

[54] SOLENOID DEVICE

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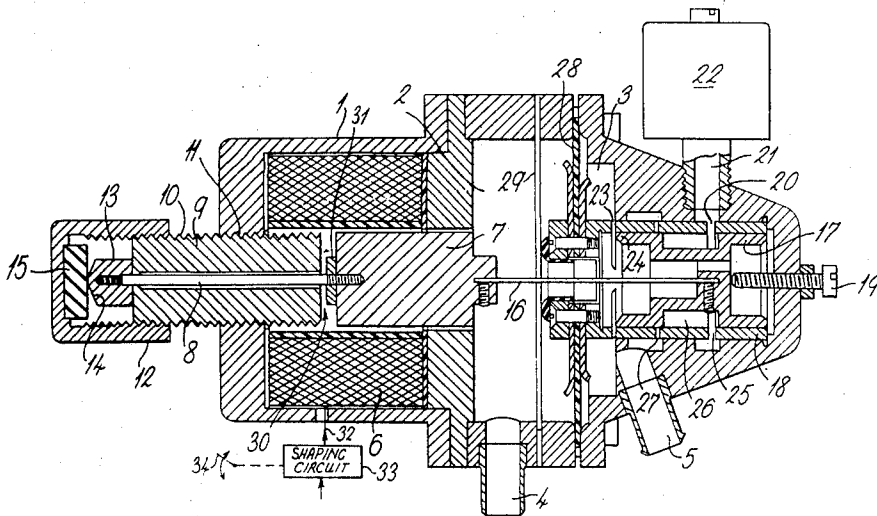
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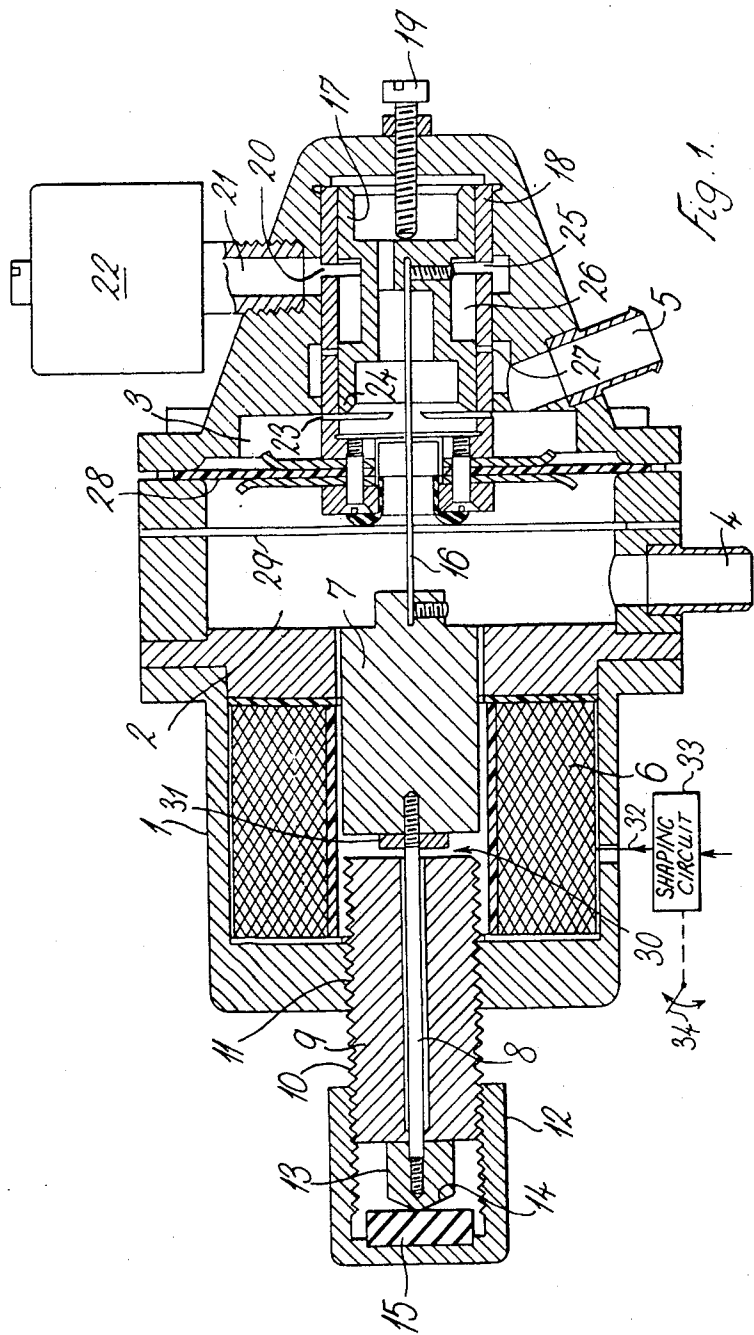
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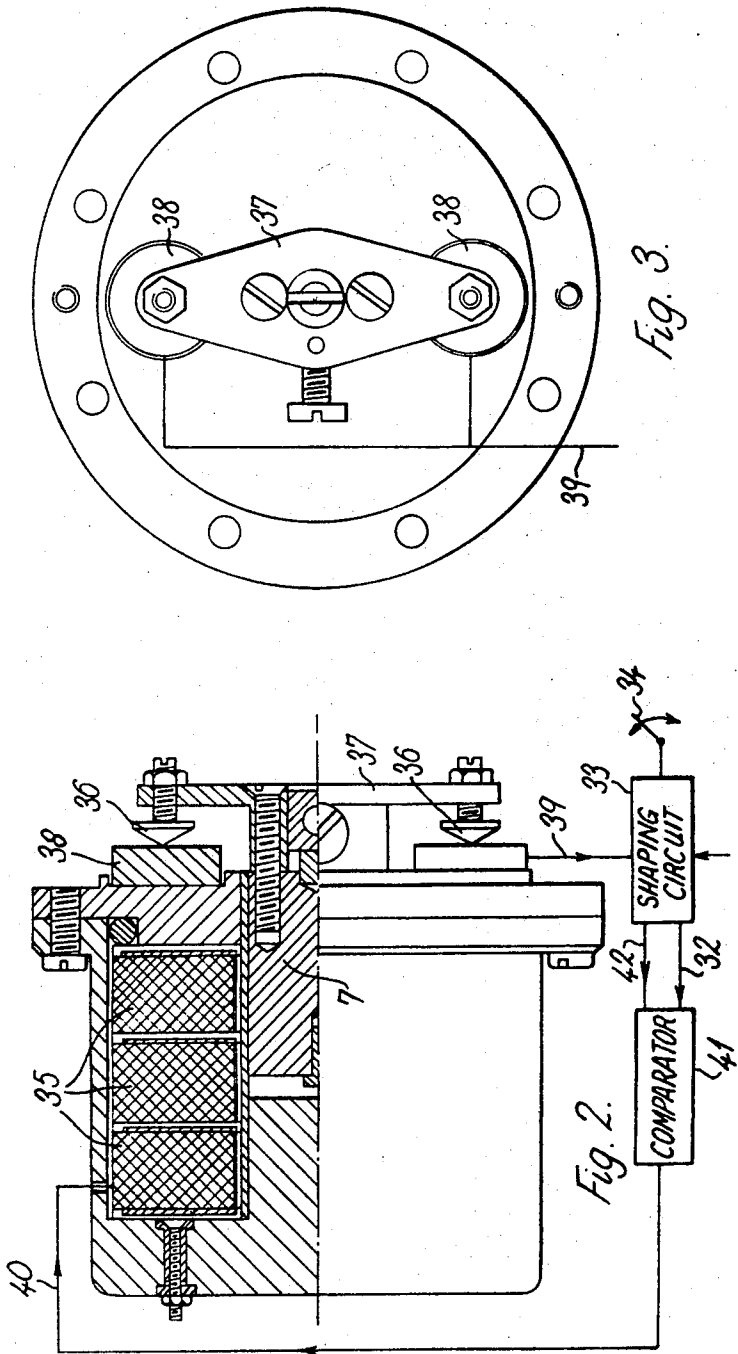
[57] ABSTRACT

A solenoid device capable, by variation of coil current, of holding the core at positions intermediate the ends of its working range of movement. A force matching device, for example a resilient pad mounted on the coil and lying in the path of the core, opposes the approach of the core to the coil. The characteristics of this device are chosen to match the increasing electromagnetic force of attraction between coil and core as they approach and as coil current rises. The solenoid device may be used in an electromagnetic control valve in which the valve setting is required to be proportionate to the input signal.

3 Claims, 4 Drawing Figures







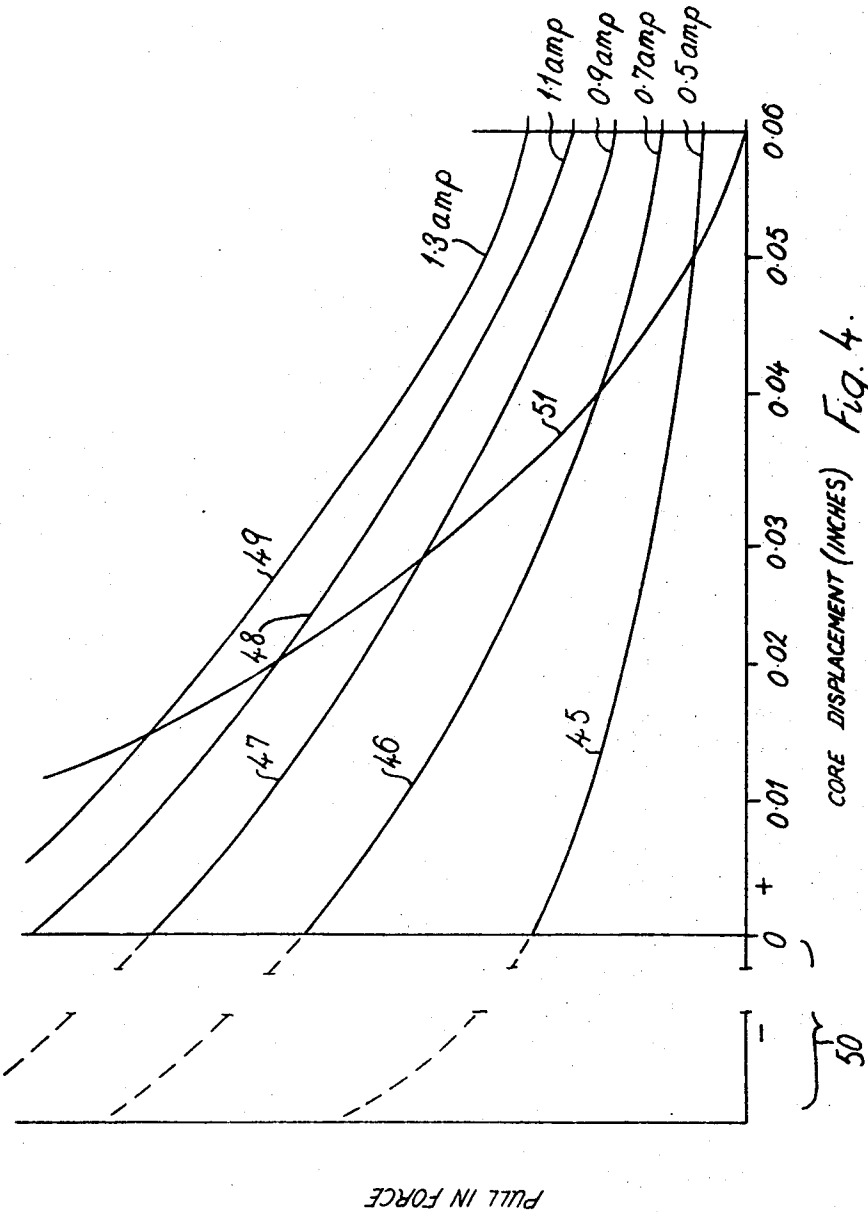


Fig. 4.

SOLENOID DEVICE

This invention relates to solenoid devices, and uses for them. A solenoid essentially comprises a coil and a core. The coil may be electrically energized and surrounds a cylindrical space; the core may move into and out of this space along its axis. When the coil is energized the resulting magnetic field draws the core into the space, to one extreme end of its travel. When the current is turned off, a return spring or the like usually moves the core to the other extreme end of its travel. There have been proposals to use springs, etc. to cushion the approach of the core to each end of its travel, and to avoid it jamming in these positions, but these have not overcome the limitation that the solenoid, even when thus modified, is essentially a two-position, on-off device. There are many applications in which it would be useful to use a solenoid not merely to select one of two positions, but to select one of an infinite number of positions along a linear scale, by means of linear variation of the operating current. Unfortunately, the force exerted upon the core of an ordinary solenoid by the magnetic force of the coil is not related in linear fashion to the displacement of the core within the coil; in fact, the force rises steeply as the core comes closer to the center of the coil. Methods have been proposed to achieve greater linearity, for instance by providing several co-axial coils arranged in line, but such methods have obviously tended to be both bulky and expensive.

Our invention is a solenoid device capable of holding the core at positions, determined by the coil current, that lie between the extreme ends of its full range of movement. Our invention includes an electromagnetic control valve using such a solenoid device, is defined by the claims at the end of this specification, and will now be described by way of example with reference to the accompanying drawings in which:

FIG. 1 is an axial section through part of the control valve for a servo brake unit;

FIG. 2 is a similar section through part of an alternative unit;

FIG. 3 is an end elevation of the apparatus of FIG. 2, and

FIG. 4 is a graph illustrating the characteristics that must be found for the force matching device.

The valve comprises a housing 1 enclosing two separated spaces 2 and 3. Space 2 is connected by port 4 to the vacuum side of the control valve for a servo brake unit (not shown). Space 3 communicates by way of port 5 with the active side of the diaphragm of the same servo brake unit. The coil 6 of a solenoid according to the invention is mounted in the housing 1, and the core 7 of the same solenoid is guided to slide along the axis of coil 6. Core 7 carries a push rod 8, which slides within a sleeve 9 externally threaded at 10. One end of this sleeve screws into a threaded hole 11 at one end of the housing 1. The other end of the sleeve receives an internally threaded cap 12. The remote end of push rod 8 carries a metal indenter 13 with a conical face 14, which penetrates more and more deeply into a resilient rubber block 15, carried by the cap 12, as core 7 travels to the left in response to energization of coil 6. Block 15 constitutes a force matching device as specified in the claims. The shape of face 14 and the characteristics of block 15 are so chosen that the non-linear rise of reaction force in response to greater penetration matches

the typical non-linear rise of the force of attraction between coil 6 and core 7 as the latter travels to the left. In a typical application the block 15 might be one-fourth inch thick, and the total axial travel of core 7 might be 0.070 inch. A typical mean operating current for coil 6 is of the order of one amp, and variable positioning of core relative to coil is obtained by supplying the current to the coil by means of a constant voltage with variable pulse length, with mark/space ratio modulation from 10 to 90 percent. This current reaches the coil 6 in the form of the output signal 32 of a shaping circuit 33 which determines the mark/space ratio according to the setting of an operating member 34, which could for instance be a car brake pedal.

The right-hand end of core 7 is joined by a light push rod 16 to a valve spool 17, sliding within a sleeve 18 which itself slides within housing 1. Travel of spool 17 to the right is limited by metal indenter 13 abutting on sleeve 9. Screw 19 is for setting-up adjustment only. Air at atmospheric pressure enters the housing by way of port 20, conduit 21 and air filter 22. When core 7 is in an extreme leftward position block 15 is balancing the greatest force of attraction obtainable between coil 6 and core 7 at which time current is supplied at the highest possible mark space ratio. In this position a small predetermined gap 39 is fully closed and core 7 is separated from sleeve 9 by non-magnetic spacing washer 31.

With the valve in the position shown, ports 20 and 5 are not in communication, but port 5 is in communication with port 4 by way of space 3, port 23 and space 2. Vacuum therefore exists to both sides of the servo diaphragm in the brake unit, and therefore the brakes are not applied. If operating member 34 is now moved from its idle position to an active position so as to demand actuation of the brakes to a certain degree, core 7 is pulled to the left and pulls spool 17 with it. The tip 24 of spool 17 now covers port 23, thus sealing space 3 from space 2. If the leftwards movement continues, air from port 20 reaches space 3 by way of port 25, land 26 and port 27. This of course destroys the equality of pressures to either side of the servo diaphragm, and applies the brakes. The increase in pressure in space 3 also causes feedback diaphragm 28 to deflect to the left, which causes sleeve 18 to do the same since this is mounted on diaphragm 28. The left-hand tip of this sleeve thus meets cantilever spring 29 and deflects it to a degree proportional to the braking effort across diaphragm 28. This movement of sleeve 18 tends to close port 27, thus destroying communication between ports 20 and 5, and thus creating a feedback system creating a stable state in which the brakes are applied to a degree determined by the distance that core 7 has travelled to the left. By use of the indenter 13 and block 15 according to this invention, this distance may bear a convenient linear relationship to the mark/space ratio of the current flowing in the coil. The braking force applied by the servo brake unit, once the stable state is achieved, is also of course reflected in the degree of displacement of the feedback diaphragm 28 and sleeve 18. When the current supply is cut off, block 15 drives indenter 13, and hence spool 17 via rod 16 to the right. Only then will spring 29 return sleeve 18 to the right-hand end of its travel and diaphragm 28 resume its normal undeflected shape. Of course, in practice, FIG. 1 is vertical with screw 19 downmost and this restoring action is therefore assisted by gravity. Rod 16 may be

made light enough to bow if the spool 17 unfortunately jams at the left-hand end of its travel, but strong enough to behave as quite rigid if the spool is moving normally.

There is obvious scope for variation of the materials of parts 15 and 13, and of the shaping of face 14. Alternatively core 7 could bear against a variable rate spiral spring, or an equivalent fluid-operated device with characteristics to match those of the solenoid.

In the alternative construction of FIGS. 2 and 3 the single coil 6 has been replaced by three coils 35 in series. Keeping the other parameters of the instruments of FIGS. 1 and 2, 3 as similar as possible, this modification has improved the time constant by up to 15 percent by reducing the inter-turn capacitive effects from which the single larger coil suffered. It will also be seen that within indenters 36 are carried on a bridge 37 carried on the opposite end of the core 7, and that these bear against a member 38 forming part of a force matching device of a different kind. The member 38 is a resilient force transducer. The resilience however is not chosen to match the forces of attraction between core and coil; it is instead roughly linear, that is to say reaction force varies roughly directly with penetration of the member by indenters 36. Force transducer 38 emits an electrical signal 39 representing the reaction force that it is exerting at any instant, and this signal is fed as another input to the same circuit 33 that determines the mark/space ratio. In this version of the invention the circuit is programmed to convert signal 39 to the level it would have had if member 38 had possessed non-linear characteristics like block 15 instead of simpler linear ones. In this version the input to coils 35 is the output or error signal 40 of a comparator 41 which receives as inputs the converted version 42 of signal 39, and the signal 32.

The unit illustrated in FIGS. 2 and 3 is more compact and had less possible sources of air leakage than the unit illustrated in FIG. 1. This is specially convenient if it is desired to run a system, of which the unit is part, under some pressure other than ambient. The unit of FIGS. 2 and 3 could of course use a resilient block with non-linear characteristics, like item 15 of FIG. 1, instead of member 38 and the associated electrical devices which convert the linear reaction of member 38 into a non-linear function 42. The version of FIGS. 2 and 3 also has the advantage of avoiding the changes in spring stiffness characteristic that may in time affect a elastic block such as item 15 in FIG. 1. The version of FIGS. 2 and 3 will however be more subject to drift of electronic components, since they are more numerous in this version. Neither version as described compensates for hysteresis errors in the components; detection and compensation of these would require, for in-

stance, the combination of a non-linear device like item 15 of FIG. 1 with a high-gain positional feedback system to monitor the relative position of coil and core.

FIG. 4 illustrates the characteristics required of a block 15. Each of functions 45 - 49 represents the forces that the coil will exert upon the core over a working range of core movement extending from 0.00 inch (core fully in) to 0.06 inch (core farthest out), for a given mean core current. The six functions cover mean currents rising in equal steps of 0.2 amp. from 0.5 amp. (function 45) to 1.3 amp. (function 49). The distance 50 represents the thickness of spacing washer 31, i.e. the further distance that the core would have to travel into the coil beyond its "fully in" position before metal-to-metal contact between spacing washer 31 and sleeve 9 positively stopped further movement. In practice the gap 30 may be about as wide as the full working range of movement. Function 51 represents the corresponding reaction force/penetration of block relationship that must exist in block 15 if it is to match the pull-in force as required, that is to say if it is to halt core 7 0.01 inch further in for each increment of 0.20 amps. in the coil current.

We claim:

1. A solenoid device comprising: a coil and a core, said core being mounted for a working range of movement towards and away from said coil, said coil being adapted to generate a first electromagnetic force to attract said core, said first force gradually increasing according to a first predetermined pattern as coil current increases and the separation of the coil and core decreases, a force matching device, said device being adapted to generate a second force opposing the mutual approach of the coil and core, said second force gradually increasing according to a second predetermined pattern as the separation of the coil and core decreases, and wherein said first and second patterns are matched, whereby said coil may hold said core at positions between the extreme ends of said working range of movement, said positions being dependent upon coil current.

2. A solenoid device according to claim 1 wherein the two said patterns are such that unit incremental change in coil current produces an unvarying unit movement of the core within its working range of movement.

3. A solenoid device according to claim 1, in which the force matching device is elastic, in which this device is fixed relative to one of said coil and core members, and in which the other of said members distorts the device upon relative movement of the two members.

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