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(54) **PLUNGER TYPE ELECTROMAGNET.**

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(56) References cited:

DE-A- 3 318 034
DE-A- 3 318 034
GB-A- 2 099 223
JP-A-57 138 113
JP-A-59 177 904
JP-U- 4 941 239
JP-U- 5 929 003
JP-Y- 1 390
JP-Y- 4 841 207
JP-Y- 5 930 289
JP-Y- 6 127 140
US-A- 3 223 802
US-A- 4 016 965
US-A- 4 470 030

PATENT ABSTRACTS OF JAPAN vol. 7, no. 186 (E-193)(1331) 16 August 1983,& JP-A-58 89804

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Description

Technical Field

This invention relates to a plunger type electromagnet for use in solenoid valve and the like for controlling the flow of fluid such as air, water, fuel and the like.

Background Art

The plunger type electromagnet is designed

1) to make use of electromagnetic attractive force acting on a movable element upon energization of a coil wound around a stationary element of magnetic substance.

Also,

2) there has been used the so-called "latching type" electromagnet wherein the magnetomotive force generated by energization of a coil and the magnetomotive force by a permanent magnet are allowed to act in series on the plunger of magnetic substance.

The above-mentioned plunger type electromagnet, however, suffers from the following disadvantages.

(1) It inherently requires the presence of a gap between a yoke and the plunger, so that a large ampere-turn is required to magnetize across such a gap. Particularly, the latching type electromagnet requires a larger ampere-turn because a permanent magnet having a large magnetic reluctance is inserted in series in the magnetic circuit developed by coil energization. This entails to enlarge the size of the electromagnet.

(2) There is another disadvantage in that the magnetic attractive force at the gap acts in a given direction along the circumference of the plunger because of the fluctuation in the magnetic flux density as viewed in the circumferential direction of the plunger, whereby the operating frictional resistance of the plunger is increased.

(3) In combination with the condition as set forth in (1) above, in the case of an electromagnet of the type in which the coil must be kept energized as long as the attractive force is to be applied, power consumption is increased accordingly.

(4) Due to deviation in the machining accuracy during mass production of electromagnets, in the material property or in the spring force and the like, there is a likelihood that under the action of the residual magnetic flux, the plunger is not released away from the stationary element even after electric current to the coil is cut off.

(5) With respect to the electromagnet of the type providing the latching function in which the plunger is retained under the action of a permanent magnet even after the power supply to the coil is cut off, there is a need for an electromagnet wherein such a permanent magnet is omitted in order to reduce the production cost, as long as the same latching function is performed in the absence of a permanent magnet.

(6) In the conventional electromagnet, the differential coefficient of the permeance, at the moment where the plunger is attracted toward the stationary element, as differentiated along the direction of movement of the plunger is so small that it is unable to obtain a relatively large initial attractive force.

(7) In the latching type electromagnet in which an annular magnet is employed as a permanent magnet, it has customarily been necessary to magnetize the annular permanent magnet in the radial direction thereof. Magnetization of the annular permanent magnet in such a direction is difficult because of large difference in surface area between the outer and inner peripheries of the annular magnet. For this reason, it has been necessary to divide the annulus into a plurality of sectoral segments. This has resulted in a poor volumetric ratio of the annular permanent magnet, bulky size of the electromagnet, increase in the number of component parts, and low productivity.

GB-A-2 099 223 describes some self-sustaining solenoids one of which having an annular magnet being magnetized in the direction of the thickness of the annulus, which solenoid moves a plunger-like armature by the application of an operating current and retains the armature in its moved position even if the operating current is cut off. In this solenoid, a disc-shaped flange is mounted on a portion of the armature which projects out of the magnetic yoke.

Disclosure of Invention

The present invention is contemplated to solve the foregoing problems encountered during use of the plunger type electromagnet and has for its object to provide a plunger type electromagnet which is high in sensitivity, small in power consumption, compact in size, and light in weight, and which is feasible to meet the needs required by the user.

Findings underlying the present invention will be described below.

(1) Provided that the ampere-turn of a magnetic circuit is constant, the attractive force of the electromagnet is proportional to the differential coefficient of the permeance P between the plunger and the stationary element, as differentiated along the direction of movement of the

plunger.

(2) When the gap being present in the magnetic circuit is small and magnetic pole pieces are held in tight contact with each other, it is considered that the quantity of magnetic flux is roughly constant if the ampere-turn of the magnetic circuit is constant. Accordingly, the smaller the surface area of the abutment face between the magnetic pole pieces is, the greater the attractive force can be, as long as the magnetic flux density B does not become saturated.

(3) The magnetic reluctance of a magnetic circuit is inversely proportional to the cross-sectional area thereof.

Based on the foregoing findings, this invention is comprised of the following solutions in combination and has for its object to reduce the capacity of electric source required for the electromagnet, to render the electromagnet compact, and to reduce the production cost.

i) By means such as provision for an attractive plate on a magnetic pole piece and improvements in the configuration of the abutment face between the magnetic pole pieces, the magnetic reluctance of the magnetic circuit is reduced as well as the permeance of the circuit increased so as to obtain a larger attractive force for a predetermined ampere-turn.

ii) The abutment surface area between the magnetic pole pieces is calibrated in such a manner that the attractive force therebetween is increased.

iii) The permanent magnet in the form of an annulus is magnetized in the direction of thickness.

Structural features of the present invention are given in claim 1. Advantageous embodiments are defined in claims 2 to 5.

Next, with respect to the plunger type electromagnet of the latching type, the following features are applicable.

(a) The permanent magnet is shaped in the form of an annulus, is arranged coaxially with the plunger so as to surround the plunger, and is magnetized in the direction of thickness of the annulus.

(b) The permanent magnet as set forth in feature (a) above is inserted between a magnetic pole piece provided on the end face of the yoke opposite the stationary element, on the one hand, and an annular magnetic pole piece arranged coaxially with and so as to surround the plunger on the end face of the coil directed to the first-mentioned magnetic pole piece, on the other hand.

(c) The magnetic pole piece provided on the end face of the yoke opposite the stationary element is inserted within the yoke, with the plunger extending through the magnetic pole piece, an attractive plate being provided at an end of the plunger opposite the stationary element in such manner that the attractive plate intersects the plunger axis at a right angle and inscribes the inner face of the yoke, the length of the plunger being such that the face of the attractive plate is in registration with the end face position of the yoke when the plunger is not attracted to the stationary element, the permanent magnet as set forth in feature (a) above being arranged between the attractive plate and the magnetic pole piece.

(d) In the electromagnet as set forth in feature (c) above, the permanent magnet is arranged between the magnetic pole piece and the coil and an annular magnetic pole piece is arranged between the permanent magnet and the coil coaxially with the plunger so as to surround the plunger.

(e) There are provided: an attractive plate arranged at an end of the plunger opposite the stationary element in such manner as to intersect the plunger axis at a right angle and to inscribe the inner face of the yoke; a permanent magnet annular in form which is arranged coaxially with the attractive plate at the side of the attractive plate opposite the plunger and which is magnetized in the direction of thickness of the annulus; and, an annular magnetic pole piece arranged coaxially with the attractive plate at the side of the permanent magnet opposite the attractive plate. The length of the plunger is such that the face of the annular magnetic pole piece is in registration with the end face position of the yoke when the plunger is not attracted to the stationary element.

As set forth hereinbefore, the present invention is made based on the well known findings and it provides dominant advantageous effects and contributes in many respects to a wide variety of civil and industrial fields.

That is,

(a) With an electric power equivalent to the same ampere-turn as used hitherto, it is possible to generate an attractive force which is several times of what is obtainable with the conventional device.

(b) With an electric power equivalent to a fraction of the ampere-turn used in the conventional device, it is possible to generate the same attractive force as in the prior art.

(c) It is possible to readily manufacture those electromagnets having various functions such as monostable and bistable functions.

From the foregoing properties, the following specific characteristics are obtainable.

(1) It is possible to enhance the sensitivity and to save energy.
(2) The electromagnet may be made compact in size and light in weight.
(3) It is possible to control the magnetic remanence.
(4) The product is simple in structure and suitable for mass production.

Brief Description of Drawings

Figs. 1 - 4 are cross-sectional views showing examples of the prior art electromagnet;
Fig. 5 is a cross-sectional view illustrating the attractive plate according to the invention as affixed to the plunger;
Fig. 6 is a cross-sectional view showing the abutment faces of the stationary element and the plunger according to the invention;
Fig. 7 is a cross-sectional view showing an embodiment of the invention wherein the permanent magnet and the attractive plate according to the invention are provided;
Fig. 8 is a cross-sectional view showing another embodiment of the electromagnet shown in Fig. 7;
Fig. 9 is a cross-sectional view showing another embodiment of the invention wherein the permanent magnet is mounted to the outer side of the attractive plate;
Fig. 10 is a view showing a working example of improved abutment faces; and
Fig. 11 is a graph showing the input and attractive force relationship of the electromagnet according to the invention as compared with that of the prior art.

Best Mode for Carrying Out the Invention

First, the prior art will be described with reference to the accompanying drawings. Referring to Fig. 1 wherein the conventional device without a permanent magnet is shown, the electromagnet includes a stationary element 12 fixed to a yoke 10, a plunger 14 adapted to abut against the stationary element 12, a spring 16 for spacing the stationary element 12 and the plunger 14 away from each other by a predetermined distance, a coil 18 for magnetizing, upon energization, a magnetic circuit comprised of the stationary element 12, the plunger 14 and the yoke 10 and for attracting the plunger 14 against the bias of the spring 16 to cause it to adhere to the stationary element 12, and a bobbin for winding the coil. Fig. 1 illustrates the rest position in which the coil 18 is de-energized and wherein the plunger 14 is spaced away from the stationary element 12 by the bias of the spring 16. Upon energization of the coil 18, the plunger 14 will be attracted toward the stationary element 12 against the bias of the spring 16, to operate a contact or a valve (not shown) and the like connected to the plunger 14. Upon de-energization of the coil 18, the plunger will be returned to the position shown in Fig. 1.

Figs. 2 and 4 illustrate examples of the conventional devices wherein a permanent magnet is provided. In addition to the stationary element 12, a permanent magnet 24 or an annular permanent magnet 26 is employed in combination. In Fig. 2 , there is shown the rest position in which the coil 18 is de-energized and wherein the plunger 14 is spaced away from the stationary element 12 by the bias of the spring 16. Upon supplying electric current to the coil 18 in such a direction that magnetomotive force having the polarity identical to that of the magnetomotive force by the permanent magnet 24 is induced by the coil, the plunger 14 will be attracted under the combined action of both magnetomotive forces toward the stationary element 12 against the bias of the spring 16 to operate a contact or a valve (not shown) and the like connected to the plunger 14. This condition is maintained only under the action of the permanent magnet 24 even when the coil 18 is de-energized. The so-called "latching" function continues until the electric current is supplied to the coil 18 in such a direction that magnetomotive force having the polarity opposite to that of the magnetomotive force by the permanent magnet 24 is induced by the coil, whereupon the plunger returns to the position shown in Fig. 2 .

Fig. 3 illustrates an example of the conventional abutment faces of the stationary element 12 and the plunger 14.

In Fig. 4, the part above the center line indicates the plunger 14 as spaced away from the stationary element 12, while the part below the center line designates the plunger 14 as attracted to the stationary element. The solid line denotes the line of magnetic force generated by the permanent magnet, while the broken line indicates the line of magnetic force developed by energization of the coil.

The present invention is contemplated to overcome the problems encountered in the conventional plunger type electromagnets described above. The embodiments of the invention will now be described with reference to the drawings.

Fig. 5 illustrates the mode of connection between the attractive plate 22 and the plunger 14. As shown, the attractive plate 22 is affixed by a screw to the plunger 14 by way of an O-ring 21 for limited swinging movement with respect thereto. With this arrangement, the plunger is brought into tight contact with the stationary element and the yoke when the coil is energized, whereby the reluc-

tance of the magnetic circuit is reduced. This arrangement also permits to lower the machining accuracy of the plunger with respect to the stationary element and the yoke, so that the production cost of electromagnet may be reduced.

Fig. 6 shows an improved configuration of the abutment faces of the plunger 14 and the stationary element 12 so as to enhance the sensitivity. Assuming that, in Fig. 6,

U is the magnetizing ampere-turn,

x is the length of the gap as measured in the direction of movement of the plunger, and,

F is the attractive force,

the attractive force F is expressed by the formula

$$F = \frac{1}{2} U^2 \frac{dP}{dx} \qquad (4)$$

Accordingly, assuming that the ampere-turn of the magnetic circuit is constant, it will be noted that the attractive force F is proportional to the differential coefficient of the permeance P as differentiated with respect to the gap length $\underline{x}$ in the vicinity of the illustrated position (Δx) between the plunger 14 and the stationary element 12. Therefore, by designing the abutment faces of the plunger 14 and the stationary element 12 as shown in Fig. 6, the differential coefficient may be increased so as to in turn increase the attractive force. It will be appreciated that, in contrast to the conventional configuration shown in Fig. 3, a greater attractive force may be developed by the configuration shown in Fig. 6.

Fig. 7 illustrates an embodiment of the invention wherein an annular permanent magnet 50 and an attractive plate 22 are provided. The magnetic pole piece 52 at the end face of the yoke 10 is inserted within the yoke. The length of the plunger 14 is such that the face of the attractive plate 22 is brought into registration with the end face position of the yoke when the plunger 14 is not attracted to the stationary element 12. The annular permanent magnet 50 is arranged between the attractive plate 22 and the magnetic pole piece 52.

Fig. 8 illustrates a second embodiment of the electromagnet provided with the annular permanent magnet 50 and the attractive plate 22. The annular permanent magnet 50 is positioned between the magnetic pole piece 52 and the coil 18, while the annular magnetic pole piece 48 is arranged between the annular permanent magnet 50 and the coil 18.

Fig. 9 illustrates another embodiment wherein the annular permanent magnet 50 is provided at the outer side of the attractive plate 22. The annular permanent magnet 50 and an annular magnetic pole piece 54 are mounted to the surface of the attractive plate 22. The length of the plunger 14 is such that the face of the annular magnetic pole piece 54 is brought into registration with the end face of the yoke 10 when the plunger 14 is not attracted to the stationary element 12.

It should be noted that, throughout the drawings of Figs. 7, 8 and 9, the upper half of the drawings indicates the plunger 14 as spaced away from the stationary element 12 and the lower half thereof illustrates the plunger 14 as attracted to the stationary element 12.

Fig. 10 shows a working example of improved abutment faces of the stationary element 12 and of the plunger 14. Fig. 10(a) is a view thereof partly in cross-section, Fig. 10(b) is a plan view, Fig. 10(c) is a cross-sectional view of the plunger 14, and Fig. 10(d) is a cross-sectional view of the stationary element 12. In these drawings, the unit of dimension is expressed in mm. In this example, the distance of travel of the plunger 14 is 2.5 mm.

Fig. 11 is a graph showing the relationship between the input to the electromagnet and the attractive force, with respect to the working example of Fig. 10 and with respect to the conventional electromagnet having the same dimension but provided with neither an attractive plate nor an improved abutment face. It will be appreciated from the graph of Fig. 11 that according to the invention it is possible to obtain a greater attractive force with less input power as compared with the conventional device.

Claims

1. A plunger type electromagnet comprising:
a yoke (10);
a stationary element (12) fixed to said yoke (10);
a plunger (14) having an end face adapted to be adhered to and released from said stationary element (12);
a spring (16) for biasing said plunger (14);
a coil (18) for attracting said plunger (14) to cause it to adhere to the stationary element (12) upon magnetization by energization of the coil (18);
a permanent magnet (50) for retaining said plunger (14) at an energized position even when the coil (18) is de-energized, said permanent magnet (50) is formed in an annular shape, is arranged coaxially with said plunger (14) so as to surround the plunger (14) and is magnetized in the direction of the thickness of the annulus;
characterized in that
an attractive plate (22), provided at an end of said plunger (14) opposite the end to which said stationary element (12) adheres, inscribes the inner face of said yoke (10) and
a magnetic pole piece (52, 54), positioned at

one pole side of said permanent magnet (50) the other side of which facing said attractive plate (22), is inserted within said yoke.

2. The plunger type electromagnet according to claim 1, wherein said magnetic pole piece (52) is annular and is arranged such that said plunger (14) is extending through it.

3. The plunger type electromagnet according to any of claims 1 or 2, wherein the length of said plunger (14) being such that the face of said attractive plate (22) is brought into registration with the end face of said yoke (10) when said plunger (14) is not attracted to said stationary element (12).

4. The plunger type electromagnet according to claim 1, wherein said permanent magnet (50) is mounted at the side of said attractive plate (22) opposite said plunger (14) and said magnetic pole piece (54) is mounted on the other side of said permanent magent (50).

5. The plunger type electromagnet according to claim 4, wherein the length of said plunger (14) is such that the outer face of said magnetic pole piece (54) is brought into registration with the end face of said yoke (10) when said plunger (14) is not attracted to said stationary element (12).

Patentansprüche

1. Kolbenartiger Elektromagnet, der aufweist:
   - ein Joch (10);
   - ein Stationärelement (12), das an dem Joch (10) befestigt ist;
   - einen Kolben (14) mit einer Endfläche, die angepaßt ist, um sich an das Stationärelement (12) anzulegen und sich von diesem zu lösen;
   - eine Feder (16) zum Vorspannen des Kolbens (14);
   - eine Spule (18) zum Anziehen des Kolbens (14), um ihn zu veranlassen, sich an das Stationärelement (12) nach Magnetisierung durch Anregung der Spule (18) anzulegen;
   - einen Permanentmagnet (50) zum Halten des Kolbens (14) an einer angeregten Position, selbst wenn die Spule (18) nicht mehr angeregt ist, wobei der Permanentmagnet (50) in einer ringförmigen Form gebildet ist, koaxial mit dem Kolben (14) angeordnet ist, um den Kolben (14) zu umgeben, und in der Richtung der Dicke des Ringes magnetisiert ist;

   dadurch gekennzeichnet, daß
   - eine Anzugsplatte (22), die an einem Ende des Kolbens (14) gegenüber dem Ende, an dem das Stationärelement (12) anliegt, bereitgestellt ist, die die Innenfläche des Jochs (10) einbeschreibt, und
   - ein magnetisches Polstück (52, 54), das an einer Polseite des Permanentmagneten (50) positioniert ist, dessen andere Seite der Anzugsplatte (22) gegenüberliegt, innerhalb des Jochs eingefügt ist.

2. Kolbenartiger Elektromagnet nach Anspruch 1, wobei das magnetische Polstück (52) ringförmig ist und derart angeordnet ist, daß sich der Kolben (14) durch dieses erstreckt.

3. Kolbenartiger Elektromagnet nach einem der Ansprüche 1 oder 2. wobei die Länge des Kolbens (14) derart ist, daß die Fläche der Anzugsplatte (22) in eine registerhaltige Position mit der Endfläche des Jochs (10) gebracht wird, wenn der Kolben (14) nicht zum Stationärelement (12) hin angezogen wird.

4. Kolbenartiger Elektromagnet nach Anspruch 1, wobei der Permanentmagnet (50) an der Seite der Anzugsplatte (22) gegenüber dem Kolben (14) montiert ist und das magnetische Polstück (54) an der anderen Seite des Permanentmagneten (50) montiert ist.

5. Kolbenartiger Elektromagnet nach Anspruch 4, wobei die Länge des Kolbens (14) derart ist, daß die äußere Fläche des magnetischen Polstücks (54) in eine registerhaltige Position mit der Endfläche des Jochs (10) gebracht wird, wenn der Kolben (14) nicht zu dem Stationärelement (12) hin angezogen wird.

Revendications

1. Un électro-aimant du type à noyau plongeur, comprenant :
   une culasse (10);
   un élément fixe (12) fixé à cette culasse (10);
   un noyau plongeur (14) possédant une face d'extrémité conçue pour venir se coller à cet élément fixe (12) et s'en libérer;
   un ressort (16) pour solliciter ce noyau plongeur (14);
   une bobine (18) pour attirer le noyau plongeur (14) afin de le faire coller à l'élément fixe (12) du fait de la magnétisation par activation de la bobine (18);
   un aimant permanent (50) pour maintenir le noyau plongeur (14) en une position activée

même quand la bobine (18) est désactivée, cet aimant permanent (50) ayant une forme annulaire, étant configuré coaxialement avec le noyau plongeur (14) afin d'entourer ce noyau plongeur (14) et étant magnétisé dans le sens de l'épaisseur de l'anneau;

caractérisé en ce qu'

une plaque d'attraction (22), disposée à une extrémité du noyau plongeur (14) opposée à l'extrémité qui se colle à l'élément fixe (12), entoure la face intérieure de la culasse (10) et

une pièce polaire magnétique (52, 54), disposée à l'un des pôles de l'aimant permanent (50) dont l'autre pôle fait face à la plaque d'attraction (22), est insérée à l'intérieur de cette culasse.

2. L'électro-aimant du type à noyau plongeur selon la revendication 1, dans lequel la pièce polaire magnétique (52) est annulaire et est configurée de telle manière que le noyau plongeur (14) s'étende au travers d'elle.

3. L'électro-aimant du type à noyau plongeur selon l'une quelconque des revendications 1 ou 2, dans lequel la longueur du noyau plongeur (14) est telle que la face de la plaque d'attraction (22) soit amenée en alignement avec la face d'extrémité de la culasse (10) lorsque le noyau plongeur (14) n'est pas attiré vers l'élément fixe (12).

4. L'électro-aimant du type à noyau plongeur selon la revendication 1, dans lequel l'aimant permanent (50) est monté du côté de la plaque d'attraction (22) qui est opposé au noyau plongeur (14), et la pièce polaire magnétique (54) est montée de l'autre côté de cet aimant permanent (50).

5. L'électro-aimant du type à noyau plongeur selon la revendication 4, dans lequel la longueur du noyau plongeur (14) est telle que la face extérieure de la pièce polaire magnétique (54) soit amenée en alignement avec la face d'extrémité de la culasse (10) lorsque le noyau plongeur (14) n'est pas attiré vers l'élément fixe (12).

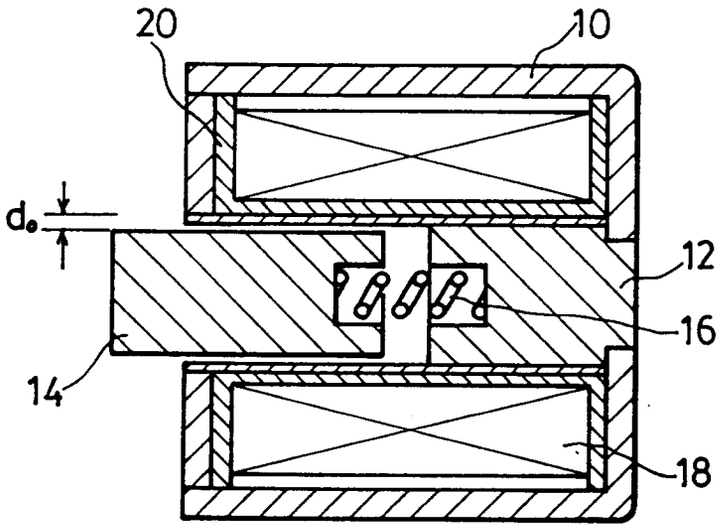


FIG. 1

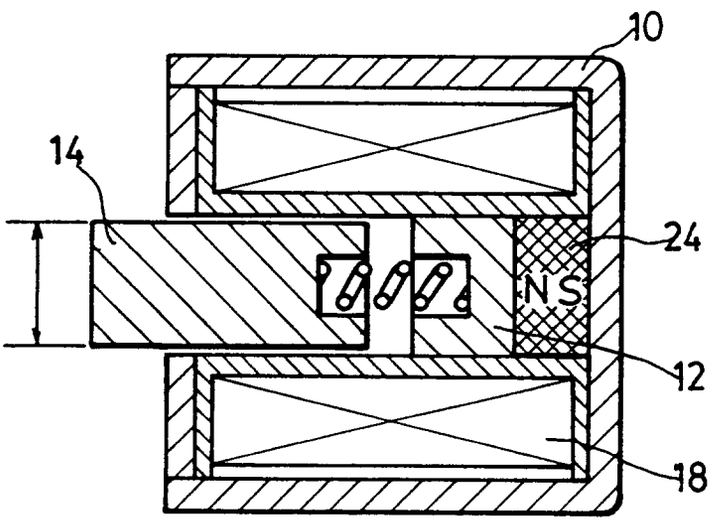


FIG. 2

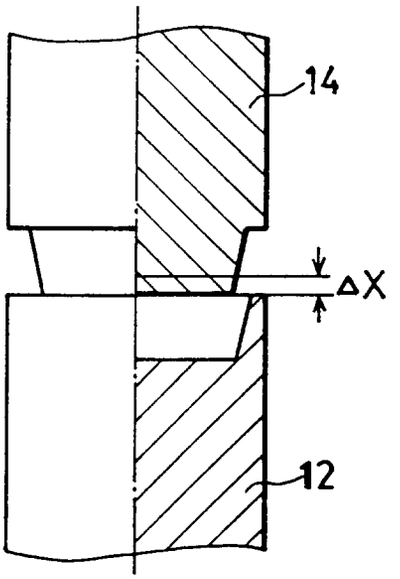


FIG. 3

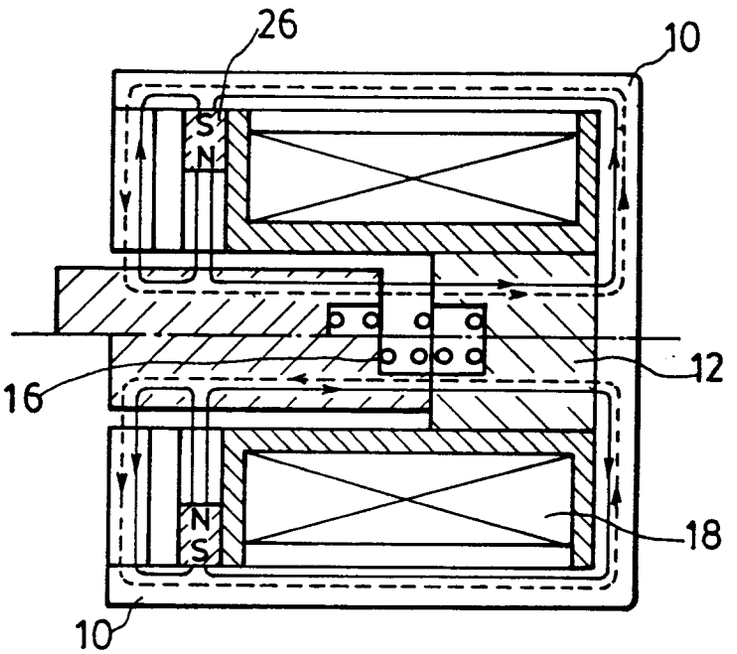


FIG. 4

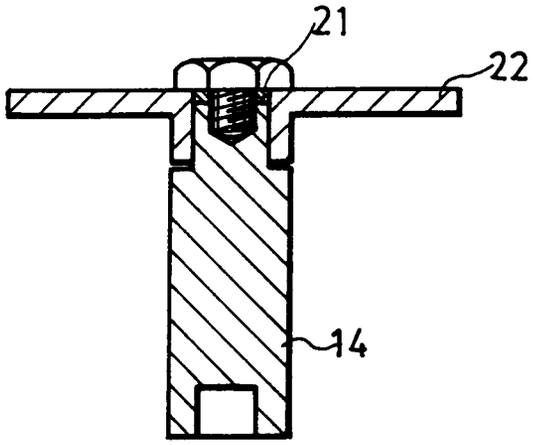


FIG.5

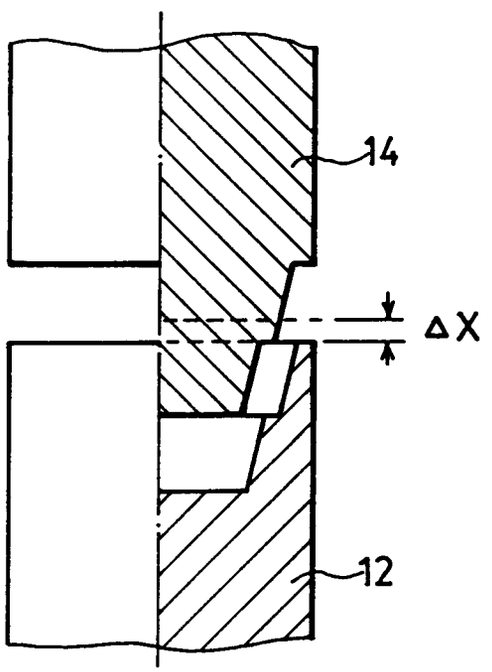


FIG.6

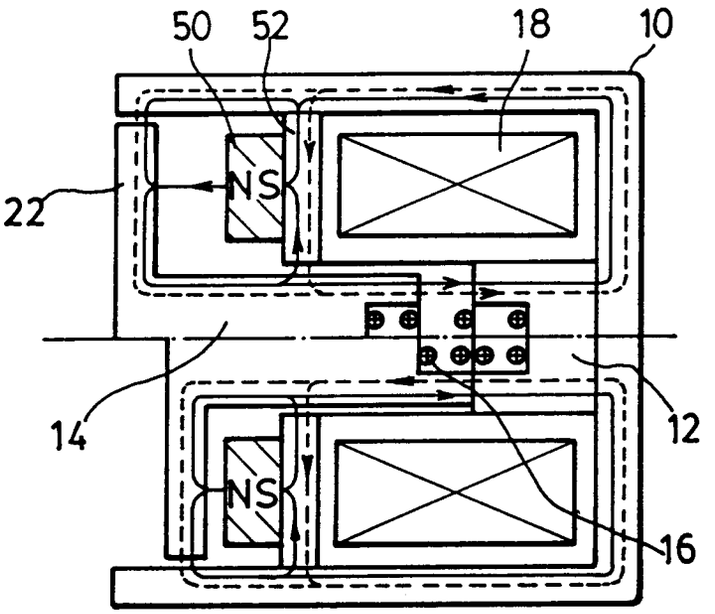


FIG. 7

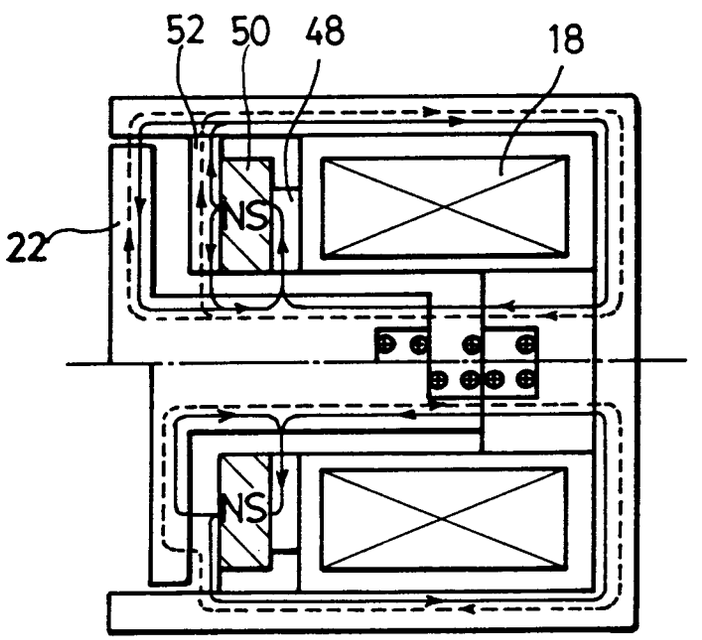


FIG. 8

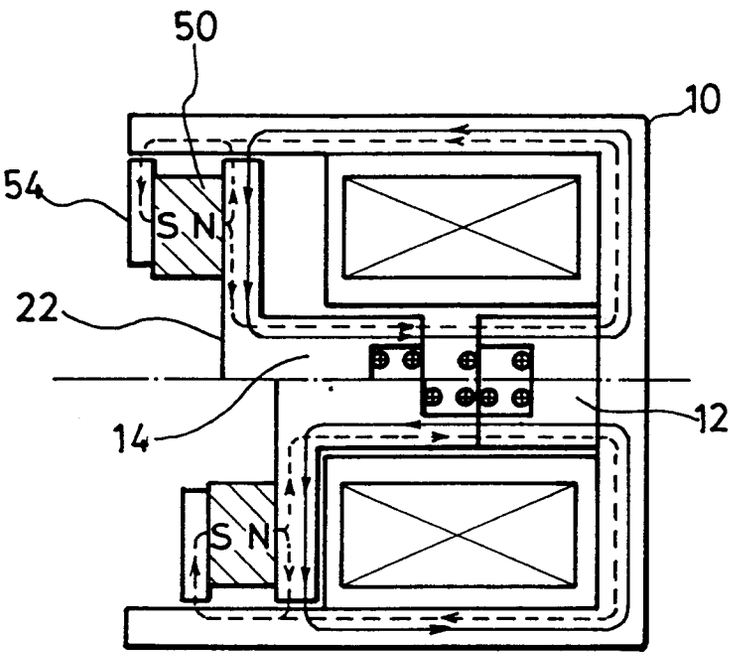
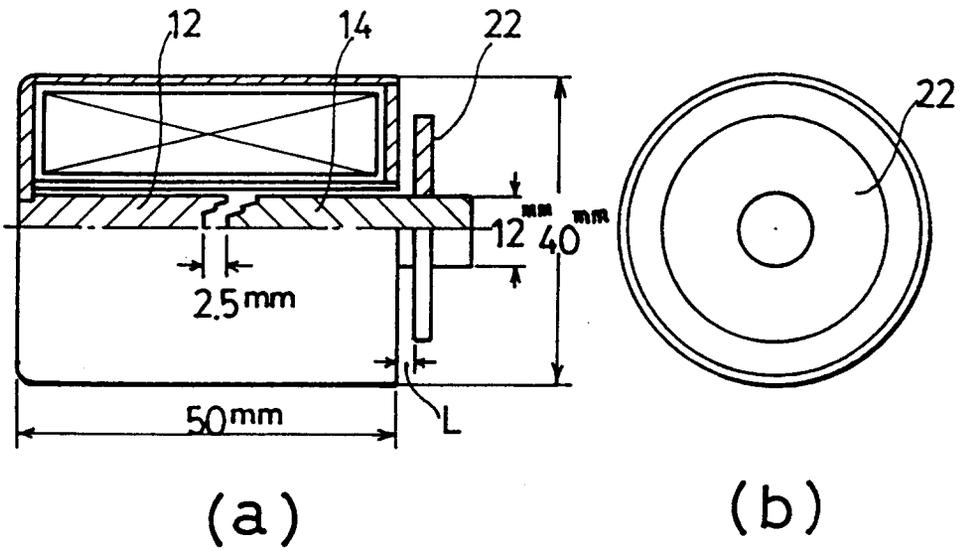
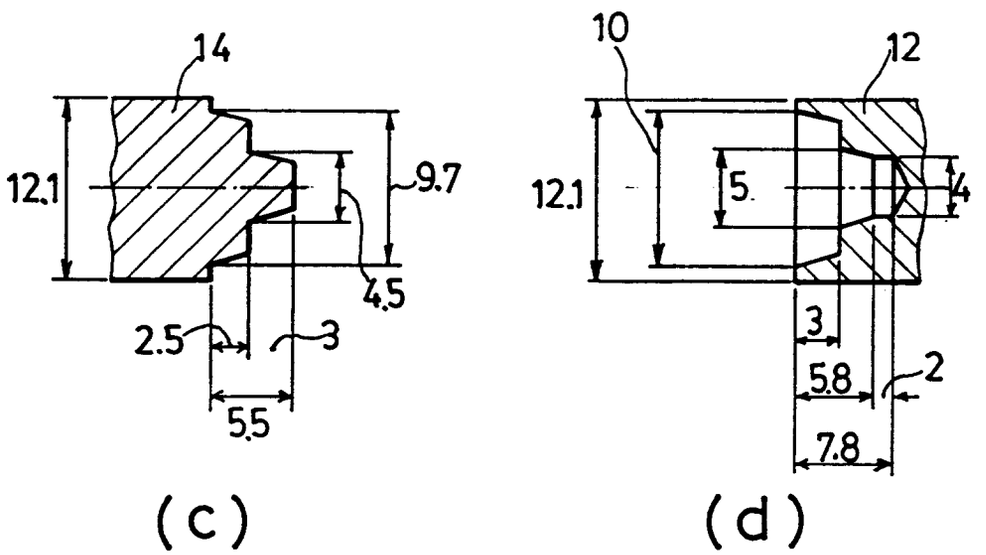


FIG. 9


12
14
22
12 mm
40 mm
2.5 mm
50 mm
L
22

(a) (b)


14
12.1
9.7
4.5
2.5
3
5.5
10
12
12.1
5
4
3
5.8
2
7.8

(c) (d)

FIG. 10

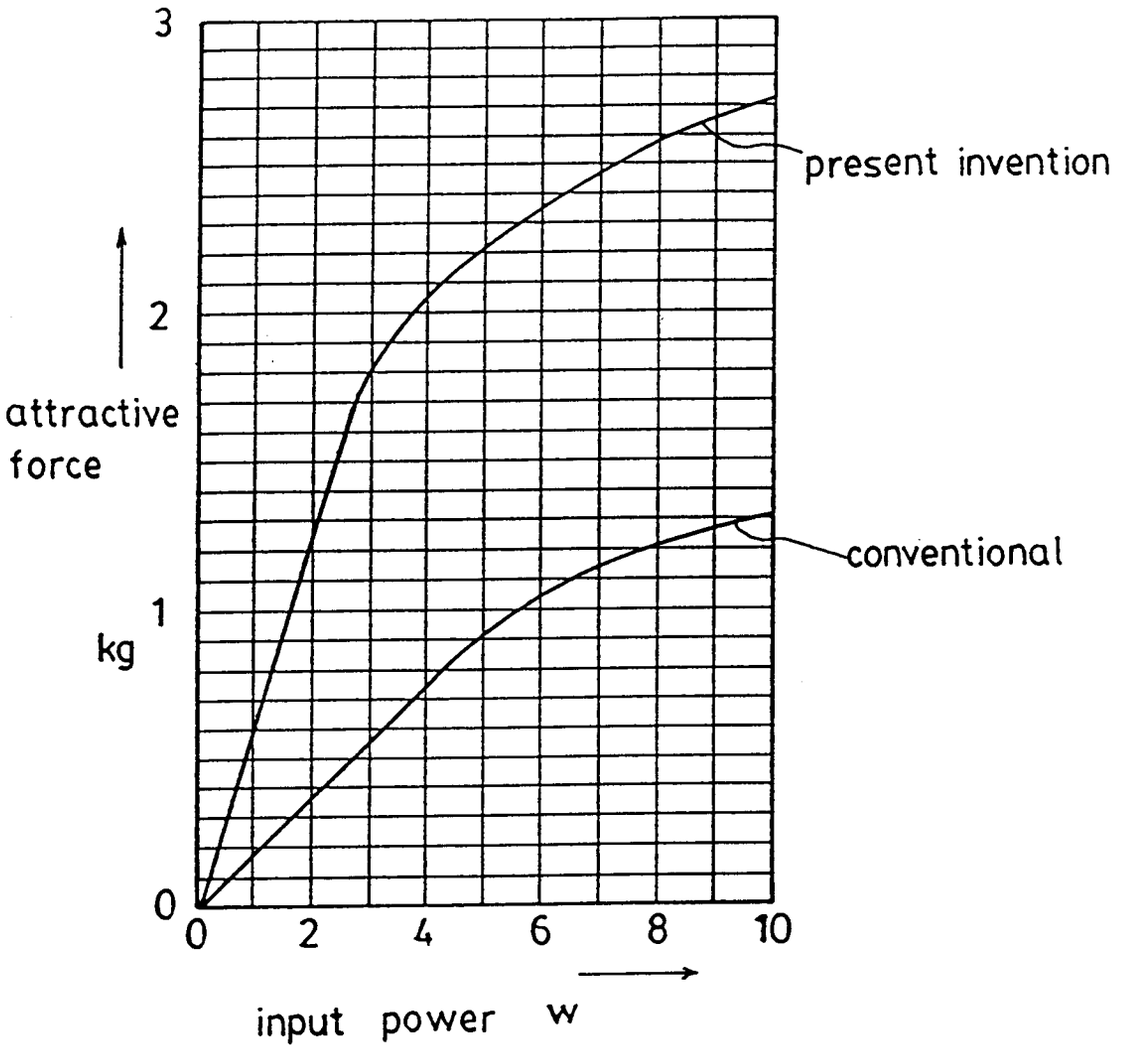

3
2
1
0
attractive force
kg
present invention
conventional
0
2
4
6
8
10
input power w

FIG.11