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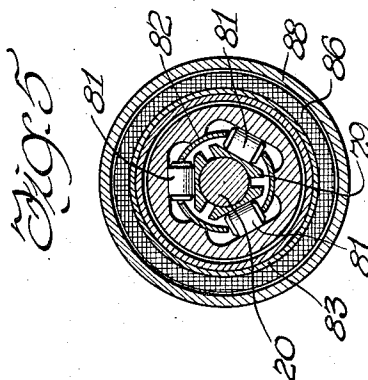
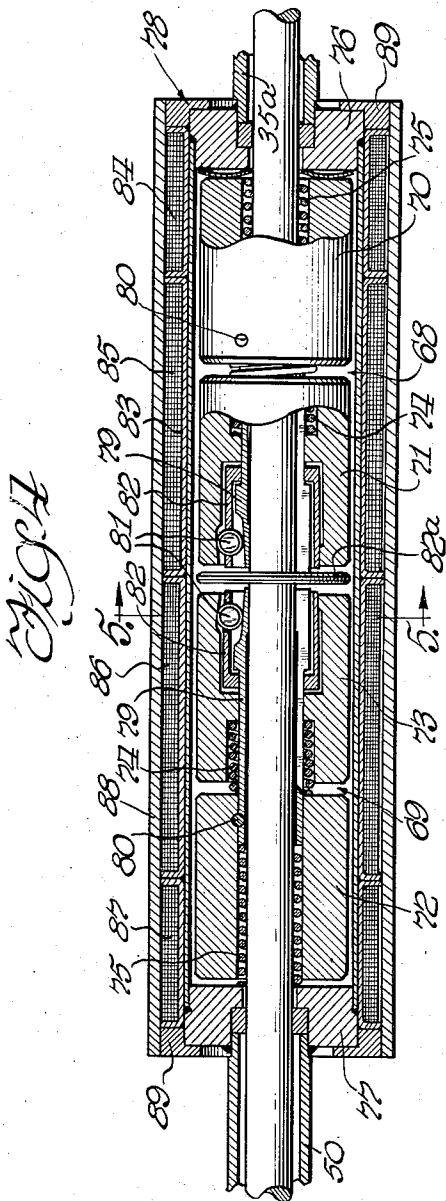
J. N. YOUNG

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ELECTROMAGNETIC APPARATUS FOR MOVING A ROD

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4 Sheets-Sheet 2



INVENTOR.
Joseph N. Young
BY
Roland A. Anderson
Attorney

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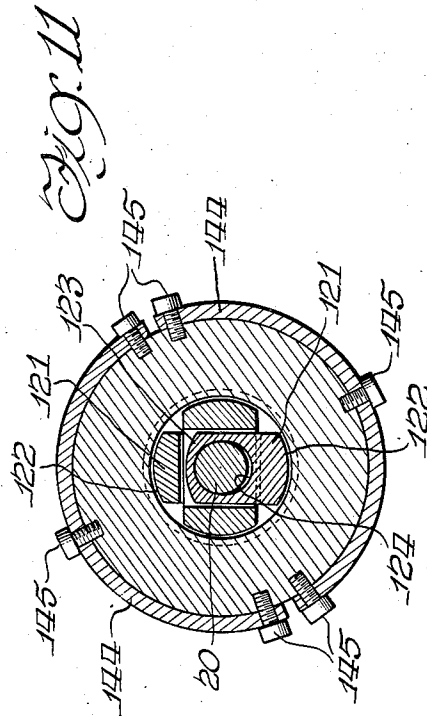
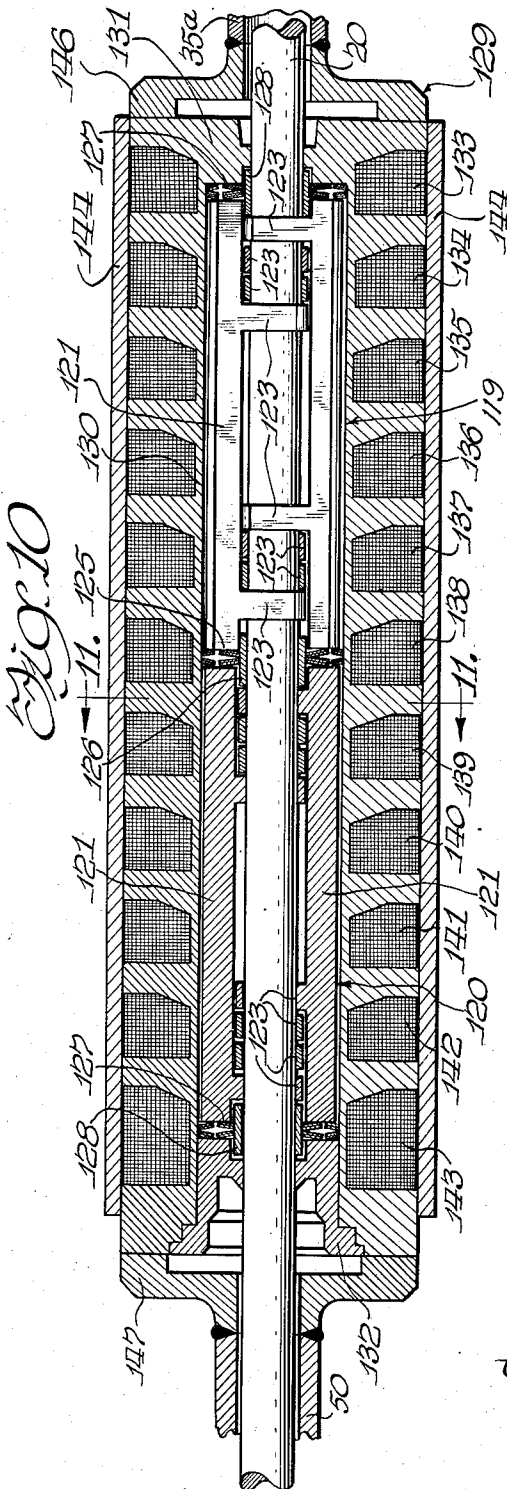
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INVENTOR.
Joseph N. Young
BY
Hend A. Anderson
Attorney

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ELECTROMAGNETIC APPARATUS FOR MOVING A ROD

Joseph N. Young, Chicago, Ill., assignor to the United States of America as represented by the United States Atomic Energy Commission

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14 Claims. (Cl. 310—14)

The present invention relates to an apparatus for moving an object in small amounts or steps and more specifically to an apparatus of this type in which small movements are produced by electromagnetic means.

It is well known in the field of nuclear reactors to shift a rod of neutron-absorbing material into or out of a reactor for varying and controlling the reactivity level. The apparatus that shifts the rod for this purpose must be capable of moving the rod in both directions in small amounts and yet of enabling the rod to be moved rapidly for a long distance when an emergency arises requiring shut-down of the reactor. Since it is highly desirable that the apparatus for shifting the neutron-absorbing rod be exterior to the rod, there is a considerable problem in providing effective seals between, the reactor, the rod, and the apparatus for moving it. The problem is very acute in a reactor in which a liquid is being circulated under pressure.

The apparatus of the present invention functions without the need for seals through which moving parts extend. The neutron-absorbing rod and certain parts of the present apparatus are completely enclosed in a liquid-tight housing, while other parts of the apparatus are external to the housing and act thereacross by electromagnetic forces. Incidentally, there is no need for lubrication of the present apparatus, because the parts thereof in the housing have either rolling or bending action, and the parts external to the housing are stationary.

According to the present invention, a neutron-absorbing rod is mounted in a housing with gripping units that engage the rod, and coils for magnetizing the gripping units to make them grip, shift, and release the rod are located outside the housing.

In the drawings:

Fig. 1 is a longitudinal sectional view of one form of the apparatus of the present invention;

Fig. 2 is a transverse section taken on the line 2—2 of Fig. 1;

Fig. 3 is a longitudinal sectional view of a spring-loaded mechanism for shifting a rod in an emergency, the mechanism forming part of the present invention;

Fig. 4 is a longitudinal sectional view of a second form of the apparatus of the present invention;

Fig. 5 is a transverse section taken on the line 5—5 of Fig. 4;

Fig. 6 is a longitudinal sectional view of a third form of the apparatus of the present invention;

Fig. 7 is a transverse sectional view taken on the line 7—7 of Fig. 6 and illustrating the construction of a gripping unit and a magnetic coil;

Fig. 8 is a longitudinal sectional view taken on the line 8—8 of Fig. 6 and illustrating the gripping unit;

Fig. 9 is a transverse sectional view taken on the line 9—9 of Fig. 6 and illustrating how the gripping unit engages a rod;

Fig. 10 is a longitudinal sectional view of a fourth form of the apparatus of the present invention; and

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Fig. 11 is a transverse section taken on the line 11—11 of Fig. 10.

A rod 20 which is illustrated in Figs. 1 and 2 is formed as an extension of a neutron-absorbing rod, not shown, and may be formed of nonmagnetic or magnetic material, although nonmagnetic material such as stainless steel is somewhat preferable. The rod 20 is embraced by two gripping units 21 and 22 which may be identical but are reversely arranged with respect to one another as illustrated. The gripping unit 21 comprises an outer collar 23 having a thin longitudinally slotted sleeve-like extension 24. The gripping unit 21 further comprises an inner collar 25 which is positioned on the sleeve-like extension 24 and provided at its inner end with a recess 26 having a conical surface 27. The gripping unit 21 also includes a set of steel balls 28 which are positioned in the recess 26 and distributed about the extension 24. Movement of the collars 23 and 25 toward one another along the rod 20 causes the conical surface 27 to urge the balls 28 against the sleeve-like extension 24 and the latter to grip the rod 20. Movement of the collars 23 and 25 in the opposite direction releases the sleeve-like extension 24 from the rod 20. A ring 29, which is hooked over the end of the sleeve-like extension 24 to retain the balls 28 in the collar 25, completes the gripping unit 21. The collars 23 and 25 are formed of magnetic material such as soft iron. The retaining ring 29 may be made of nonmagnetic material such as stainless steel.

The gripping unit 22 has an outer collar 30 and an inner collar 31 which may be identical to the outer collar 23 and the inner collar 25 of the gripping unit 21, respectively, in construction, material, and relative arrangement, but the gripping units 21 and 22 are reversed with respect to one another so that the inner collars 25 and 31 are adjacent one another and the outer collars 23 and 30 are away from one another.

The gripping units 21 and 22 are enclosed in a housing 32 which comprises a sleeve 33 and end fittings 34 and 35 which are, respectively, brazed and threaded to the ends of the sleeve 33. The parts of the housing 32 are formed of nonmagnetic material such as stainless steel. The end fitting 34 is welded or soldered to a sleeve or tube 35a which is formed of nonmagnetic material such as stainless steel and is adapted to be connected with the reactor so as to communicate with a section thereof in which there may be fluid under pressure. Magnetic stops 36 and 37 which take the form of short tubular sections of magnetic material such as soft iron are secured inside the housing 32 adjacent its ends, the stop 36 having a threaded connection with the fitting 35 and the stop 37 having a shoulder 37a engaging one end of the sleeve 33. Rings 38 of nonmagnetic material such as stainless steel position the rod 20 in the stops 36 and 37.

On the exterior of the housing sleeve 33 four magnetic coils 40, 41, 42, and 43 are positioned. Coil 40, termed an outer coil, overlaps magnetic stop 37 and outer collar 23. Coil 41, termed an inner coil, overlaps collars 23 and 25. Coil 42, termed an inner coil, overlaps collars 31 and 30. Coil 43, termed an outer coil, overlaps collar 30 and magnetic stop 36. Coils 40 and 41 are to be energized to exert magnetic force in one direction, and coils 42 and 43 are to be energized to exert magnetic force in the opposite direction. The coils 40, 41, 42, and 43 are enclosed in a split sleeve 44 of magnetic material such as soft iron and are retained against lengthwise movement on the sleeve 33 by rings 45 which are suitably secured to the sleeve 33 and are formed of magnetic material such as soft iron.

The coils 40, 41, 42 and 43 are energized by an electric power source 45a through the individual switches 45b. The switches 45b may be operated by hand or by

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cam-driver means (not shown) and not forming a part of this invention.

Let it be assumed that the rod 20 is to be moved in steps to the left as viewed in Fig. 1. At the start of a given cycle all four coils 40, 41, 42, and 43 are energized, and so both gripping units 21 and 22 are holding the rod 20. The gripping unit 21 is drawn to the right against the magnetic stop 37, for the magnetic field set up by the coils 40 and 41 has pulled the outer collar 23 against the stop 37 and the inner collar 25 against the outer collar 23. The gripping unit 22 is drawn to the left against the magnetic stop 36, for the magnetic field set up by the coils 42 and 43 has pulled the outer collar 30 against the stop 36 and the inner collar 31 against the outer collar 30. Now coils 42 and 43 are deenergized, and the result is that collar 31, under the action of the coil 41 moves to the right toward collar 25 and away from the collar 30. Thus the sleeve extension 24 on the collar 30 releases the rod 20. Now coil 42 is reenergized to pull collar 30 to the right toward collar 31, and the result is a regripping of the rod 20 to the right of the position at which the collars 30 and 31 gripped the rod at the start of operation. Next coil 43 is reenergized, and coil 41 is deenergized. This causes magnetic stop 36 to pull collar 30 to the left and collar 25 to release its pull on collar 31, and so collars 30 and 31, being pulled toward one another by coil 42, regrip the shaft 20, are moved conjointly to the left, and shift the shaft a step to the left. In the meantime, the inner collar 25 has been moved slightly to the left under the pull thereon by the collar 31 due to the coil 42 and has caused the sleeve-like extension 24 on the outer collar 23 to release the rod 20. Now coil 41 is reenergized, and there is a return to the start of the cycle at which all four coils 40, 41, 42, and 43 are energized. A new cycle of operations is performed as previously described, resulting in a new leftward step of movement of the rod 20. During all leftward movement of the rod 20 the right-hand outer coil 40 remains energized, and the right-hand outer collar 23 stays pulled against the magnetic stop 37 under the influence of the coil 40.

For movement of the rod 20 in steps to the right the coils 40, 41, and 42 are deenergized and reenergized in the same order as the coils 43, 42, and 41, respectively, in the cycle previously described, the coil 43 remaining continuously energized as was the coil 40.

If the rod 20 is vertical rather than horizontal as shown, the various collars 23, 25, 30, and 31 will be pulled by gravity along the rod 20 when released from the magnetic fields. When all coils 40, 41, 42, and 43 are deenergized, the gripping units completely release the rod 20 so that it may move freely in either direction and will drop if vertical. It is contemplated that dropping of the rod will move neutron-absorbing material into the nuclear reactor, with resulting decrease in the level of reactivity.

It is contemplated that the apparatus of Figs. 1 and 2 may be operated in conjunction with the mechanism of Fig. 3 which is adapted to utilize the force of a loaded spring in support of gravity in the insertion of a neutron-absorbing rod in the reactor in the occurrence of emergency conditions. The mechanism of Fig. 3 should be visualized as being located to the left of Fig. 1, being spaced therefrom or being closely coupled thereto without change in the functional relationship of the apparatus and mechanism. The mechanism of Fig. 3 has a housing 46 which comprises a sleeve 47, an end fitting 48 having a threaded connection with one end of the sleeve 47, and an end fitting 49 welded or soldered to the other end of the sleeve 47. The end fitting 49 is welded or soldered to one end of a tube 50 having its other end welded or soldered to the end fitting 35 of the housing 32 of Fig. 1. The sleeve 47, end fittings 48 and 49, and tube 50 are formed of nonmagnetic material such as stainless steel.

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Within the sleeve is a magnetic stop 51 in the form of a tubular section of a material such as soft iron. The stop 51 is retained at one end of the sleeve 47 adjacent the end fitting 48 by means of a flange 52 on the stop 51 which is abutted by an internal shoulder on the sleeve 47 and by means of a ring 53 carried within the stop 51 and abutting the end fitting 48. The ring 53 is formed of non-magnetic material such as stainless steel and serves to position the rod 20 in the stop 51. The end of the stop 51 away from the flange 52 has a facing 54 of non-magnetic material such as stainless steel.

Also within the sleeve 47 is a tubular section 55 formed of a magnetic material such as soft iron. The tubular section 55 is urged away from the magnetic stop 51 by means of a coil spring 56 mounted on the tubular section and magnetic stop and having its ends in engagement with the flange 52 on the magnetic stop and with a shoulder 57 on the tubular section. Between the tubular section 55 and the rod 20 is a sleeve 58 of nonmagnetic material such as stainless steel. One end of the sleeve 58 projects beyond the end of the tubular section 55 facing the magnetic stop 51. The other end of the sleeve 58 is formed as an externally enlarged flange or ring 59 which is recessed at a plurality of peripherally spaced regions to receive a plurality of balls 60 and shoes 61. The end of the tubular section 55 is appropriately recessed to receive the enlarged flange 59, the balls 60, and shoes 61 and has a plurality of angled or inclined surfaces 62 in engagement with the balls 60. An annular cap 63 is secured by screws 64, and in the cap 63 there are a spring 65 of the bellows type and a pressure ring 66. The balls 60, shoes 61, cap 63, screws 64, spring 65, and pressure ring 66 are formed of nonmagnetic material such as stainless steel.

When the rod 20 is being moved to the left as viewed in Fig. 3, it moves the tubular section 55 to the left toward the magnetic stop 51 because of the action of the angled surfaces 62 in the recess in the tubular section 55 in making the balls 60 push the shoes 61 against the rod 20. Thus leftward movement of the rod 20 compresses and loads the spring 56. When the tubular section 55 comes quite close to the magnetic stop, the section is drawn toward the stop by a magnetic field set up by an energized magnetic coil 67 which surrounds the sleeve 47, the stop, and the section. However, the tubular section 55 cannot abut the stop 51 or the facing 54 thereon because of the protruding end of the sleeve 58. After the sleeve 58 engages the facing 54 on the stop 51, further leftward movement of the rod 20 can take place without corresponding movement of the tubular section 55, because the sleeve 58 is urged rightward with respect to the tubular section 55, bringing the balls 60 outward along the inclined surfaces 62 and relieving the pressure of the shoes 61 against rod 20. When the rod 20 is to move suddenly to the right as viewed in Figs. 1 and 3, all the coils 40, 41, 42, 43 and 67 are deenergized, causing the gripping units 21 and 22 to release the rod 20 and the tubular section 55 to be released from the magnetic stop 51. Now the spring 56 urges the tubular section 55 to the right. When the sleeve 58 loses contact with stop 51, the spring 65 shifts the balls 60 along the angled surfaces 62, causing the shoes to reengage the rod 20. So the rod 20 is moved rightward under action of the spring 56. When rightward movement has proceeded to the point of establishing engagement between the cap 63 and the end fitting 49, the tubular section 55 is of course stopped. Further movement of the rod 20 to the right tends to drag the shoes 61 to the right which in turn tend to move the balls 60 to the right to region of the angled surfaces at which the balls 60 will no longer press the shoes 61 against the rod 20. Thus the rod 20 can move farther to the right independently of the tubular section 55.

In the second form of apparatus of the present invention of Figs. 4 and 5, the rod 20 is embraced by two grip-

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ping units 68 and 69 which respectively comprise outer and inner collars 70 and 71 and outer and inner collars 72 and 73, each of the collars being formed of magnetic material such as soft iron. The gripping units 68 and 69 differ from the gripping units of Figs. 1 and 2 principally in being provided with coil springs 74 which urge the inner collars 71 and 73 away from the outer collars 70 and 72, respectively, and with coil springs 75 which urge the outer collars 70 and 72, respectively, away from magnetic stops 76 and 77, which constitute end fittings of a housing 78. The gripping units 68 and 69 also differ in that the outer collars 70 and 72 have separate slotted sleeve-like extensions 79 secured by pins 80 thereto. The extensions 79 are of magnetic material such as soft iron. The gripping units 68 and 69 also differ in that the inner collars 71 and 73 use rollers 81 to make the sleeve-like extensions 79 grip the rod 20. As shown in Figs. 4 and 5, the rollers 81 are held in peripherally spaced relation by cages 82 lodged between the sleeve-like extensions 79 and the inner collars 71 and 73. The springs 74 and 75, the pins 80, the rollers 81, and the cages 82 are formed of nonmagnetic material such as stainless steel. A washer 82a of nonmagnetic material such as stainless steel is positioned on the rod 20 between the inner collars 71 and 73.

The housing 78 includes, besides the magnetic stops 76 and 77, a sleeve 83 which is formed of nonmagnetic material such as stainless steel and has its ends soldered or welded to the magnetic stops. Around the sleeve 83 four magnetic coils 84, 85, 86, and 87 are mounted. Coil 84, termed an outer coil, is relatively short and overlaps the outer collar 70 and the magnetic stop 76. Coil 85, termed an inner coil, is relatively long and extends the full length of the inner collar 71 and overlaps the outer collar 70. Coil 86, termed an inner coil, is relatively long and extends the full length of the inner collar 73 and overlaps the outer collar 72. Coil 87, termed an outer coil is relatively short and overlaps the outer collar 72 and the magnetic stop 77. The coils 84, 85, 86, and 87 are embraced by a split sleeve 88 of magnetic material such as soft iron, which sleeve is mounted at its ends on flanged rings 89 which are formed of magnetic material such as soft iron and are carried by the magnetic stops 76 and 77 and secured thereto by soldering or welding. Coils 84 and 85 are energized to produce magnetism in one direction, and coils 86 and 87, in the opposite direction. The coils 84, 85, 86 and 87 are energized by a power source through individual switches (not shown) in a manner similar to that described for the first embodiment shown in Figures 1 and 2. The magnetic stop 76 is welded or soldered to the nonmagnetic tube or sleeve 35a which is adapted to be connected with the reactor so as to communicate with a section thereof in which there may be fluid under pressure. The magnetic stop 77 is welded or soldered to the nonmagnetic tube 50 which can be directly capped at its ends or connected to the spring-loaded device of Fig. 3 which is capped by the end fitting 48.

Let it be assumed that the rod 20 is to be moved by the apparatus of Figs. 4 and 5 in steps to the left. At the start of a cycle each of coils 84, 85, 86, and 87 is energized so that in each of the gripping units 68 and 69, the outer collar is pulled against the spring 75 toward the associated magnetic stop and the inner collar is urged against the spring 74 toward the outer collar. Thus both gripping units grip the rod 20. Now the coils 86 and 87 are deenergized, with the result that the spring 74 urges the collars 72 and 73 apart and the sleeve-like extension 79 is caused to release the rod 20. Springs 74 and 75 and the pull of collar 71 produced by the coil 85 move the collar 73 to the right along the rod 20. Now the coil 86 is reenergized with the result that 72 is pulled rightward toward the collar 73 and the roller 81 make the sleeve-like extension on the collar 72 regrip the rod 20. Now the coil 87 is reenergized, and the coil 85 is deenergized.

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The stop 77 under influence of coil 87 moves collar 72 to the left and collar 72 under influence of coil 86 moves collar 73 to the left. Thus collars 72 and 73 move conjointly leftward toward the magnetic stop 77 while maintaining the grip of the associated extension 79 on the rod 20 and so shift the rod 20 to the left. The rod 20 can move to the left, because the gripping unit 68 has released the rod by virtue of deenergization of coil 85 and movement of the collar 71 away from the collar 70 under the action of the associated spring 74. Now the coil 85 is reenergized, and a new cycle can begin. The coil 84 has remained energized throughout the cycle. When the rod 20 is to be moved in steps to the right, the described cycle of deenergization and reenergization of the coils 87, 86, and 85 is performed on the coils 84, 85, and 86, respectively.

The apparatus of Figs. 4 and 5 is capable of being used with the rod 20 extending vertically so that gravity can aid the shifting of the collars 70, 71, 72, and 73 along the rod.

The third form of apparatus of the present invention of Figs. 6 to 9 differs from the first and second forms in that each of gripping units 90 and 91 is composed of a single tubular element 92 which flexes or becomes distorted under magnetic forces applied thereto so as to grip the rod 20 which passes therethrough. Each tubular element 92 is slotted longitudinally and transversely so as to comprise two relatively short aligned sections 93 of slightly less than semi-cylindrical extent well spaced from one another so as to form a very wide transverse gap or slot 94, two relatively long aligned sections 95 of slightly less than semi-cylindrical extent slightly spaced from one another so as to form a very narrow transverse gap or slot 96, and two thin longitudinally extending diametrically opposed spring strips 97 which are connected at their ends to the sections 93 and 95 and are elsewhere spaced therefrom so as to form longitudinal gaps or slots 98. The regions at which the ends of the strips 97 are connected form junctures between the outer ends of the sections 93 and 95 at their sides. Each end of each tubular section 92 is provided on the inner side with an outer annular rib 99 and an inner annular rib 100. Each of the ribs 99 and 100 has a protuberance 101, the circumferential length of which is illustrated in Fig. 9 for one of the ribs 99. The protuberances 101 on the ribs 100 lie on the same side of the rod 20 as the wide transverse slot 94, and the protuberances 101 on the ribs 100 lie in diametrically opposed relation to the protuberances on the ribs 99.

The gripping units 90 and 91 are separated at their inner ends by a flanged annular disk 102 of nonmagnetic material such as stainless steel, a plain annular disk 103 of magnetic material such as soft iron, and a cushion 104 between the disks 102 and 103. At the outer end of each of the gripping units 90 and 91 there are a flanged annular disk 105 of magnetic material such as soft iron and a cushion 106. Each of the cushions 104 and 106 comprises two concentric stacks of Belleville washers each of which is of magnetic material such as soft iron except for a central washer in each stack which is of nonmagnetic material such as stainless steel. Beyond each cushion 106 which is beyond the associated disk 105 there is a magnetic stop, the one adjacent the gripping unit 90 being designated 107 and the one adjacent the gripping unit 91 being designated 108. The magnetic stops 107 and 108, which may be of soft iron, form end fittings of a housing 109 which includes a sleeve 110 of nonmagnetic material such as stainless steel soldered or welded at its ends to the magnetic stops 107 and 108. The magnetic stop 107 is welded or soldered to the nonmagnetic sleeve 35a which is adapted to be connected with the reactor so as to communicate with a section thereof in which there may be fluid under pressure. The magnetic stop 108 is welded or soldered to the nonmagnetic

tube 50 which may be capped directly or connected to the spring-loaded device of Fig. 3 which is capped by the end-fitting 48.

Mounted on the exterior of the sleeve 110 are an outer coil 111 which overlaps the magnetic stop 107 and the outer end of the gripping unit 90, an inner coil 112 which surrounds the gripping unit 90 at the transverse slots 94 and 96, a central coil 113 which overlaps the inner ends of the gripping units 90 and 91, an inner coil 114 which surrounds the gripping unit 91 at the transverse slots 94 and 96, and an outer coil 115 which overlaps the magnetic stop 108 and the outer end of the gripping unit 91. Each of the coils 111, 112, 113, 114, and 115 is housed in an annular casing 116, which has its ends and outer side formed of a magnetic material such as soft iron and its inner side formed of a nonmagnetic material such as stainless steel. The casings 116 of the coils are separated by rings 117 which embrace the sleeve 110 and are formed of magnetic material such as soft iron. Spiral tubing 118 for a coolant is mounted in each of the coils. Each of the coils 111, 112, 113, 114, and 115 is energized to create magnetism in the same direction in a manner similar to that described for the first embodiment shown in Figures 1 and 2.

Let it be assumed that the rod 20 is to be moved in steps to the left as viewed in Fig. 6 by the apparatus of Fig. 6. At the start of a cycle, coils 111, 112, 114, and 115 are energized and the coil 113 is deenergized. The coils 112 and 114 bend or distort the gripping units 90 and 91 so that the narrow gaps 96 are made narrower and the protuberances 101 on the ribs 99 and 100 engage the rod 20. The gripping unit 90 is held to the right as far as possible by being urged toward the magnetic stop 107 by the magnetic field set up by the outer coil 111. The gripping unit 91 is held to the left as far as possible by being urged toward the magnetic stop 108 by the magnetic field set up by the outer coil 115. Now the coils 114 and 115 are deenergized, and the gripping unit 91 moves to the right under the pull of gravity if the rod 20 is vertical and the gripping unit 91 is above the gripping unit 90. The central coil 113 is energized to pull the gripping unit 91 to the right in the event that it does not move with gravity if the rod 20 is horizontal. Coil 114 is reenergized to distort the gripping unit 91 again and make it grip the rod 20. Coils 112 and 113 are deenergized to make it possible for the gripping unit 91 to shift the rod 20 leftward, and this action occurs when the coil 115 is reenergized to move the gripping unit 91 toward the magnetic stop 108. Now coil 112 is reenergized, and the cycle has been completed. Coil 111 has remained energized throughout the cycle, and consequently the gripping unit has remained as far to the right as possible, being drawn toward the magnetic stop 107.

When the rod 20 is to be moved to the right in steps, the cycle of deenergization and reenergization is carried out on the coils 111, 112, 113, and 114 in the manner just described for the coils 115, 114, 113, and 112, respectively.

In an alternate method of operation in which the outer coil 111 or 115 remains energized for movement of the rod 20 out of the end of the apparatus at which the particular outer coil lies, the procedure is as follows, for example, for movement out of the end of the apparatus at which the outer coil 111 is located: Coils 111, 112, 114, and 115 are energized at the outset, causing the gripping units 90 and 91 to hold the rod 20. Coil 112 is deenergized, causing gripping unit 90 to release the rod 20. Now coil 115 is deenergized and coil 113 is energized, causing the gripping unit 91 to move rightward while holding the rod 20, which is also moved rightward. Now coil 112 is reenergized, causing the gripping unit 90 to renew its hold on the rod 20. Now the coil 114 is deenergized, causing the gripping unit 91 to release the rod 20. Now the coil 113 is deenergized and the coil 115 is reenergized, causing the gripping unit 91 to move left-

ward along the rod 20. Now the coil 114 is reenergized, and the cycle of operation has been completed.

This method of operation for movement of the rod 20 in one direction is advantageously combined with the previously described method of operation for movement of the rod in the opposite direction for one outer coil, either 111 or 115, remains continuously energized, and so the controls for energizing and deenergizing the various coils are relatively simple.

The cushions 104 and 106 between the gripping units 90 and 91 and at their outer ends not only protect the apparatus against shock, but also prevent slipping of the rod 20 in the gripping units. Without the cushions 104 and 106, the shock of an abrupt stop would tend to cause the rod 20 to slip within the gripping units 90 and 91 because of its own inertia.

In the apparatus of Figs. 10 and 11 each of gripping units 119 and 120 comprises four segments 121 which are formed of magnetic material such as soft iron and extend longitudinally of the rod 20 about which they are distributed in equally spaced relationship. Each segment has an arcuate outer side 122 and a pair of transverse portions 123 toward or near its ends, which portions extend transversely of the rod 20 from the inner side of the segment and receive the rod in openings 124 which loosely fit the rod. The transverse portions 123 of the various segments 121 of the gripping unit 119 or 120 are at various locations adjacent the ends of the segments so as to be arranged one after another along the rod 20 without interference with one another, as shown in Fig. 10. Between the gripping units 119 and 120 there is a cushion 125 positioned on a short sleeve 126 of nonmagnetic material such as stainless steel. At the outer ends of the gripping units 119 and 120 there are cushions 127 positioned on short sleeves 128 of nonmagnetic material such as stainless steel. Each of the cushions 125 and 127 comprises two concentric stacks of Belleville washers each of which is formed of magnetic material such as soft iron except for a central disk in each stack which is formed of nonmagnetic material such as stainless steel.

The gripping units 119 and 120 are positioned in a housing 129 which is formed of magnetic material such as soft iron and comprises a sleeve 130, a magnetic stop 131 integral with one end of the sleeve 130, and a separately formed magnetic stop 132 inserted in the other end of the sleeve 130 and soldered or welded thereto. The sleeve 130 has a plurality of exterior annular grooves distributed in spaced relation along the sleeve, the grooves receiving an outer coil 133, inner coils 134, 135, 136, and 137, a central coil 138, inner coils 139, 140, 141, and 142, and an outer coil 143. The outer coil 133 overlaps the magnetic stop 131 and the outer end of the gripping unit 119. The inner coils 134, 135, 136, and 137 surround the gripping unit 119 between its ends. The central coil 138 overlaps the inner ends of the gripping units 119 and 120. The inner coils 139, 140, 141, and 142 surround the gripping unit 120 between its ends. The outer coil 143 overlaps the magnetic stop 132 and the outer end of the gripping unit 120. The coils 133-143 are enclosed by two semi-cylindrical shells 144 of magnetic material such as soft iron secured to the sleeve 130 by screws 145.

When energized, the coils 133-143 set up magnetic fields acting alternately in opposite directions; that is, the magnetic field of coils 133, 135, 137, 139, 141, and 143 act in one direction, and the magnetic fields 134, 136, 138, 140, and 142 act in the opposite direction, and are so energized by means of a power source and switches substantially as shown and described in the first embodiment of the invention of Figures 1 and 2. The magnetic stop 131 is connected by soldering or welding to a fitting 146 which is formed of nonmagnetic material such as stainless steel. The fitting 146 is soldered or welded to the nonmagnetic sleeve 35a which is adapted to be connected with the reactor so as to communicate with a sec-

tion thereof in which there may be fluid under pressure. The end of the sleeve 130 at which the magnetic stop 132 is mounted is welded or soldered to a fitting 147 which is formed of nonmagnetic material such as stainless steel. The fitting 147 is welded or soldered to the nonmagnetic tube 50, which may be capped directly or connected to the device of Fig. 3 which is capped by the end fitting 48.

Let it be assumed that the rod 20 is to be moved to the left by the apparatus of Figs. 10 and 11. All but the central coil 138 is energized at the start of a cycle. Energization of coils 134 to 137 and coils 139 to 142 pulls the segments 121 radially outward toward the coils and produces a gripping engagement between the transverse portions 123 of the segments 121 and the rod 20. Gripping units 119 and 120 are, respectively, in positions as far to the right and as far to the left as possible as viewed in Fig. 10, because energization of outer coils 133 and 143 has drawn the gripping units 119 and 120 toward the magnetic stops 131 and 132, respectively. Now coils 139 to 143 are deenergized and coil 138 is energized so that the gripping unit 120 is shifted along the shaft to the right, because the gripping unit has released its hold on the rod, and the magnetic stop 132 no longer pulls the gripping unit. Now the coils 139 to 142 are reenergized to renew the hold of the gripping unit 120 on the rod 20. Now coil 138 is deenergized and coil 143 is reenergized so that the gripping unit 120 may move to the left. Simultaneously coils 134 to 137 are deenergized to release the hold of the gripping unit 119 on the rod 20 so that the gripping unit 120 when moved to the left as aforesaid moves the shaft to the left. Now the coils 134 to 137 are reenergized, and a cycle has been completed. Throughout the cycle, coil 133 has remained energized and consequently the gripping unit 119 has been held against shifting along the length of the shaft 20.

The rod 20 may be moved in steps to the right by the apparatus of Figs. 10 and 11 by a cycle of energization and deenergization in which the coils 134 to 137, coil 133, coil 138, and coils 139 to 142 are deenergized and energized in the manner described for the coils 139 to 142, coil 143, coil 138, and coils 134 to 137, respectively.

Shifting of the rod 20 in steps may take place when the rod is vertical or horizontal.

The cushions 125 and 127 between the gripping units 119 and 120 and at their outer ends not only protect the apparatus of Figs. 10 and 11 against shock, but also prevent slipping of the rod 20 in the gripping units. Without the cushions 125 and 127, the shock of an abrupt stop would tend to cause the rod 20 to slip within the gripping units 119 and 120 because of the rod's own inertia.

There is an alternate method of operation of the apparatus of Figs. 10 and 11 which method is similar to the alternate method described for the apparatus of Figs. 6 to 9 in that outer coil 133 or 143 remains energized for movement of the rod 20 out of the end of the apparatus at which the outer coil 133 or 143 is located. Let it be assumed that the rod 20 is to move to the right while the outer coil 133 at the right end remains energized. At the outset coils 133—137 and 139—143 are energized so that both gripping units 119 and 120 hold the rod 20. Now coils 134—137 are deenergized, causing gripping unit 119 to release the rod 20. Now coil 138 is energized and coil 143 is deenergized, causing the gripping unit 120 to move rightward while holding the rod 20, which is also moved rightward. Now coils 134—137 are reenergized, causing gripping unit 119 to renew its hold on the rod 20. Now coils 139—142 are deenergized, causing gripping unit 120 to release its hold on the rod 20. Now coil 138 is deenergized and coil 143 is reenergized, causing the gripping unit 120 to move leftward along the rod 20. Now coils 139—142 are reenergized, and the cycle is completed.

In all the forms of the invention disclosed in present application the rod 20 which is to be adjusted is mounted in a sealed enclosure which includes the tubes 35a and

50 and the housing 32 (Fig. 1), 78 (Fig. 4), 109 (Fig. 6), or 129 (Fig. 10), on which the magnetic coils are externally mounted for controlling gripping units that lie within the housing in engagement with the rod 20. Thus there need be no moving part going through a seal, and the problem of preventing the escape of fluid from the reactor is considerably simplified, in spite of the fact that the rod 20 to be adjusted lies within the tube 35a which has been indicated as being connectable with a section of the reactor in which there may be fluid under pressure.

The intention is to limit the invention only within the scope of the appended claims.

What is claimed is:

15 1. Apparatus for moving a rod in steps, comprising two gripping units surrounding the rod, each gripping unit comprising two magnetizable sections arranged to grip the rod when moved in one direction with respect to one another and to release the rod when moved in the opposite direction with respect one another, a first set of two coils surrounding one gripping unit, a second set of two coils surrounding the other gripping unit, means for energizing the first set of coils to produce a magnetic force in one direction along the rod, and means for energizing the second set of coils to produce a magnetic force in the opposite direction along the rod, the coils of each set being separately or conjointly energizable.

2. Apparatus for moving a rod in steps, comprising two gripping units formed of magnetic material and surrounding the rod, a first set of two outer and inner coils surrounding one gripping unit, a second set of two outer and inner coils surrounding the other gripping unit, the inner coil of each set being closer to the coils of the other set than is the outer coil, the various coils occupying different positions lengthwise of the rod, means for energizing the inner coil of the first set to make the said one gripping unit grip the rod, and means for energizing the outer coil of the first set to make the same pull the said one gripping unit and the rod while gripped thereby in a direction away from said other gripping unit.

3. The apparatus specified in claim 2, each gripping unit comprising inner and outer collars disposed respectively opposite the inner and outer coils of the associated set, and means cooperating with the collars for causing movement of the collars toward one another to produce gripping of the rod and movement of the collars away from one another to bring about releasing of the rod.

4. The apparatus specified in claim 2, each gripping unit comprising inner and outer collars disposed respectively opposite the inner and outer coils of the associated set, the outer collar having a slotted sleeve-like extension within the inner collar, the inner collar having in the end away from the outer collar a recess provided with a conical wall spaced outward from the extension, and a plurality of balls located in the recess in engagement with the conical surface and the extension, whereby movement of the collars toward one another causes the conical surface to press the balls against the sleeve-like extension and the sleeve-like extension against the rod.

5. The apparatus specified in claim 2, each gripping unit comprising inner and outer collars disposed respectively opposite the inner and outer coils of the associated set, the outer collar having a slotted sleeve-like extension within the inner collar, the inner collar having in the end away from the outer collar a recess provided with a conical wall spaced outward from the extension, and a plurality of rollers located in the recess in engagement with the sleeve-like extension and with surfaces of the recess spaced radially outward from the extension, a cage lodged between the inner collar and the sleeve-like extension for retaining the rollers in peripherally spaced relation between the inner collar and the extension, whereby movement of the collars toward one another causes the rollers to press the sleeve-like extension against the rod for gripping, and a spring urging the collars apart where-

by the rollers permit the sleeve-like extension to release the rod.

6. The apparatus specified in claim 2, each gripping unit comprising a tubular element having longitudinal and transverse slots, the transverse slots being approximately midway between the ends of the tubular element, the transverse slot on one side being very wide and the transverse slot on the other side being very narrow, whereby energization of the inner coil of the associated set transversely distorts the tubular element to bring about engagement between the ends of the tubular element and the rod.

7. The apparatus specified in claim 6, the tubular element comprising two short and two long semi-cylindrical sections and two straps, one short section being joined to one long section on both sides at one end of the tubular element, the other short section being joined to the other long section at the other end of the tubular element, the straps extending longitudinally of the tubular element in diametrically opposed relation to one another and having their ends secured to the sections at their junctions with one another, the short sections being aligned with one another and forming the said very wide transverse slot between them, the long sections being aligned with one another and forming the said very narrow slot between them.

8. The apparatus specified in claim 7, the inner coil of each set surrounding the associated gripping unit at the wide and narrow transverse slots thereon, the outer coil of each set surrounding and extending beyond the outer end of the associated gripping unit, the apparatus further comprising a central coil positioned between the inner coils in overlapping relation with the inner ends of the tubular elements.

9. The apparatus specified in claim 8 and further comprising a housing mounting the coils and enclosing the gripping units and having openings in its ends through which the rod extends, and three cushioning means, a first acting between the gripping units, a second acting between one gripping unit and the adjacent end of the housing, and a third acting between the other gripping unit and the other end of the housing.

10. The apparatus specified in claim 2, each gripping unit comprising a plurality of magnetic segments distributed about the rod and extending longitudinally thereof, each segment having a pair of transverse longitudinally spaced portions provided with openings loosely receiving the rod, whereby the segments of a given gripping unit are shifted transversely of the rod through energization of the associated inner coil and cause the rod to be gripped by the said transverse portions of the segments at their openings.

11. The apparatus specified in claim 10 and further comprising a housing mounting the coils and enclosing the gripping units and having openings in its ends through which the rod extends, each inner coil taking the form of four coils separated from one another and from the associated outer coil lengthwise of the rod by magnetizable material of the housing, the apparatus further comprising a central coil mounted in the housing around the inner ends of the gripping units and being spaced from the innermost ones of the inner coils by magnetizable material of the housing, and means for energizing the eleven coils forming the outer, inner, and central coils to produce magnetism acting in opposite directions from one of the eleven coils to the next.

12. The apparatus specified in claim 10 and further comprising a housing mounting the coils and enclosing the gripping units and having openings in its ends through which the rod extends, and Belleville washers acting as cushions between the gripping units, between one gripping unit and the adjacent end of the housing, and between the other gripping unit and the adjacent end of the housing.

13. Apparatus for returning a rod quickly to an original position, said apparatus comprising first and second sleeves of permeable material surrounding the rod, a spring urging the sleeves apart, means holding the first sleeve against movement, means fixing the second sleeve to the shaft, means responsive to movement of the second sleeve into immediate adjacency to the first sleeve for releasing the fixing means to free the second sleeve from the rod, and means for passing magnetic flux through the sleeves to hold them in immediate adjacency with one another and thus to keep the second sleeve freed from the rod.

14. Apparatus for moving a rod in steps, comprising a gripping unit formed of magnetic material and surrounding the rod, a gripper coil surrounding said gripping unit, a mover unit formed of magnetic material surrounding said rod and adjacent to said gripping unit, a mover coil surrounding said mover unit, means for energizing the gripper coil to make said gripping unit grip the rod and means for energizing the mover coil to make said mover unit pull said gripping unit and said rod towards said mover unit.

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