April 1, 1958 J. R. McCLESKEY 2,829,319

ELECTROMAGNETIC DEVICE

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Fig. 1

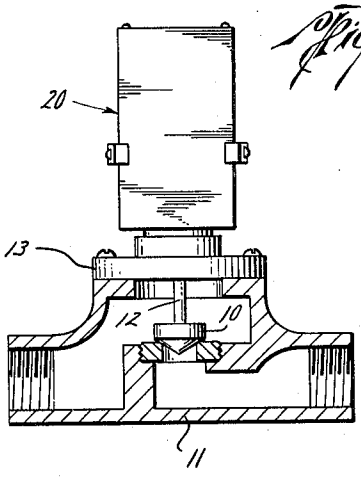


Fig. 2

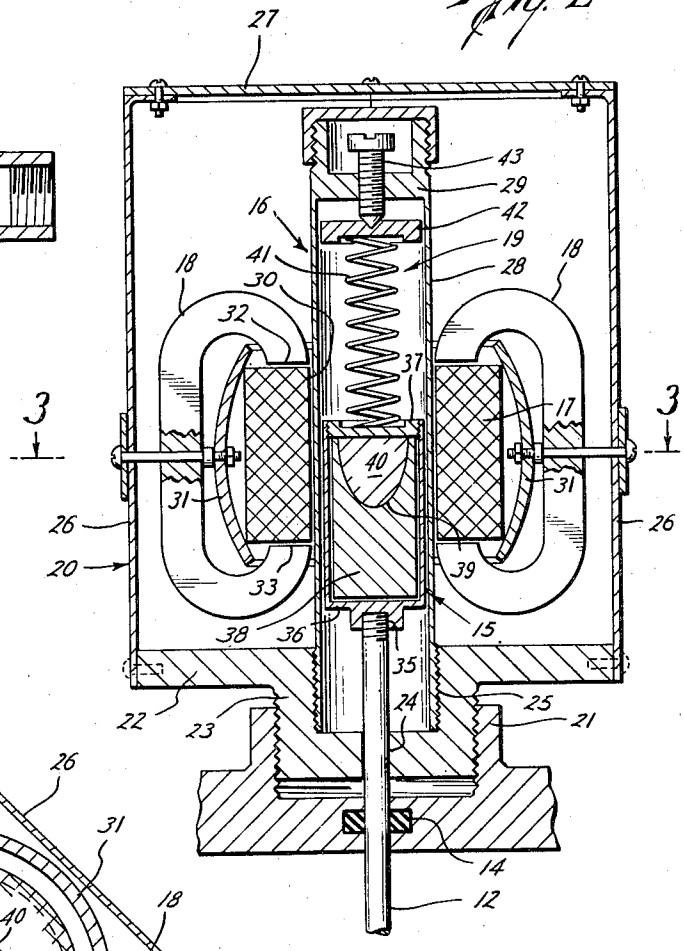
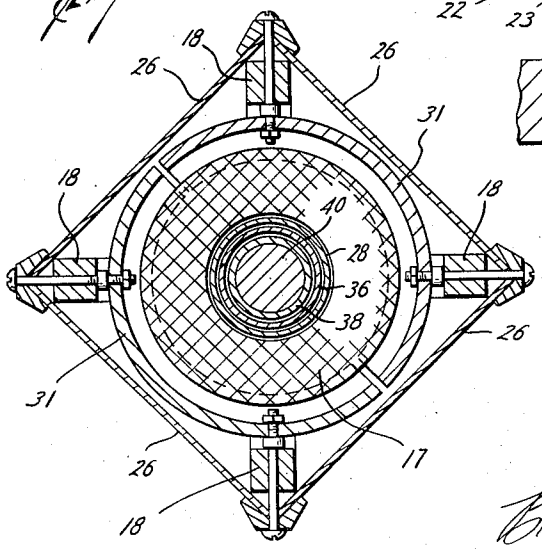


Fig. 3



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ELECTROMAGNETIC DEVICE

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14 Claims. (Cl. 317—191)

This invention relates to an electromagnetic device in which several magnetic fields are combined and concentrated. In one aspect it relates to an electromagnetic device employing several combined magnetic fields, at least one of which is variable to reciprocate an armature.

It is well known that both permanent magnets and electromagnets provide magnetic fields which will exert a force on a paramagnetic body within these fields. I have found that combining certain fields in a certain way greatly adds to their usable power. I have found that by arranging an electric winding or coil, and a core magnet, either permanent or electric, in certain relationship with each other the force exerted by the combined fields of the coil and the core magnet in the center of the coil far exceeds the sum of the maximum forces which either of these elements will exert alone.

It is an object of this invention to provide an electromagnetic device in which magnetic fields are combined with each other in a manner to exert a usable force in excess of the sum of the forces of the two fields acting alone.

Another object is to provide an electromagnetic device in which an electromagnetic coil and at least one core magnet are combined in a manner to provide a field within the bore of the coil which will exert a greater force than the sum of the forces of the magnets acting alone and in which the intensity of the combined field may be varied by varying a signal in one of the magnets.

Another object of this invention is to combine the electromagnetic field of a winding and of a core magnet in such a way that the resultant combined magnetic field will exert a force on a paramagnetic object within the center of the winding which exceeds the sum of the forces which would be exerted by both of these elements with their fields separated.

Another object is to provide a shielding for an electromagnetic coil to increase the force which the field of the coil will exert on a paramagnetic object inserted within the bore of the coil.

Another object is to provide an electromagnetic device in which an electromagnetic coil and a core magnet are combined in a manner to provide a field within the bore of the coil which will exert a greater force than the sum of the forces of the two elements acting alone and in which movement of an armature in the bore of said coil upon energizing the coil is in linear increments in response to incremental increases in D. C. signal in the winding.

Another object of this invention is to provide a magnetic device having a lineally movable armature which may be electrically moved to and held in any position between the limits of its movement in either direction.

Another object of this invention is to provide a magnetic device having a lineally movable armature in which incremental movement of the armature is provided by incremental increases in current passing through the electromagnetic coil.

Another object is to provide an electromagnetic device in which the armature is provided with a greater range of

lineal movement than is normally found in devices of this character.

In electric motors of the solenoid or relay type, the work per unit increase of signal goes up rather rapidly and quickly reaches what is usually referred to as the knee of the curve in which the work and the signal increase coincide along a substantially straight line for a short portion of the curve. Thereafter, the work per unit signal decreases and continued increase of signal provides a progressively lesser percentage of work per increase of signal.

It is another object of this invention to extend the straight line portion of the work per unit signal curve of a reciprocating armature electromagnetic device.

Other objects, features and advantages of the invention will be apparent from a consideration of the specification, drawings and the appended claims.

In the drawing, wherein there is shown by way of illustration, one embodiment of this invention and wherein like reference numerals indicate like parts:

Fig. 1 is a view in vertical elevation through a valve controlling flow through a conduit, with operation of the valve controlled by an electromagnetic motor shown in elevation and constructed in accordance with this invention;

Fig. 2 is a view on an enlarged scale in vertical cross-section through the electromagnetic motor of Fig. 1; and

Fig. 3 is a view in horizontal cross-section of the electromagnetic device taken along the lines 3—3 of Fig. 2.

While the electromagnetic device of this invention may be used in many applications, it is particularly useful for regulating the movement of a valve member such as valve member **10** to control flow through a valve body **11**. The valve member **10** depends from a valve stem **12** which is reciprocally mounted in cover plate **13** of the valve body to which the electromagnetic operator is secured. The seal between valve stem **12** and cover plate **13** is preferably provided by an interference type seal **14** so as to provide a minimum of friction to operation of the valve stem by the electromagnetic operator.

Referring now to the electromagnetic device, it will be seen to include an armature or plunger indicated generally at **15** connected to valve stem **12**, which armature is reciprocal in a path defined by cylindrical cage or guide indicated generally at **16**. The path of plunger **15** is surrounded by a winding **17** and a plurality of core magnets **18** which may be either permanent magnets or electromagnets. The plunger is biased to the position shown in the drawings by adjustable resilient means indicated generally at **19**. The magnetic device is supported in a suitable housing indicated generally at **20** which is secured to a boss **21** in the top of cover plate **13**.

Referring more in detail to the motor, the housing **20** includes a base plate **22** having a threaded end fitting **23** which is threadedly secured within boss **21**. Valve stem **12** passes through a guideway **24** in end fitting **23** and is secured to plunger **15**. End fitting **23** is counterbored and threaded at **25** to provide a mounting means for the guide **16**. Four side wall pieces **26** are secured to base plate **22** and the housing is completed by a top cover plate **27** secured to the upper end of the side walls **26**.

The plunger guide **16** is provided by an elongate tubular member **28**, preferably formed from material which is not a conductor of magnetic lines of force. Member **28** is closed on its upper end by a web **29** and its lower end is open and threadedly secured in counterbore **25** of base **22**.

The coil or winding **17** is of the conventional electromagnetic type having a central opening or bore **30** therethrough which closely fits the outer periphery of guide **16** and when energized with an electric signal creates a magnetic field in the bore **30**.

In order to contract the magnetic field of the winding there is provided an annular shield **31** of diamagnetic material, preferably bismuth, surrounding the outer periphery of the winding. By diverting the field inwardly, the magnetic field within the bore **30** of the coil **17** is strengthened.

The magnets **18** may conveniently be referred to as core magnets as they are of the type in which flux will travel through a core of paramagnetic material such as iron between upper gap face **32** and lower gap face **33**. The magnets **18** may conveniently be permanent magnets or they may be provided by a core having an electrical winding intermediate its ends to induce a magnetic field between gaps **32** and **33** upon supplying a signal to such winding. While other types of magnets might be used, it has been found that best results will be attained with a magnet having its gap faces confronting each other as faces **32** and **33** of magnets **18**, which type of magnet, either permanent or electric, will be hereinafter conveniently referred to as a "C" magnet. When "C" magnets are positioned with their gap faces confronting each other and immediately adjacent the two ends of the coil as shown in Fig. 2, they will combine with the winding **17** to provide a magnetic field acting upon armature **15** which will exert a greater force on armature **15** than the sum of the total forces of all of the permanent magnets **18** acting together and the coil **17**. The "C" magnets should be equally spaced circumferentially about the plunger **15** with their gap faces spaced equidistant from the central axis of the bore through winding **17** so that there will be no side thrust on the plunger.

Tests were conducted with an apparatus constructed in accordance with this invention and substantially as shown in the drawings of this application except that the shield **31** was not employed and the plunger **15** did not have the bismuth insert **40** therein but had a frustral conical terminal portion on its end adjacent the resilient means **19**. The entire plunger was constructed of soft iron. In this test, the resilient means was omitted to permit determination of the force of the several fields. With the plunger positioned at approximately the same relationship as shown in Fig. 2, which was the point at which the greatest force on the plunger was found to exist, it was found that the measured force exerted by the coil field alone with a constant signal of .04 amp. in the coil **17** was 2 grams. Similar tests were made with the four "C" permanent magnets alone. It was found that the force of the field of the permanent magnets alone was 93.3 grams. The same tests were then made with the permanent magnets and winding acting in the association illustrated in the drawing. A constant signal of .04 amp. of current at the same voltage used in testing the coil alone was passed through the coil and it was found that the coil and magnets together exerted a force of 186.6 grams. Approximately 15 readings were made on each of the above tests and the results given are the average of the readings taken.

From the above test, it will be seen that the combination of the "C" magnets and the coil in the relationship shown resulted in an increase force equaled to approximately twice the sum of the forces of the fields of the permanent magnets and the coil acting alone.

With the type of structure shown in Fig. 2, it was found that the maximum power could be obtained from the motor by positioning the plunger **15** in approximately the relationship with the coil **17** illustrated in Fig. 2; that is, the end of the plunger within the coil positioned at approximately the mid point of the axial distance through coil **17**.

It will be appreciated that with the plunger so far inserted into the coil **17** when the coil is not energized, it is desirable to provide for maximum travel of the plunger. Maximum travel will be obtained by preventing the plunger from becoming saturated and for this reason it is desired to gradually increase the amount of paramagnetic metal of the plunger in the strongest part of the field at a gradual rate as the plunger moves into the coil. The field is believed to be concentrated at approximately the axial mid point through the coil **17**.

The plunger **15** may conveniently be provided with a cylindrical housing **36** having one closed end threadedly secured to stem **12** at **35** at one end of the housing. The other end of the housing is closed by a plug **37** threadedly secured to the housing. Within plunger housing **36**, there is positioned a body of paramagnetic material **38** which is held between the closed end of housing **36** and plug **37**. In order that the amount of paramagnetic material **38** be gradually increased in the strong portion of the field of the magnets to prevent saturation, the end of body **38** adjacent plug **37** is provided with a semielliptical depression **39**. This will keep the percentage of saturation of body **38** approximately constant as the plunger moves into the coil and provide for longer travel of the plunger. The addition of material in the strong part of the field may be provided by other shapes of plungers but the described shape is preferred for reasons which will presently appear.

To increase the travel of the armature, it is preferable that the semielliptical depression be filled with an insert **40** of diamagnetic materials such as bismuth. The material will be repelled by the field and tend to increase the throw of the plunger.

It will be appreciated that the semielliptical shape will also provide for a constant air gap between the paramagnetic plunger material **38** and coil **17** throughout more than half of the plunger with the plunger in its rest position as shown in Fig. 2, and this distance will increase as the plunger seeks center when the coil **17** is energized.

It might be pointed out at this point that the plunger **15** will always have a side wall portion positioned a constant distance from the gap faces **33** of each of the "C" magnets and the end of the plunger within the coil will always be spaced from the gap faces **32** of the "C" magnets a sufficient distance that the air gap between gap faces **32** and the adjacent end of plunger **15** will be large enough that this air gap may be considered as substantially constant.

The plunger will always be attempting to seek center between the "C" magnets **18** and the resilient assembly **19** is provided to maintain the plunger in the position shown when the winding **17** is not energized. A coil spring **41** is positioned between plug **37** of the plunger and a spring carrier **42** in the closed end of guide **16**. Spring carrier **42** may be held at selected positions in guide **16** by an adjusting screw **43** threadedly carried by guide **16**. By adjustment of screw **43**, the plunger **15** is positioned in the desired rest position against the force of the "C" magnet field. Preferably, spring **41** has straight line characteristics so that movement of plunger **15** will be linear with increasing D. C. signal in coil **17**.

With the device so constructed a direct current signal may be introduced into coil **17** and such signal will cause plunger **15** to move upwardly a short distance until the additional force of the combined fields of the several magnets is opposed by the increased force of spring **41** due to its being placed under additional compression. This will raise valve **10** from its seat a short distance. If desired, an additional signal may be introduced into coil **17** and this will cause an additional increment of movement of plunger **15**. In other words, the plunger **15** will move longitudinally in increments in response to added increments of D. C. signal in coil **17**. It will be appreciated that when core magnets **18** are electromagnets, a D. C. signal in either or both the coil **17** and core magnets **18** will give a changing field strength to control movement of plunger **15**.

With the plunger constructed with a semielliptical end as shown in Fig. 2, the travel of the plunger will be linear to the signal in coil **17**.

The paramagnetic material 38 of plunger 15 is preferably magnetic iron. It is well known that the permeability of magnetic iron increases rapidly with increases in induction. The permeability curve of iron shows a knee portion where the permeability remains substantially constant with increasing induction and then begins to fall off and decrease rather rapidly with increases in induction. By employing the semielliptical plunger, in the manner explained above the portion of the permeability curve for plunger 15 as it moved into the coil, in which permeability remains substantially constant with increases in induction may be extended.

The "C" magnets are preferably selected to provide a magnetic field whose inductance will saturate the plunger in its rest position to the extent that its permeability is approximately at the beginning of the substantially straight line portion of the inductance-permeability curve for the plunger in rest position. Then as direct current signal is imposed on the coil 17, movement of plunger 15 is lineal with increases in the signal and the lineal characteristic of the plunger will be maintained over a longer range than with the conventional flat nose or flustral conical nose plunger.

From the above it will be seen that all of the objects of this invention have been obtained. There has been provided an electromagnetic device in which the plunger may be drawn into the coil a desired amount to regulate flow through a valve or the like, as well as drawn to its full inserted position to provide a snap action such as is conventional with a solenoid. The field of a number of magnets has been combined in a manner to provide a force which is greater than the sum of the several magnets when used alone. A design of plunger has been provided which when used with the electromagnetic device of this invention will provide for straight line movement of the plunger with added increments of signal to the coil 17. A diamagnetic insert in the plunger and a shield for the winding 17 both increase the power of the device, and the former contributes to an increased distance of travel for the plunger.

While this invention has been explained in its application to a device for reciprocating a valve member it will be appreciated that it may be used in any application where a concentrated, controllable field is desired. For instance, the invention may be used to advantage in an electron accelerator or kindred apparatus.

From the foregoing it will be seen that this invention is one well adapted to attain all of the ends and objects hereinabove set forth, together with other advantages which are obvious and which are inherent to the structure.

It will be understood that certain features and subcombinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of the claims.

As many possible embodiments may be made of the invention without departing from the scope thereof, it is to be understood that all matter herein set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

The invention having been described, what is claimed is:

1. An electromagnetic device comprising, a magnetic field generating coil having a central opening therein, a paramagnetic plunger mounted for reciprocation in said opening, and a plurality of curved magnets arranged symmetrically about the coil with the confronting gap faces of each magnet respectively adjacent the two ends of the coil and spaced a substantially equal distance from the central axis of the coil by substantially the inner radius of the coil, the polarity arrangement of said magnets being the same so that the north poles thereof are adjacent one end of the coil and the south poles adjacent the other end of the coil.

2. An electromagnetic device comprising, a magnetic field generating coil having a central opening extending along the central axis thereof, a paramagnetic plunger mounted for reciprocation in said opening, and a plurality of "C" magnets arranged symmetrically about the coil with gap faces of each magnet adjacent the two ends of the coil respectively and spaced a substantially equal distance from the central axis of the coil by substantially the inner radius of the coil, the polarity arrangement of said magnets being the same so that the north poles thereof are adjacent one end of the coil and the south poles adjacent the other end of the coil.

3. An electromagnetic device comprising, a magnetic field generating coil having a central opening extending along the central axis thereof, a paramagnetic plunger mounted for reciprocation in said opening, resilient means opposing movement of the plunger into the coil, and a plurality of "C" magnets arranged symmetrically about the coil with the gap faces of each magnet adjacent the two ends of the coil respectively and spaced a substantially equal distance from the central axis of the coil by substantially the inner radius of the coil, the polarity arrangement of said magnets being the same so that the north poles thereof are adjacent one end of the coil and the south poles adjacent the other end of the coil.

4. An electromagnetic device comprising, a magnetic field generating coil having a central opening extending along the central axis thereof, a plurality of "C" magnets arranged symmetrically about the coil and spaced a substantially equal distance from the central axis of the coil by substantially the inner radius of the coil, the polarity arrangement of said magnets being the same so that the north poles thereof are adjacent one end of the coil and the south poles adjacent the other end of the coil, a plunger mounted for reciprocation in said central opening, one end of said plunger extending into said coil when the coil is not energized to a point approximately one-half the axial distance through the coil, and adjustable resilient means for maintaining the plunger in said position against the force of the magnetic field generated by the "C" magnets, said resilient means exerting an ever increasing force as the plunger is moved further into the coil by a D. C. current being passed through the coil to provide for incremental movement of the plunger in response to incremental increases in said D. C. current.

5. An electromagnetic device comprising a magnetic field generating coil having a central opening extending along the central axis thereof, a plurality of "C" magnets arranged symmetrically about the coil with the gap faces of each magnet adjacent the two ends of the coil and spaced a substantially equal distance from the central axis of the coil by substantially the inner radius of the coil, the polarity arrangement of said magnets being the same so that the north poles thereof are adjacent one end of the coil and the south poles adjacent the other end of the coil, a plunger mounted for reciprocation in said central opening, one end of said plunger extending into said coil when the coil is not energized to a point approximately one-half the axial distance through the coil, and adjustable resilient means for maintaining the plunger in said position against the force of the magnetic field generated by the "C" magnets, said resilient means having straight line characteristics and exerting an ever increasing force as the plunger moves further into the coil by a D. C. current being passed through the coil to provide incremental movement of the plunger in proportion to incremental increases in said D. C. current.

6. An electromagnetic device comprising, a magnetic field generating coil having a central opening therein, an annular diamagnetic shield surrounding the outer periphery of the coil, a paramagnetic plunger mounted for reciprocation in said opening, and a plurality of curved magnets arranged symmetrically about the coil with the confronting gap faces of each magnet adjacent the two ends of the coil and spaced a substantially equal distance from the central axis of the coil by substantially the inner radius of the coil, the polarity arrangement of said

magnets being the same so that the north poles thereof are adjacent one end of the coil and the south poles adjacent the other end of the coil.

7. The device of claim 6 wherein the annular diamagnetic shield is formed of bismuth.

8. An electromagnet device comprising, a magnetic field generating coil having a central opening extending along the central axis thereof, a plurality of "C" magnets arranged symmetrically about the coil with the gap faces of each magnet adjacent the two ends of the coil and spaced a substantially equal distance from the central axis of the coil by substantially the inner radius of the coil, the polarity arrangement of said magnets being the same so that the north poles thereof are adjacent one end of the coil and the south poles adjacent the other end of the coil, a plunger mounted for reciprocation in said central opening, one end of said plunger extending into said coil when the coil is not energized to a point approximately one-half the axial distance through the coil, and adjustable resilient means for maintaining the plunger in said position against the force of the magnetic field generated by the "C" magnets, said plunger in all of its operative positions having a portion positioned between the gap faces of each of the "C" magnets at one end of the coil and spaced from the gap faces of each "C" magnet at the other end of the coil a sufficient distance that changes in the air gap between said last mentioned gap faces and the adjacent end of the plunger will not substantially vary the forces acting on the plunger due to the field of the "C" magnets alone, said resilient means exerting an ever increasing force as the plunger is moved further into the coil by a D. C. current being passed through the coil to provide for incremental movement of the plunger in response to incremental increases in said D. C. current.

9. An electromagnet device comprising, a magnetic field generating coil having a central opening extending along the central axis thereof, a plurality of "C" magnets arranged symmetrically about the coil with the gap faces of each magnet adjacent the two ends of the coil and spaced a substantially equal distance from the central axis of the coil by substantially the inner radius of the coil, the polarity arrangement of said magnets being the same so that the north poles thereof are adjacent one end of the coil and the south poles adjacent the other end of the coil, a plunger mounted for reciprocation in said central opening, one end of said plunger extending into said coil when the coil is not energized to a point approximately one-half the axial distance through the coil, the end of said plunger extending into the coil provided in its end face with a semielliptical depression in its end face, and resilient means for maintaining the plunger in said position against the force of the magnetic field generated by the "C" magnets.

10. The device of claim 9 wherein the semielliptical depression in the end of the plunger is filled with an insert of diamagnetic material.

11. The device of claim 9 wherein the insert of diamagnetic material is formed of bismuth.

12. An electromagnetic device comprising, a magnetic field generating coil having a central opening therein and at least one curved core magnet positioned with its confronting gap faces adjacent the two ends of the coil respectively and spaced from the central axis of the coil by substantially the inner radius of the coil.

13. An electromagnetic device comprising, a magnetic field generating coil having a central opening therein, and a plurality of curved core magnets arranged symmetrically about the coil with the confronting gap faces of each magnet respectively adjacent the two ends of the coil and spaced a substantially equal distance from the central axis of the coil by substantially the inner radius of the coil, the polarity arrangement of said magnets being the same so that the north poles thereof are adjacent one end of the coil and the south poles adjacent the other end of the coil.

14. The device of claim 13 wherein the field of one of said magnetic coil and core magnets is of variable strength to control the combined field strength of the several magnets within the bore of the coil.

References Cited in the file of this patent

UNITED STATES PATENTS

40,133	Van Choate	Sept. 29, 1863
1,552,676	Carpenter et al.	Sept. 8, 1925
1,646,219	Schilling	Oct. 18, 1927
2,671,836	Anger et al.	Mar. 9, 1954