Dec. 23, 1969 J. C. MACY 3,486,147

ELECTROMAGNETIC ACTUATING DEVICE

Filed Aug. 28, 1967 5 Sheets-Sheet 1

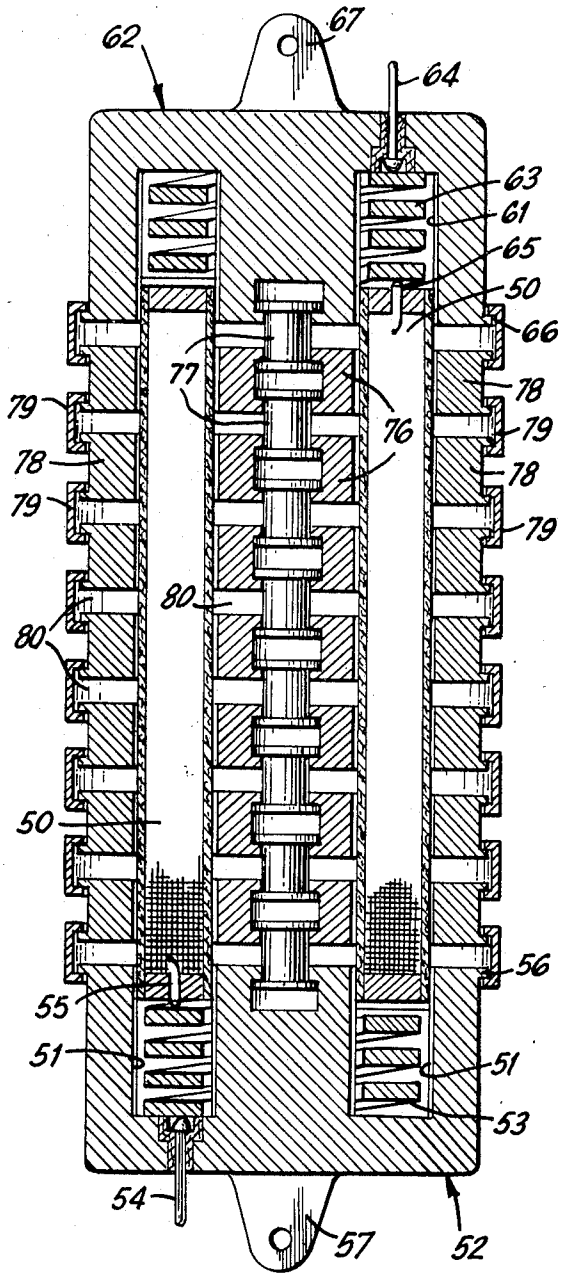


FIG. 1

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ELECTROMAGNETIC ACTUATING DEVICE

Filed Aug. 28, 1967 5 Sheets-Sheet 2

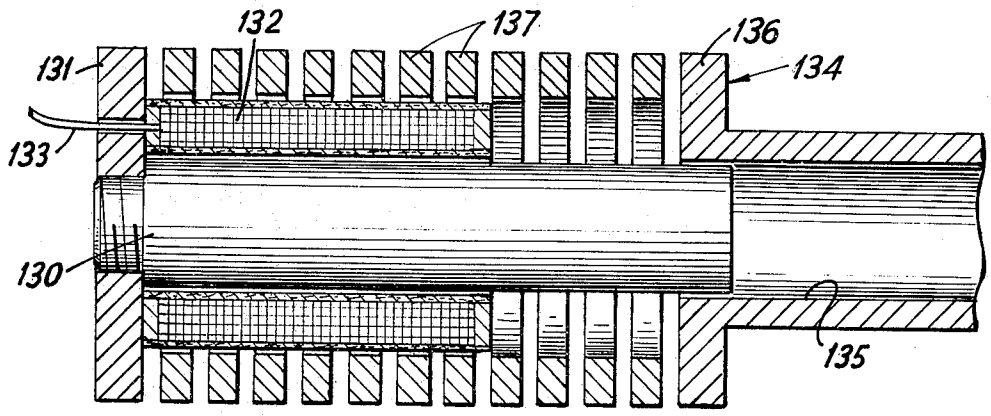


FIG.2

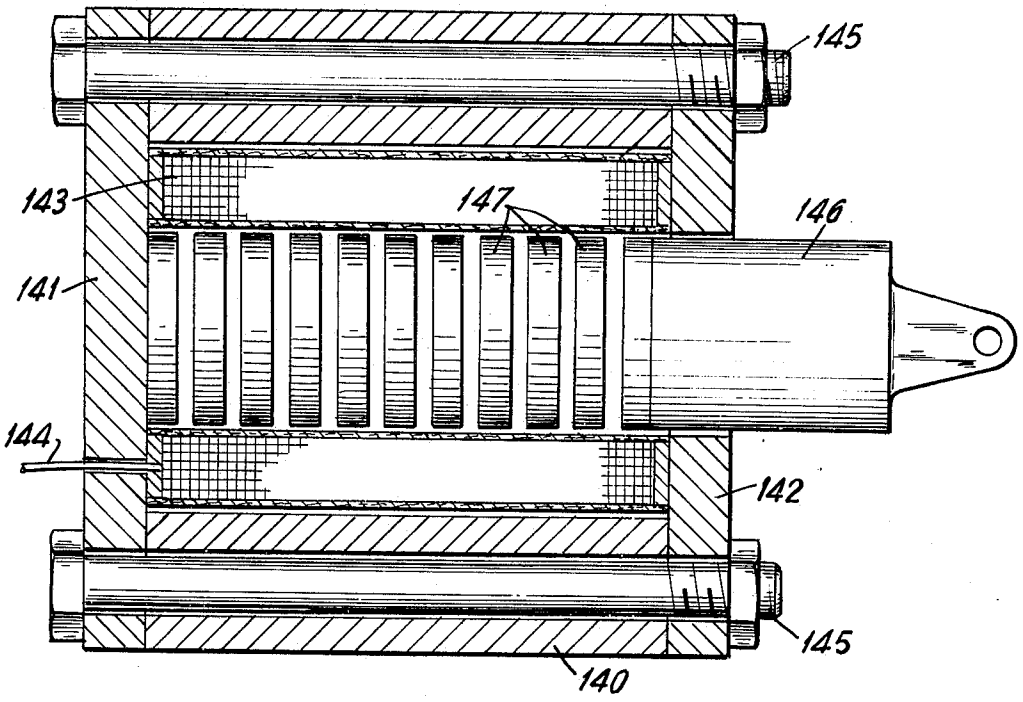


FIG.3

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ELECTROMAGNETIC ACTUATING DEVICE

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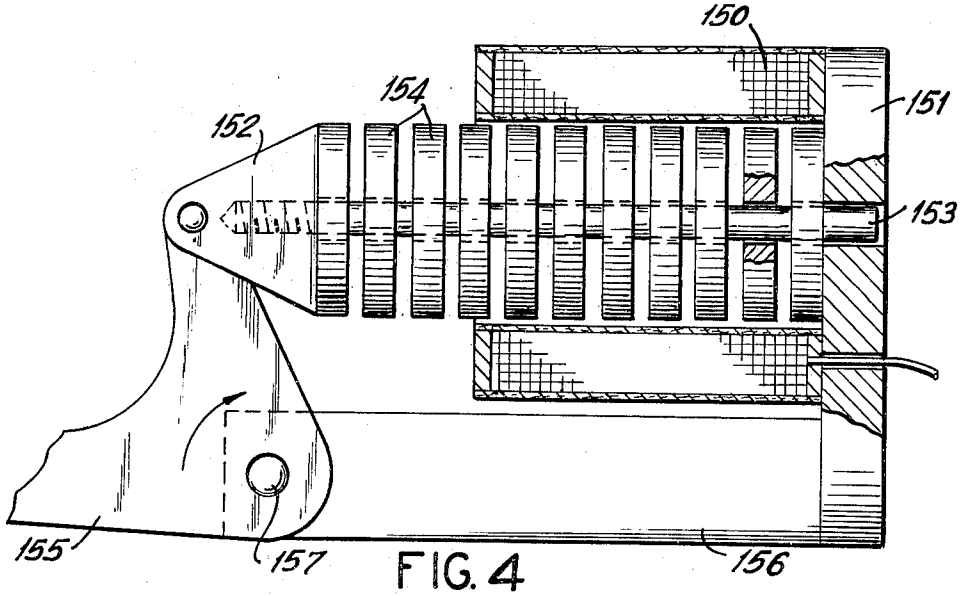


FIG. 4

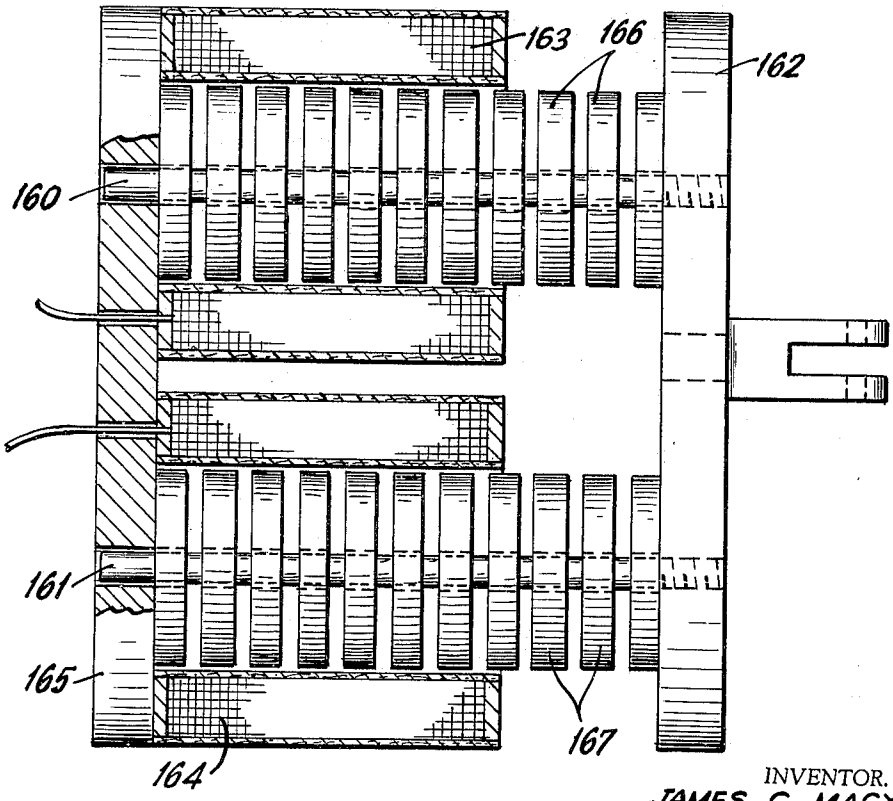


FIG. 5

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ELECTROMAGNETIC ACTUATING DEVICE

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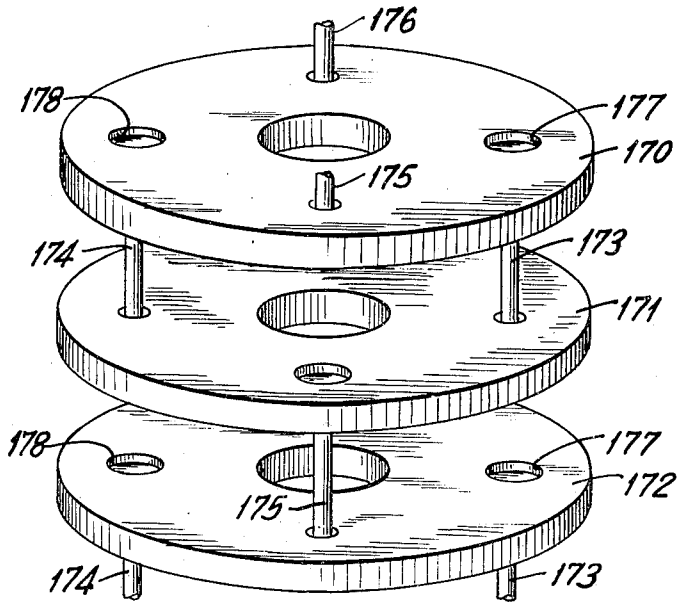


FIG. 6A

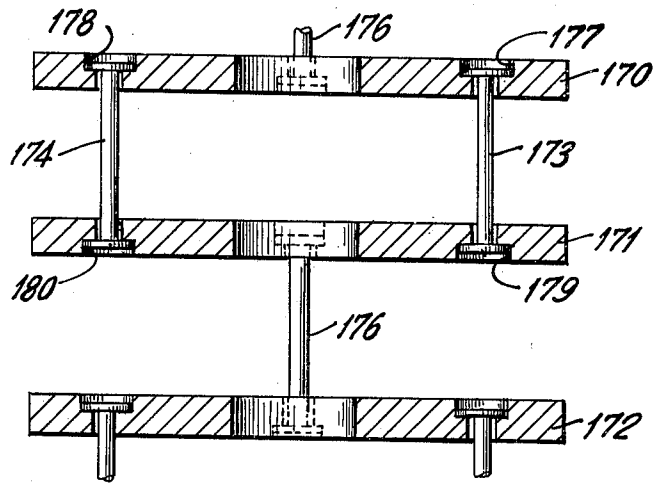


FIG. 6B

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ELECTROMAGNETIC ACTUATING DEVICE

Filed Aug. 28, 1967 5 Sheets-Sheet 5

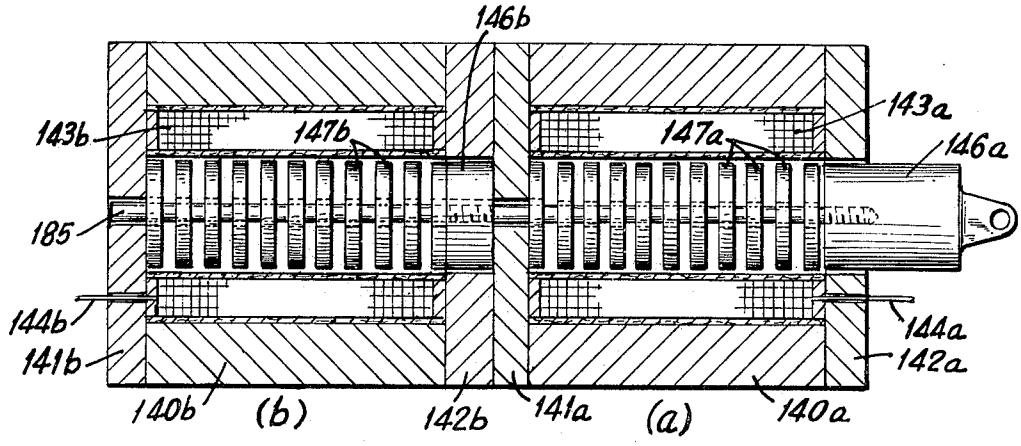


FIG. 7A

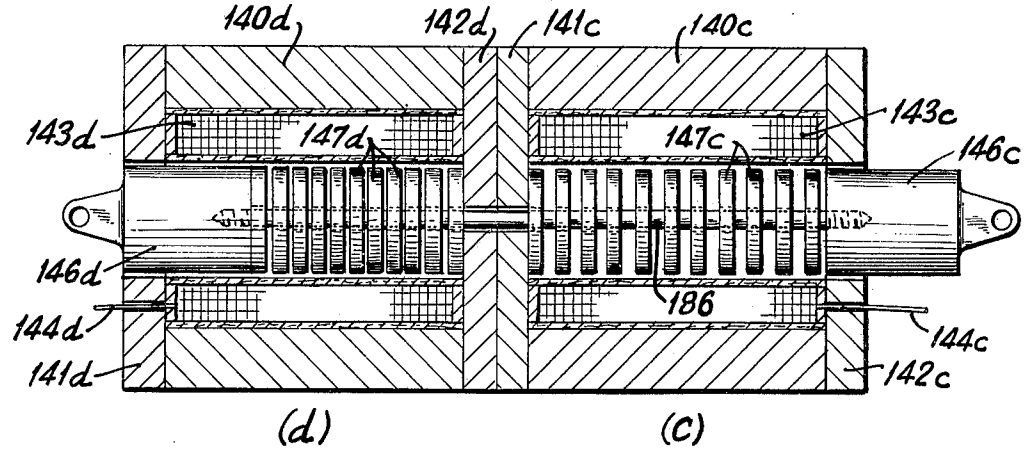


FIG. 7B

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United States Patent Office 3,486,147
Patented Dec. 23, 1969

3,486,147

ELECTROMAGNETIC ACTUATING DEVICE

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Continuation-in-part of application Ser. No. 486,454, Sept. 10, 1965. This application Aug. 28, 1967, Ser. No. 663,792

Int. Cl. H01f 7/08, 3/14

U.S. Cl. 335—264 1 Claim

ABSTRACT OF THE DISCLOSURE

Magnetic actuating devices wherein the existing magnetic gap is broken up into a plurality of increments. The structure can include a single electric coil with a plurality of magnetic segments to break up the magnetic gap; a plurality of electric coils with associated core pieces; or a helical coil core piece arrangement.

This invention relates to electromagnetic actuating devices, and more particularly, to a novel type of electromagnetic actuating device capable of providing a powerful mechanical force over a relatively long traverse. This novel electromagnetic device is referred to as a contractuator. This application is a continuation-in-part of application Ser. No. 486,454, filed Sept. 10, 1965 (now Patent No. 3,376,528 issued Apr. 2, 1968).

The conventional electromagnetic relay includes an electrical coil a movable magnetic armature, and a magnetic structure for completing the flux path around the coil. Devices of this general structure can provide a relatively powerful mechanical force as the armature is attracted in response to energization of the coil. However, the magnitude of the force is inversely proportional to the square of the working air gap length associated with the armature. Thus, any attempt at increasing the length of the stroke brings about a decrease in the force at the beginning of the stroke which is approximately proportional to the square of the distance to be traversed. Electrical devices of this general structure are, therefore, inherently short stroke devices.

By comparison, the conventional plunger-type solenoid is inherently a long stroke device and usually includes an iron plunger adapted to pass through the center of an electromagnetic coil. The mechanical force is created by the interaction between the magnetic flux of the plunger and the current passing through the energizing coil. The force created by the solenoid is relatively weak and suffers from the further disadvantage of being strongest at the middle of the stroke and weakest at the ends where maximum force is often required.

Electromagnetic devices can be classified either with the inherently short powerful stroke devices, or with the relatively long weak stroke devices. Because of the inherent characteristics of the prior electromagnetic devices, it has not been possible to achieve a powerful force over a relatively long traverse without resorting to various boosting or supplementing techniques.

An object of this invention is to provide an electromagnetic actuator capable of converting electrical energy into a relatively powerful force over a long traverse.

Another object of the invention is to provide an electromagnetic actuator which can achieve optimum performance for given size, weight, geometrical configuration and electrical power conditions.

Another object is to provide an electromagnetic actuator in which the created force can be controlled as desired throughout the stroke.

Still another object is to provide an electromagnetic actuator which can be readily mass produced and in which standardized components can be assembled to satisfy varying operational requirements.

Yet another object is to provide an electromagnetic device which can easily be integrated as an operational portion of a system.

The electromagnetic device constructed in accordance with this invention converts electrical energy directly into mechanical force and is capable of providing a powerful mechanical force without limitation on the length of the stroke or traverse. The force is created by the magnetic attraction exerted upon a plurality of interconnected magnetic members. The working gap is broken into small increments so that a substantial force can be created without suffering the normal effects associated with a long stroke.

The invention is described in greater detail with reference to the following specification which sets forth several illustrative embodiments. The drawings are part of the specification wherein:

FIGURE 1 is a cross-sectional view of an actuating device in accordance with this invention wherein a single energizing coil is employed;

FIGURE 2 is a cross-sectional view of another actuating device wherein a single energizing coil is employed in combination with magnetic segments surrounding the coil;

FIGURE 3 is a cross-sectional view of another actuating device wherein a single energizing coil is employed in combination with a cylindrical outer casing and multiple magnetic segments located within the coil;

FIGURE 4 is a cross-sectional view of another actuating device including magnetic segments located within a single energizing coil;

FIGURE 5 is a cross-sectional view of another actuating device, including a pair of energizing coils, each including multiple magnetic segments located inside the coils;

FIGURE 6 is a view of a helical actuating device in accordance with this invention with portions broken away for clarity of illustration;

FIGURES 6A and 6B are perspective and cross-sectional views, respectively, illustrating a structure for interconnecting magnetic disc segments; and

FIGURES 7A and 7B are cross-sectional views illustrating a pair of actuating devices connected to act upon a common shaft in unison and push-pull, respectively.

The mechanical force created by an electromechanical device can be expressed by the following formula:

$$P = k\frac{F^2 \mu A}{x^2}$$

where P is the pull or force, k is a constant, F is the magnetomotive force, μ is the permeability of the working gap, A is the area of the pole face, and x is the length of the working gap. It should be noted that the created force is inversely proportional to the length of the working gap. In addition, the magnetomotive force is inversely related to the gap length and therefore the force falls off rapidly as the working gap length increases.

In the illustrative embodiments, structures are described which provide a powerful force over a relatively long traverse which would normally require a corresponding long air gap. With the structure in accordance with the invention, the air gap is broken into relatively small increments to eliminate the problems associated with the long air gap. The structure also makes possible a relatively high magnetomotive force by minimizing the flux losses and by permitting use of materials in the working gap having a permeability greater than air.

An embodiment of the invention, utilizing a single electrical coil, is shown in FIGURE 1. The coil **50** is a cylindrical, concentrically wound coil encased in a suitable nonmagnetic material providing relatively smooth exterior surfaces. One end of coil **50** is accommodated within a suitably dimensioned resistively coated annular recess **51** in an end cap **52**. In recess **51**, between the end of coil **50** and the bottom of the recess, is a flat coil spring **53** constructed from an electrically conductive material. The coil spring maintains electrical contact between an external lead **54** and one of the electrical leads **55** emerging from coil **50**. The other end of coil **50** is similarly accommodated in an annular recess **61** within an end cap **62**. The other lead **65** of coil **50** is coupled to an external lead **64** via a coil spring **63** located within recess **61**. End caps **52** and **62** include extensions **57** and **67**, respectively, adapted for attachment to external equipment.

Within the central opening of coil **50** there is a plurality of internally grooved and flanged discs **76** which are coupled to one another and to the end caps by means of externally grooved and flanged coupling discs **77**. The coupling discs serve to limit the length of the working gap. A plurality of externally flanged and grooved discs **78** surrounds coil **50** and are coupled to one another and to the end caps by means of internally flanged coupling rings **79**. The coupling rings operate to limit the length of the air gap between discs **78**.

End caps **52** and **62**, and discs **76** and **78**, are preferably constructed from a magnetic material such as iron whereas coupling discs **77** and coupling rings **79** are preferably constructed from a nonmagnetic material.

When coil **50** is energized, a magnetic flux is created which passes through discs **76** and **78** and end caps **52** and **62** creating a force tending to pull the end caps together to thereby eliminate the working magnetic gaps **80** existing between the discs.

A variation of the single coil actuator with a plurality of magnetic segments for breaking up the air gap is shown in FIGURE 2. This arrangement essentially eliminates the need for magnetic segments inside the coil and, hence, all of the magnetic segments in the device are located outside the energizing coil.

A center stationary rod **130** is secured to a circular base plate **131**. A concentrically wound electrical coil is mounted surrounding rod **130** and is secured to base plate **131** with the electrical leads **133** extending through a suitable aperture in the base plate. The movable end coupling **134** includes a central aperture **135** which is dimensioned so that the end coupling can slide about the end of rod **130** toward and away from the base plate. The flange portion **136** of the end coupling has dimensions generally corresponding to that of the base plate. Flat annular magnetic segments **137** are located in the working gap between the opposing surfaces of the base plate and the flange of the end coupling. The external cylindrical surface of the electrical coil is provided with a smooth surface and the inner diameters of magnetic segments **137** are selected so that the magnetic segments can slide along the external surface of the coil. Although not shown in FIGURE 2, the magnetic segments are mechanically interconnected by nonmagnetic coupling elements which limit the maximum air gap between adjacent magnetic segments and also maintain the magnetic segments in alignment. The interconnection structure for the magnetic segments can be of the type illustrated in FIGURE 1, or of the type hereinafter described with respect to FIGURES 6A and 6B.

The central rod, the base plate, the end coupling and the magnetic segments are constructed from a low reluctance magnetic material such as soft iron. Accordingly, when the electrical coil is energized a magnetic flux is created which passes through the stationary rod, flange portion **136**, the working gap including the annular magnetic segments **137**, the base plate and then back to the stationary rod. As a result, the end coupling is drawn toward the base plate as it slides along the stationary central rod.

Another single energizing coil actuator is illustrated in FIGURE 3 wherein the plurality of magnetic segments are located within the electrical coil instead of surrounding the electrical coil as shown in FIGURE 2. This structure includes a cylindrical housing member **140** located between a pair of similar circular end plates **141** and **142**. A concentrically wound electrical coil **143** is located just inside cylindrical housing member **140** and between the end plates. The electrical leads **144** for the coil are brought out through a suitably located aperture in end plate **141**. End plate **142** is provided with a centrally located circular opening which accommodates a movable end coupling **146** with a relatively close sliding fit. Magnetic segments **147** are in the shape of flat circular discs and are located in the working gap between end coupling **146** and end plate **141**. In the actual structure, the magnetic segments, the end coupling and end plate **141** are interconnected by nonmagnetic couplings such as shown in FIGURES 1 and 6. The electrical coil is provided with a smooth inner-cylindrical surface which permits free movement of the magnetic segments and further maintains the segments in alignment.

When electrical coil **143** is energized, a magnetic flux is created which passes through end plate **141**, cylindrical housing **140** and plate **142**, and coupling member **146** and through the working gap which includes the approximately equally spaced magnetic segments **147**. As a result of the magnetic flux, the movable coupling member **146** is pulled toward end plate **141**.

FIGURE 4 illustrates a somewhat similar single coil actuator with centrally located magnetic segments, except that the cylindrical outer housing is eliminated. An electrical coil **150** is mounted on a base plate **151** with the electrical leads of the coil extending through a suitable aperture in the base plate. A movable end coupling **152** is mounted on one end of a guide rod **153** which extends through the center of the electrical coil and through an aperture in the base plate. The guide rod has a diameter which permits it to freely slide back and forth through the base plate. Magnetic segments **154** are in the shape of flat discs and are located in the working magnetic gap between end coupling **152** and base plate **151**. Each of the magnetic segments is provided with a central aperture which provides a loose fit surrounding the guide rod. Although not shown, the magnetic segments, the end coupling and the base plate are interconnected by nonmagnetic coupling elements such as shown in FIGURES 1 and 6. A pivot arm **155** is coupled to the free end of movable coupling **152** and to the free end of a magnetic support **156** which is secured to the base plate at its other end.

When the electrical coil is energized, a magnetic flux is created which passes through base plate **151**, support **156**, pivot arm **155**, and coupling **152** and through the working magnetic gap including the magnetic segments **154** therein. The magnetic flux causes end coupling **152** to travel toward base plate **151** thereby causing pivot arm **155** to rotate about pivot **157** in the direction of the arrow.

FIGURE 5 illustrates an actuating device, including a pair of electrical coils, each including a plurality of centrally located magnetic segments. A pair of parallel spaced-apart guide rods are secured to a movable end plate **162**. A pair of concentrically wound electrical coils **163** and **164** are securely mounted on a stationary base plate **165** so that the coils surround guide rods **160** and **161**, respectively. The guide rods pass through suitably located apertures in the stationary base plate with a loose sliding fit. A first set of magnetic segments **166** in the shape of flat discs are located within coil **163** in the working gap between end plates **162** and **165**. Each of

the discs is provided with a centrally located aperture which provides a loose sliding fit surrounding guide rod **160**. A similar set of magnetic segments **167** is located within coil **164** surrounding guide rod **161**.

The flux path created when the coils are energized passes through the air gap in the center of coil **163**, through end plate **165**, through the working gap in the center of the coil **164** and then through end plate **162**. Thus, the closed path of the magnetic flux passes through both working gaps and through the centers of both coils, these working gaps including the approximately equally spaced magnetic segments **166** and **167**. When the coils are energized, movable end member **162** is therefore drawn toward the stationary end member **165**.

A suitable interconnecting structure for the magnetic segments, such as shown in FIGURES 1–5 embodiments, is illustrated in FIGURES 6A and 6B. The magnetic discs **170–172** are suitably dimensioned to fit either inside or outside the electrical coils as required but, in each case, can be interconnected in substantially the same manner.

Four holes are drilled in each of the magnetic segments **170–172** and are angularly separated by 90 degrees. A pair of recesses, for example, **177** and **178** in disc **170**, is machined part way through the disc from one side in areas associated with a pair of diametrically opposite holes, whereas a similar pair of recesses is machined part way through the disc from the other side associated with the other two holes.

Brass rivets are then inserted as shown in FIGURE 6B. Rivets **173** and **174**, for example, are inserted in recesses **179** and **180**, respectively, extending up through an aligned pair of holes in discs **170** and **171**. A temporary spacer (not shown) is inserted between the discs so that the free ends of the rivets can be formed into heads within recesses **177** and **178**, respectively. When the spacer is removed, the discs can be moved toward one another, but the rivets maintain the discs in alignment and determine the maximum separation, or air gap, that can exist between adjacent discs. Rivets **175** and **176** perform similar functions relative to adjacent discs **171** and **172**. All of the magnetic segments in an actuating device can be interconnected in this fashion by alternating the portions of the rivets with each successive pair of magnetic discs. The end discs can be coupled to the end coupling members in a similar fashion.

FIGURES 7A and 7B illustrate some of the possible arrangements for interconnecting two or more actuating devices.

In FIGURE 7A, a pair of actuating devices of the type shown in FIGURE 3 is mechanically interconnected to form a combined unit which exerts a stronger pull. The components of one of the actuating devices, referred to as the (*a*) unit, include components designated **140***a*–**147***a*, whereas the other actuating device, referred to as the (*b*) unit, includes components designated **140***b*–**147***b*, these components corresponding respectively to elements **140–147** in FIGURE 3. A rod **185** is secured to end coupling members **146***a* and **146***b* and can, in similar fashion, be connected to end coupling members of additional actuating units. Except for the connections with the end coupling members, rod **185** fits loosely through the center of the units. When electrical coils **147***a* and **147***b* are energized, the (*a*) and (*b*) units pull in unison and thereby provide a pull transmitted through rod **185** which is approximately double that which could be achieved with a single actuating unit.

In FIGURE 7B, a similar pair of actuating units are mechanically interconnected to act upon the same rod **186**, but in this case, the units operate in a push-pull fashion. The components of one of the units are designated with reference numbers **140***c*–**147***c*, whereas the components of the other unit are designated with reference numbers **140***d*–**147***d*, these reference numbers corresponding respectively to components **140–147** in FIGURE 3. The (*c*) unit in FIGURE 7B occupies essentially the same position as the (*a*) unit in FIGURE 7A, but the position of the (*d*) unit is reversed relative to the position of the (*b*) unit. In this arrangement, the movable end members of the actuating units are secured to opposite ends of a common rod **186** which loosely slides through the center of the remaining elements. When coil **147***c* is energized, the (*c*) unit contracts and the shaft moves to the left, whereas when electrical coil **147***d* is energized, the (*d*) unit contracts and the shaft moves to the right.

While only a few illustrative embodiments of the invention have been described in detail, it should be obvious that there are numerous arrangements and variations within the scope of this invention. The invention is more clearly defined in the appended claim.

What is claimed is:

1. A magnetic actuating device comprising a pair of cylindrical electrical coils;

a separate plurality of magnetic discs substantially disposed within each of said coils;

a pair of relatively movable spaced-apart magnetic end members, said magnetic discs being located in working gaps between said end members;

nonmagnetic coupling means between adjacent discs and end members to limit the permissible separation between adjacent elements so that the working gaps are divided into aproximately equal increments;

said electrical coils, when energized, being operative to create a magnetic flux which passes through the center of both of said coils and through said working gaps and end members to cause relative movement of said end members.

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U.S. Cl. X.R.

335—267, 296