May 3, 1960 M. J. POLLAK 2,935,663

MAGNETIC ACTUATORS

Filed April 4, 1958 2 Sheets-Sheet 1

Fig. 1

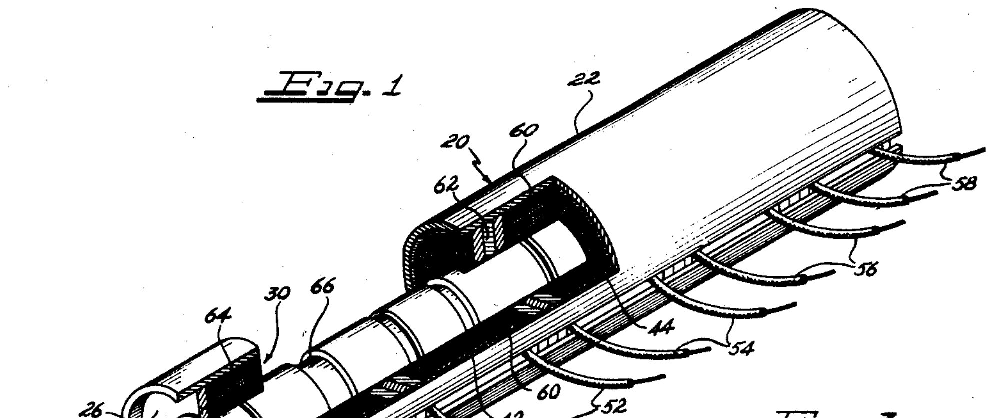


Fig. 3

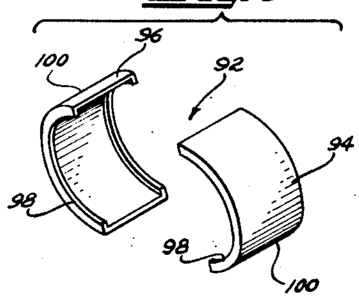
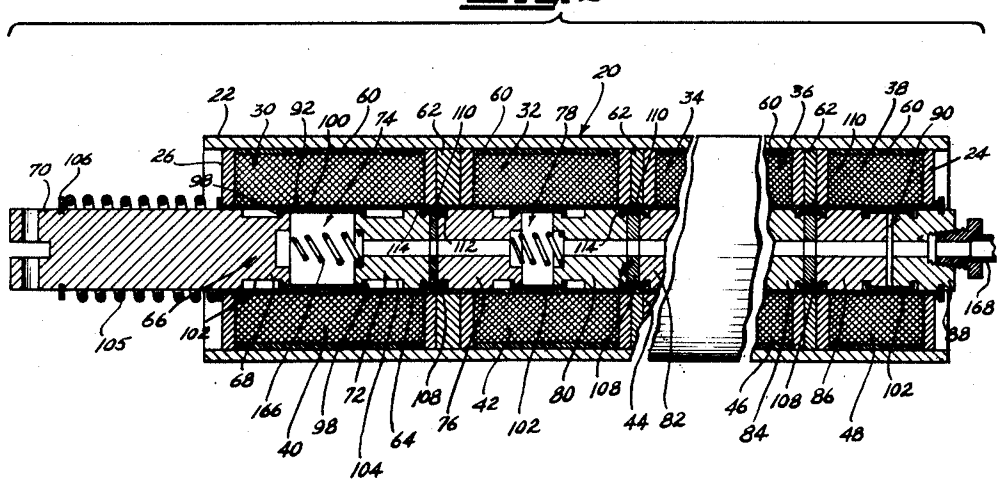


Fig. 2



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MAGNETIC ACTUATORS

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Fig. 4

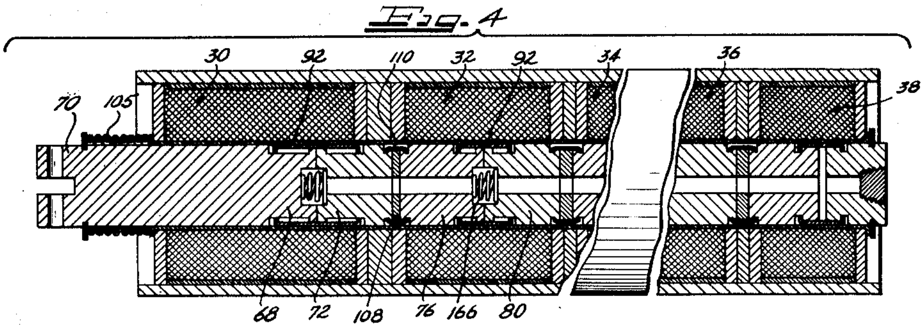


Fig. 5

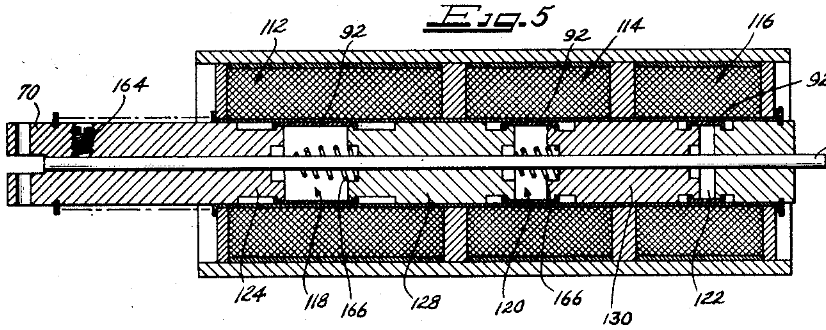


Fig. 6

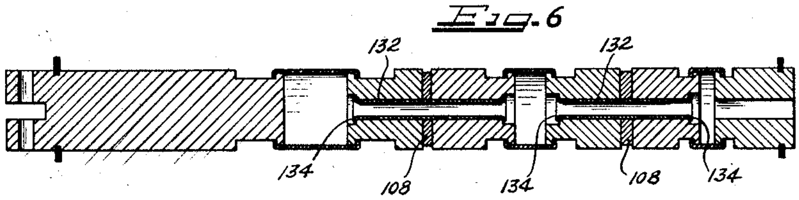


Fig. 8

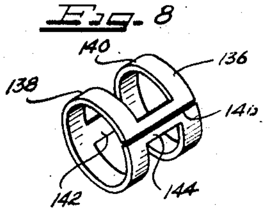


Fig. 7

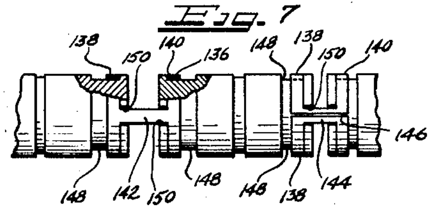


Fig. 10

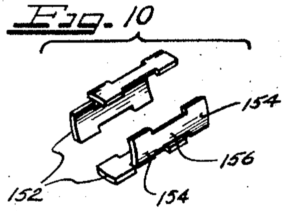
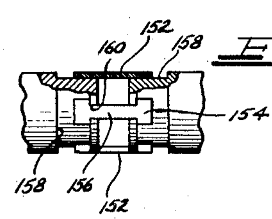


Fig. 9



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MAGNETIC ACTUATORS

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Application April 4, 1958, Serial No. 726,383

8 Claims. (Cl. 317—190)

My invention relates to magnetic actuators and more particularly relates to magnetic actuators having an output member, the mechanical positionment of which is controlled by the energization of one or more or any combination of electrical solenoids.

In general, the magnetic actuator of my invention is used to mechanically position an output member, and mechanism controlled thereby, in accordance with electrically coded information. The actuator comprises two or more electromagnetic solenoids each having a coil and a two piece magnetic core or armature separated by an air gap. One of the cores of each solenoid is adapted to move against the other core of the solenoid and close the air gap on energization of the coil, the former core being hereinafter referred to as the movable core and the latter being referred to as the relatively fixed core. The movable core of a first solenoid is connected to the output member and the relatively fixed core is connected to the movable core of an adjacent second solenoid. The relatively fixed core of the second solenoid may then be connected to the movable core of an adjacent third solenoid, etc.

The electrically coded information supplied to the actuator may take many different forms and the construction and arrangement of the actuator will vary in accordance therewith, and in particular the size of the air gaps, and therefore the extent of travel of the movable core piece of each solenoid will vary in accordance with the type of electrical information that is to be transformed into mechanical movement. In the actuator illustrated in this application, binary coded electrical information is used so that the output member of the actuator is displaced in accordance with quantities represented by the binary coded electrical information.

An object of my invention is to provide a magnetic actuator which is inexpensive to manufacture, easy to assemble, requires only low cost tooling, and minimizes the necessity of precision machining and tooling.

Another object of my invention is to provide a magnetic actuator which has an especially long life throughout which a high degree of accuracy is maintained by minimizing the effects of wear.

A further object of my invention is the provision of a magnetic actuator having novel connecting means between the movable core and the relatively fixed core of a solenoid, which connecting means allow the cores to be drawn together to close the air gap and allow precise control of the size of the open air gap.

A still further object of my invention is to provide an actuator having novel connecting means disposed about the outside or periphery of adjacent cores whereby:

(1) Uniformity in the length of the air gap is obtained with minimal precision machining and simple tooling.

(2) The greatest possible size reduction is obtainable for purposes of miniaturization without affecting efficiency.

(3) The central areas of the cores and the air gap are free of any mechanical connecting devices so that springs or other impact reducing means may be used between the cores.

(4) The center of the cores and air gap are free of inter-connecting mechanism so that a push rod may be arranged axially to allow both "push" and "pull" operation.

(5) Hydraulic damping may be readily used.

(6) Dirt and other foreign matter is prevented from entering the air gap.

(7) Uniform air gap length is maintained during use without the necessity of service adjustments.

Another object of my invention is to provide a combined air gap size control spacer and connecting means between adjacent cores, which is capable of low cost manufacture on conventional tooling, but which affords a high degree of precision.

A further object of my invention is to provide novel means for connecting adjacent cores of adjacent solenoids, which connecting means:

(1) Can be manufactured at low unit cost on inexpensive tooling.

(2) Securely fastens the adjacent cores together and holds a diamagnetic spacer therebetween.

(3) Leaves the center area of the cores free of any mechanism.

These and other objects and advantages will become readily apparent as this description proceeds and is read in connection with the attached drawings on which:

Fig. 1 is a perspective view of the actuator of my invention with parts broken away.

Fig. 2 is a sectional view taken through Fig. 1.

Fig. 3 is a detailed view showing one of the connectors shown in Figs. 1 and 2 for inter-connecting the movable and relatively fixed cores of the solenoids.

Fig. 4 is a view similar to Fig. 2 but showing two of the solenoids energized.

Fig. 5 is a sectional view showing another form of my invention wherein the connecting means between adjacent solenoids is eliminated and a single core piece is used.

Fig. 6 is a sectional view of a core assembly showing another form of my invention wherein adjacent cores of adjacent solenoids are inter-connected through an axial tubular rivet arrangement.

Fig. 7 is a partial sectional view of a core assembly showing another form of the core connector member.

Fig. 8 is a detailed perspective view of the connector member of Fig. 7.

Fig. 9 is a partial sectional view of a core assembly showing still another form of the core connector.

Fig. 10 is a detailed perspective view showing the core connector of Fig. 9.

Referring now to Figs. 1 and 2 of the drawings, the magnetic actuator is generally designated by the numeral **20** and comprises an outer cylindrical jacket **22** having a righthand closure plate **24** and a lefthand closure plate **26**. The closure plates are secured within jacket **22** by any conventional means. In Figs. 1 and 2, the magnetic actuator is shown to have 5 separate solenoids, each having an electrical coil and a movable and a relatively fixed core piece. The first or lefthand solenoid is designated by the numeral **30** and the second through fifth solenoids are generally designated by the numerals **32**, **34**, **36** and **38**. The coils of these respective solenoids are indicated by the numerals **40**, **42**, **44**, **46** and **48**, and the lead wires are designated by the numerals **50**, **52**, **54**, **56** and **58**. These lead wires pass through jacket **22** for external connection to any suitable voltage supply source. Coils **30**, **32**, **34**, **36** and **38** each have a suitable cover member

60 and the coils of the several solenoids are separated by spacers 62. Since end plates 24 and 26 are secured to jacket 22, the coils of solenoids 30, 32, 34, 36 and 38 are held in place. A central tube 64, best seen in Fig. 2, extends throughout the length of the solenoids and is swaged over at the outside face of plates 24 and 26 to hold the tube in place with the coils in proper position.

A core assembly, generally designated 66, is mounted within tube 64 and, as hereinafter explained, provides two core pieces for each solenoid. Referring now to first solenoid 30, it will be seen that a movable core 68 is arranged within coil 40 and is connected to an output member 70 and, by way of example, in the drawings movable core piece 68 and output member 70 are shown to be integral. A relatively fixed core 72 is also provided within coil 40 of solenoid 30. In Fig. 2, coil 40 is shown to be in a de-energized state and, therefore, an air gap 74 exists between cores 68 and 72. As will be hereinafter described, relatively fixed core 72 of solenoid 30 is connected to movable core 76 of solenoid 32 and, since coil 42 is shown in a de-energized state, an air gap 78 exists between movable core 76 and the relatively fixed core 80 of solenoid 32. In turn, relatively fixed core 80 is connected to movable core 82 of solenoid 34. Neither the relatively fixed core of solenoid 34 or the movable core of solenoid 36 are shown in the drawings but they are interconnected in the same way heretofore described. Referring to Fig. 2, it will be seen that the relatively fixed core 84 of solenoid 36 is connected to movable core 86 of solenoid 38, and the relatively fixed core 88 of solenoid 38 is secured to end plate 24 of actuator 20. Air gap 90 is shown in solenoid 38, since coil 48 of this solenoid is de-energized.

The two cores of each solenoid are interconnected in such a way as to allow the core pieces to be drawn together to close the air gap upon energization of the coil and on de-energization to enable the core pieces to move apart a limited fixed distance which represents the length of the air gap. I have provided a novel core connector which accomplishes this purpose. Referring to Figs. 2 and 3, it will be seen that the connector, generally designated 92, comprises two half rings 94 and 96 each having inwardly depending flange 98 on the edges thereof, interconnected by faces 100. Cores 68 and 72 of solenoid 30 are respectively provided with annular grooves 102 and 104 in their outer faces. In the assembled position, flanges 98 of connector 92 extend within grooves 102 and 104. Similar connectors 92 are shown for the remaining solenoids.

A spring 105 is arranged under compression between end plate 26 of the actuator and a washer 106 provided on output member 70.

In operation of my actuator, when all of the coils are de-energized, spring 105 urges output member 70 to the left, as viewed in Figs. 1 and 2, and this in turn positions movable core 68 of solenoid 30 in the manner shown in Fig. 2. Since the flange 98 of connector 92 bears against the side wall of annular groove 102 of core 68, relatively fixed core 72 will be pulled into the position shown in Fig. 2 by virtue of the fact that flange 98 bears against the side wall of annular groove 104 in core 72. Since core 72 is connected to core 76 of solenoid 32, it will be, in turn, positioned in accordance with Fig. 2, and in the same manner as heretofore described the movable cores and the relatively fixed cores of the remaining solenoids will be positioned as shown due to the interaction of the several connectors 92 and the cooperating annular grooves on the cores. In summary, with all coils de-energized, spring 105 exerts sufficient force through the "chain-like" core assembly to open all air gaps.

When the coil of any of the solenoids is energized, the air gap of that solenoid will be closed by movement of the movable core against the relatively fixed core and this corresponding movement will be transmitted to the output member 70. For example, referring to Fig. 2, if coil 40 of the first solenoid 30 is energized, core 68 will move to the right closing air gap 74 and this in turn will move output member 70. If coil 42 of solenoid 32 were energized rather than the first solenoid, movable core 76 will move to the right closing air gap 78 and this in turn will move relatively fixed core 72 of solenoid 30 to the right an equal distance. Since connector 92 of solenoid 30 connects together cores 68 and 72 of solenoid 30 by means of the flanges on connector 92 and the annular grooves in the cores, output member 70 will be moved to the right a distance equal to the length of the air gap 78 in solenoid 32. Likewise, if any one of the solenoids to the right of solenoid 32 is energized, output member 70 will be moved to the right a distance equal to the length of the air gap of the particular solenoid which is energized.

Referring now to Fig. 4, it will be seen how my actuator serves as a totalizer in which the movement of output member 70 will represent the sum total of the air gap lengths for all solenoids enregized. In Fig. 4, solenoids 30 and 32 are shown to be energized. Thus, as previously described, when solenoid 30 is energized, movable core 68 will move to the right to close the air gap moving output member 70 therewith. At the same time, the magnetic forces exerted between cores 68 and 72 will hold the cores together and make them act as an integral piece. The voltages to be applied to the various solenoids will usually be applied simultaneously but can be applied in any particular sequence without affecting the operation. Assuming that the energizing voltage for solenoid 32 is applied at the same time as the voltage applied to solenoid 30, movable core 76 of solenoid 32 will be attracted against relatively fixed core 80 and this, in turn, moves the core pieces of solenoid 30 and the output member 70 to the right a distance equal to the length of the air gap of solenoid 32. The positionment of the other cores to the right of solenoid 32 will in no way be affected. Thus, in summary, it will be seen that energizing solenoids 30 and 32 will move output member 70 a distance equal to the length of the air gap of solenoid 30 plus the length of the air gap of solenoid 32. If any one or more of the other solenoids are energized, output 70 will be moved an added distance equal to the length of the air gap of whichever solenoid is energized.

Strictly for purposes of illustration, the actuators I have shown in the drawings are for use in transmitting binary coded electrical information into digital mechanical displacement of the output member. By using five solenoids and binary coded electrical information, 32 distinct mechanical positions of the output member 70 can be achieved. To accomplish this, the length of the air gap for solenoid 38 is such that its closure represents one increment of movement of the output member. The length of the air gap of solenoid 36 is made equal to two increments of movement, and the length of the air gaps of solenoids 34, 32 and 30 are made respectively equal to 4, 8 and 16 increments of movement of output member 70. Thus by way of example and referring to Fig. 4, it will be seen that solenoids 30 and 32 are energized and, since solenoids 30 and 32 relate respectively to 16 and 8 increments of movement of the output member, the output member will be moved a total of 24 increments.

Upon de-energization of one or more of the solenoids, the air gap of that solenoid or solenoids will snap open under the action of spring 105. To illustrate this, and assuming by way of example that solenoid 32 of Fig. 4 is de-energized, the magnetic forces holding cores 76 and 80 together will be released. Immediately spring 105 will move the output member to the left. This, in turn, moves core 68 of solenoid 30 to the left and, since we are assuming that solenoid 30 is still energized, core 72 of solenoid 30 will also move to the left and this, in turn, opens the air gap of solenoid 32 by moving core 76 to the left. If both solenoids 30 and 32 of Fig. 4 were de-energized, the magnetic forces holding the respective cores of these solenoids together would vanish and spring 105 would first open the air gap of solenoid 30. When this air gap is opened, ring connector 92 of solenoid 30 will then serve as a connection between cores 68 and 72 and will pull core 72 of solenoid 30 and core 76 of solenoid 32 to the left, thereby opening the air gap of solenoid 32. It must be understood that connector 92 controls the distance the core of a solenoid can move apart and therefore controls the air gap length.

It is important to appreciate that all voltages may be applied and removed simultaneously and, in this condition, the output member will move from a zero position to a position representing the voltages and then back to a zero position, or the voltages can be applied and removed in any given order and the output member will only move from one representative position to another without necessitating its return to the zero position.

Another important feature of my invention is the provision of novel means for connecting together adjacent cores of separate solenoids, as best seen in Fig. 2. Adjacent cores of separate solenoids are separated by diamagnetic spacers 108, in order that the electromagnetic lines of force created by one solenoid will not adversely affect the operation of the adjacent solenoid. These spacers are disc-like in shape. In order to hold adjacent cores of separate solenoids together and to securely hold the diamagnetic spacers 108 in place, I have provided a sleeve 110 having inturned flanges 112. The adjacent core pieces of separate solenoids are provided at the ends which abut spacer 108 with machined grooves 114 into which flanges 112 of sleeve 110 extend. Thus in assembled position, sleeve 110 holds the adjacent cores together and at the same time also properly positions diamagnetic spacers 108.

As previously explained, one of the important advantages of my invention is the ease of assembly of the actuator. After the coils, spacers 62, end plates 24 and 26, and jacket 22 have been assembled on tube 64, it is only necessary to slip sleeves 110 in position and deform the sleeve to produce the inwardly extending flanges 112 which engage grooves 114 to lock the cores together. Connectors 92 are then placed in the necessary grooves on the cores and the entire core assembly may be slid into tube 64. Core 88 of solenoid 38 is secured to end plate 24 in any appropriate manner and, as hereinafter explained, in some cases this may require a fluid tight connection.

Since the cores of the actuator and connectors 92 and 110 will be in sliding engagement with tube 64, the tube must have a high resistance to abrasion and a low coefficient of friction, and since tube 64 is disposed within the coils, it must be of a non-magnetic material.

The diamagnetic spacers 108 shown in Figs. 1, 2 and 4 are used so as to minimize the amount of stray magnetic flux linkage between adjacent solenoids, in order to provide a highly sensitive actuator. However, in certain insensitive actuators, this is not essential. In Fig. 5, I have shown such an actuator wherein integral cores are used between adjacent solenoids. In this drawing, three solenoids, 112, 114 and 116, are shown having air gaps 118, 120 and 122, respectively. Connectors 92 interconnect the cores at the air gaps. A movable core 124 of solenoid 112 is made integral with output member 70. Instead of providing a separate relatively fixed core for solenoid 112 and a separate movable core for solenoid 114 and spacers therebetween, a single integral core piece 128 is provided. Similarly an integral core piece 130 is provided for solenoids 114 and 116. The operation of the device is similar to that hereinbefore described and, when sensitivity requirements allow, the construction of Fig. 4 enables the production of a less expensive actuator.

Fig. 6 shows a core assembly wherein different means are used for securing adjacent cores of separate solenoids together. Diamagnetic spacers 108 are used between the adjacent core pieces and the core pieces abut thereagainst.

A hollow tube 132 of diamagnetic material extends through a central boring in the core pieces and the ends of the hollow tube are peened or rolled over as indicated at 134 to secure tube 132 in place and at the same time securely interconnect adjacent cores.

In Figs. 1 through 6, connector 92 has been illustrated as a split circular ring having an inwardly extending flange along each edge. However, it should be understood that this invention is not limited to that specific structure and the connecting means may take many forms. For example, in Figs. 7 and 8, I have shown a connector 136 which comprises solid end sections 138 and 140 interconnected by transverse sections 142 and 144. One transverse section is split as at 146 to enable the ring connector to be inserted over the core pieces and the core pieces are provided with annular grooves 148 into which end sections 136 and 138 are seated. In addition, the core pieces are provided with grooves 150 axially on opposite sides which extend from grooves 140 to the air gap face of the core. The width of grooves 148 and the width of end sections 138 and 140 of connector 136 are dimensioned in accordance with the desired length of the air gap.

In Figs. 9 and 10, I have shown still another form of connecting means for interconnecting cores and to control the length of air gap therebetween, which comprises a series of separate "dumb-bell shaped" members 152 having enlarged end portions 154 and a reduced central portion 156. Annular grooves 158 are provided on the core pieces and axially extending grooves 160 are provided which extend from grooves 158 to the air gap face of the core piece. Thus enlarged end portions 154 of the connector are placed in grooves 158 and center portion 156 extends through grooves 160. Hence in the same manner as heretofore described, the cores may move together to close the air gap under magnetic forces, and may move apart only a distance equal to the predetermined length of the air gap, and thereafter connectors 152 will cause the core pieces to move together.

It is an important feature of my invention that the interconnections between the core pieces may be made at or near the surface of the core pieces and thereby the entire central area remains free of obstruction. This enables the accomplishment of many desirable results, of which I will name only a few.

Referring to Fig. 5, it will be seen that a rod 162 extends throughout the central length of the actuator and is secured by set screw 164 to output member 70. The righthand end of rod 162 projects beyond the righthand end of the actuator. Thus, in operation, a double ended output can be obtained from the actuator to operate more than one mechanism or to make the actuator operable from either end. In the example shown in Fig. 4, output member 70 will move to the right when one solenoid is energized and, at the same time, rod 162 will be moved to the right. In other words, output member 70 can exert a pull on appropriate mechanism while the righthand end of rod 162 can exert a push on appropriate mechanism. This double ended output, when desired, can be a characteristic of all of the actuators shown herein.

In addition, it will be seen by referring to Figs. 2, 4 and 5 that springs 166 can be arranged within the air gap between adjacent cores of a solenoid. These springs serve the dual function of cushioning the impact between the cores when the coil of a solenoid is energized and serve to exert a force to open the air gap of the solenoid when the coil is de-energized. It should be understood that while it is frequently desirable to reduce the impact with which the cores come together upon coil energization, it is also frequently desirable to control the force/time function of air gap closure. Thus various types of counter force springs or various combinations of such springs may be arranged within the air gap of each individual solenoid stage according to the particular length of the air gap and thereby control the force/time closure function of that stage.

Many other advantages will flow from the feature of having the central part of the cores unobstructed and these will be evident to one skilled in the art. However, as one further example, reference is invited to Fig. 2 of the drawings. By providing a liquid seal between core 38 of solenoid 38 and tube 64 and by providing a sliding pressure type relationship between output member 70 and tube 64, a hydraulic fluid may be introduced through coupling 168 shown at the righthand end of Fig. 2. This hydraulic fluid will fill all cavities in core assembly 66, including the area in the air gaps of each solenoid. Thus complete hydraulic damping may be accomplished.

When any one of the solenoids is de-energized to snap open the air gap of that solenoid, an appreciable impact will be created on the connector for the core pieces of that solenoid. It is an important feature of my novel connector that a large area of the connector is in contact with a large area of the core pieces and this provides a uniform distribution of the forces to reduce the possibility of part fractures and wear. For example, as seen in Fig. 2, when a solenoid is de-energized and the core pieces snap apart, the entire area of flanges 98 of connector 92 will bear against the shoulder of grooves 102 and 104 in the cores. Thus the impact forces will not exceed the strength of the materials involved, and of equal importance is the fact that wear of the connector and cores will be minimized and thereby provide longer life for the actuator.

One of the outstanding features of my actuator is the fact that no complicated tooling and machining operations are required and yet a precision type actuator is obtainable. The air gap spacer-connectors shown in this application are all characterized by the fact that they may be produced by manufacturing processes which achieve precision at low unit cost and with a high degree of repeatability for dimensional accuracy. In particular, the connetcors may be made by stamping operations. Likewise, the grooves in the cores which cooperate with the air gap spacer-connectors may be formed by simple machining operations.

Since the connectors span the air gap of each solenoid, it is, of course, important that they be of a non-magnetic material or otherwise the air gap would be short circuited. Also, since the connectors are subjected to impact forces, and therefore wear, it is important that these parts have adequate hardness and strength. I have found that materials such as beryllium copper meet these requirements and, in the case of beryllium copper, the parts can be easily formed by stamping operations and heat treated to provide a high degree of hardness without necessitating other costly operations.

While I have shown and described several embodiments of my invention in order to comply with the appropriate statutes, I wish it to be understood that I do not desire to be limited to the specific details and features shown, since various other forms and modifications will be apparent to persons skilled in the art which fall within the scope of the appended claims.

I claim:

1. In an electromagnetic actuator having an output

member and plurality of solenoids, a core assembly comprising a first core for each solenoid, a second core for each solenoid, a connector for the cores of each solenoid, means connecting the first core of one solenoid to the second core of another solenoid so that they move as a unit, means for moving the cores of each solenoid apart, means connecting one of the cores of one solenoid to said output member, said connector for the cores of each solenoid being arranged at the periphery of said cores and engaging said cores to limit the distance the cores of each solenoid can move apart, whereby the central area of said cores are unobstructed.

2. An actuator as claimed in claim 1, wherein an opening is provided in the center of the cores of each solenoid and an actuator rod is connected to said output member and extends through the openings of said cores.

3. An actuator as claimed in claim 1, wherein a resilient member is arranged between the cores of a solenoid to reduce impact forces between the cores of said solenoid.

4. An actuator as claimed in claim 1, wherein said connector of each solenoid surrounds the periphery of said cores of each solenoid to close off the area between the cores of each solenoid.

5. An actuator as claimed in claim 1, wherein a fluid fills the voids in said core assembly and dampens movement of said cores.

6. In an electromagnetic actuator having a plurality of solenoids, a first core for each solenoid, a second core for each solenoid, said first and second core of each solenoid having an open center area, a connector for fixedly securing the first core of one solenoid to the second core of another solenoid whereby said connected first and second cores are secured together for movement as a unit, said connector comprising a sleeve extending around the periphery of said connected cores and having flanges engaging grooves in said connected cores.

7. An actuator as claimed in claim 6, wherein a diamagnetic spacer is disposed between said connected cores and held in place by said connectors.

8. In an electromagnetic actuator having a plurality of solenoids, a first core for each solenoid, a second core for each solenoid, said first and second core of each solenoid having an open center area, a connector for fixedly securing the first core of one solenoid to the second core of another solenoid whereby said connected first and second cores are secured together for movement as a unit, said connector comprising a hollow rivet extending through the open center area of said connected cores and engaging the ends of said connected cores to secure them together.

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