programs for lifting and lowering operations as described above. Represented by heavy vertical lines is the switching-on duration of the individual magnet coils which are identified in the horizontal direction of the abscissa by respective numbers.

The circuit diagram shown in FIG. 14 illustrates a switching device that permits energizing and deenergizing the magnet coils **5** to **8** in accordance with the switching programs for lifting and lowering operations shown in FIGS. 8 and 9. The energizing circuits according to FIG. 14 are connected to a direct-voltage supply by a main switch MS. When closing a motor control switch MC, a direct-current motor M is put into operation at a speed adjustable by means of a field control rheostat SC. A cam shaft with four cam bodies C_1 to C_4 is coupled with the shaft of motor M by means of a sleeve **28** fastened to the cam shaft and provided with two pairs of slots or grooves that extend parallel to the sleeve axis and are engaged by cross pins or keys **29** of the motor shaft so as to permit axial displacement of the cam shaft relative to the motor shaft. Such displacement of the cam shaft is controlled by two electromagnets EM_1 and EM_2 which can be alternately energized under control by two switches LS and HS ganged together with each other. The two magnets have a common armature linked to a lever **25** that is pivoted at **26** and engages at **27** a ring located between two discs firmly mounted on the cam shaft. Shifting the lever **25** in one or the other direction by excitation of a selected one of the two magnets causes the cam shaft to be axially shifted accordingly.

The cam bodies C_2 and C_4 consist each of a cylinder portion and a non-cylindrical lobe portion so as to have a cylindrical concentric cam counter at *c* and a lobed contour at *b* which can be selectively chosen by axially shifting the sam shaft. Each of cam bodies C_1 and C_3, however, has only one cam contour *a* of the lobe type which is as wide as the total width of the two cam paths *b*, *c* of cams C_2 and C_4. The four cams cooperate with respective followers **30** for actuating four respective switches S_1 to S_4 in the energizing circuits of the respective electromagnet coils **5** to **8**.

At the switching stage shown in FIG. 14, with the cam shaft rotating as indicated by an arrow, the switches S_3 and S_4 are just moved to closed positions and the switches S_1 and S_2 to the open positions. The cam bodies C_3 and C_4 are angularly displaced from each other to a slight extent so that the switch S_3 closes shortly prior to closing of switch S_4. Consequently, the holding magnet **6** becomes energized a short interval of time earlier than the lifting magnet **8**. At the moment when switch S_4 is being closed, the switches S_1 and S_2 are being opened. The cams C_1 and C_2 are likewise displaced angularly from each other so that the holding magnet **5** is switched on shortly ahead of the lifting magnet **7**. Furthermore, under these conditions the switch HS is closed so that, with main switch MS also closed, the electromagnet EM_2 is energized. Consequently, the cam shaft is in its illustrated left-hand limit position so that the cam followers for switches S_2 and S_4 glide on the cam contours *b* of respective cams C_2 and C_4. The resulting switching sequence for energization and deenergization of the holding and lifting coils has the result that the rod structure is being lifted in accordance with the switching program shown in FIG. 8. By closing the switch LS and simultaneously opening the switch HS, the electromagnet EM_1 is energized and the cam shaft is displaced toward the right. As a result, the cam followers for switches S_2 and S_4 cooperate with the circular contours *c* of cams C_2 and C_4 so that the holding coils **7** and **8** remain continuously switched on, whereas the switches S_1 and S_3 are alternately opened and closed. Now the lifting and holding coils are energized in accordance with the switching program of FIG. 9, and the rod structure is being lowered. It is preferable to connect the circular cam contour *c* and the lobed contour *b* on each of cams C_2 and C_4 by a curved or inclined transitional area so that the cam follower **30** can smoothly glide from one contour to the other when the cam shaft is being axially shifted.

It will be obvious to those skilled in the art, upon studying this disclosure, that my invention permits of various modifications with respect to structural details and hence can be given embodiments other than particularly illustrated and described herein, without departing from the essential features of my invention and within the scope of the claims annexed hereto.

I claim:

1. Electromagnetic apparatus for imparting motion from the outside to a rod structure within a housing, comprising a tubular housing and an elongated rod structure axially displaceable in said housing, respective moving and holding armature means surrounding said rod structure inside said housing, said moving armature means being axially reciprocable a given distance and having a biasing force tending to move it in one direction, motion control electromagnet means surrounding the housing for moving said moving armature means in the other direction when energized, holding electromagnet means surrounding the housing, said holding armature means having a plurality of clamping parts angularly displaced from one another about the axis of said rod structure and surrounding said rod structure with clearance when said holding electromagnetic means are deenergized, said parts being attractable outwardly by said holding electromagnetic means when the latter is energized to then clamp said rod structure, said moving armature means being engageable to said holding armature means to move together in the other direction, whereby said magnets can be periodically energized to progressively shift said rod structure in said housing.

2. Electromagnetic apparatus for imparting motion from the outside to a rod structure within a housing, comprising a tubular housing and an elongated rod structure axially displaceable in said housing, a plurality of sets of electromagnets around said housing and comprising each a motion control magnet and a holding magnet having respective moving and holding armature means surrounding said rod structure inside said housing, each of said moving armature means being axially reciprocable a given distance and having a biasing force tending to move it in one direction, said respective motion control magnets moving said moving armature means axially in the other direction when said corresponding electromagnetic means are energized, each of said holding armature means having a plurality of clamping parts angularly displaced from one another about the axis of said rod structure and surrounding said rod structure with clearance when said holding magnet is deenergized, said parts being attractable outwardly by said corresponding holding magnet when the latter is energized to then clamp said sleeve

to said rod structure, said moving armature means in each set of electromagnets being engageable to the holding armature means in the corresponding electromagnet for moving together in the other direction.

3. Electromagnetic apparatus for imparting motion from the outside to a rod structure within a housing, comprising a tubular housing and an elongated rod structure axially displaceable in said housing, said housing and rod structure extending in an upward direction, a plurality of sets of axially sequential electromagnets disposed around said housing, each set having a single motion control magnet for lifting and lowering said rod structure and having a single holding magnet, said two magnets having respective first and second armature means surrounding said rod structure inside said housing, said first armature means being axially reciprocable a given distance and having a biasing force tending to move it in one direction, said second armature means being movable by said first armature means so as to move together with said first armature means in the other direction when said motion control magnet is energized, said second armature means having a plurality of clamping parts angularly displaced from one another about the axis of said rod structure and surrounding said rod structure with clearance when said holding magnet is deenergized, said parts being attractable outwardly by said holding magnet when the latter is energized to then clamp said rod structure in position.

4. Electromagnetic apparatus according to claim 1, comprising a radially compressible clamping sleeve coaxially mounted between said rod structure and said clamping parts of said second armature means and forming a part of said moving armature means.

5. In electromagnetic apparatus according to claim 1, said holding armature means comprising a total of three of said clamping parts having respective segmental head portions 120° displaced from each other, each clamping part having at least one loop portion extending from said head portion around said rod structure.

6. In electromagnetic apparatus according to claim 2, each of said clamping parts having a head portion angularly spaced from that of the adjacent clamping part and having at least one loop portion extending from said loop portion around said rod structure, and an armature sleeve having projections extending substantially parallel to the sleeve axis between said head portions for radially guiding said clamping parts.

7. Electromagnetic apparatus according to claim 2, comprising respective longitudinally slitted clamping sleeves for each set of electromagnets, said sleeves being coaxially seated on said rod structure and being axially displaceable relative to said rod structure when said clamping sleeve is relaxed, said clamping sleeves being anchored to said moving armature means to axially move together therewith and being surrounded by said clamping parts to be radially compressed thereby for frictionally engaging said rod structure when said holding magnet is energized.

8. Electromagnetic apparatus according to claim 1, comprising annular stop members mounted in said housing around said rod structure for limiting axial motion of said armature means, said stop members being axially displaceble within a given range, and spring means engaging said stop members to permit axially yielding displacement thereof.

9. Electromagnetic apparatus according to claim 2, comprising current supply means, a switching device for energizing said electromagnets from said supply means and having lifting control means alternately connecting said motion control magnets and said holding magnets to said supply means for lifting said rod structure, and lowering control means connecting said supply means continuously to said motion control magnets and intermittently to said holding magnets for lowering said rod structure.

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