(12) UK Patent Application (19) GB (11) 2 079 412 A

(21) Application No **8121157**
(22) Date of filing **9 Jul 1981**
(30) Priority data
(31) **3026133**
(32) **10 Jul 1980**
(33) **Fed. Rep of Germany (DE)**
(43) Application published
20 Jan 1982
(51) **INT CL[3]**
F16K 31/08
(52) Domestic classification
F2V H10 H1B H32 H4
(56) Documents cited
None
(58) Field of search
F2V
(71) Applicants
Robert Bosch GMBH.,
Postfach 50,
7000 Stuttgart 1,
Federal Republic of Germany.
(72) Inventors
Theodor Gast,
Kurt Binder.
(74) Agents
Messrs. W.P. Thompson & Co.,
Coopers Building,
Church Street,
Liverpool L1 3AB.

(54) Solenoid valve

(57) The valve uses shell type cores (1,2) providing respective poles surrounded by windings (3,4) and clamping between them a ferromagnetic ring. These components delineate a cavity in which a valve member (8, 11) operates, comprising a permanent magnet (8). When the coils are unenergised, the valve member is maintained in a position to open the valve seat and the coils are arranged so that, on energisation, they increase the force of attraction on the valve member on the side thereof going first in the direction of movement of the valve member and decrease the force on the other side thereof. The valve member can, therefore, be operated with minimum dead time.

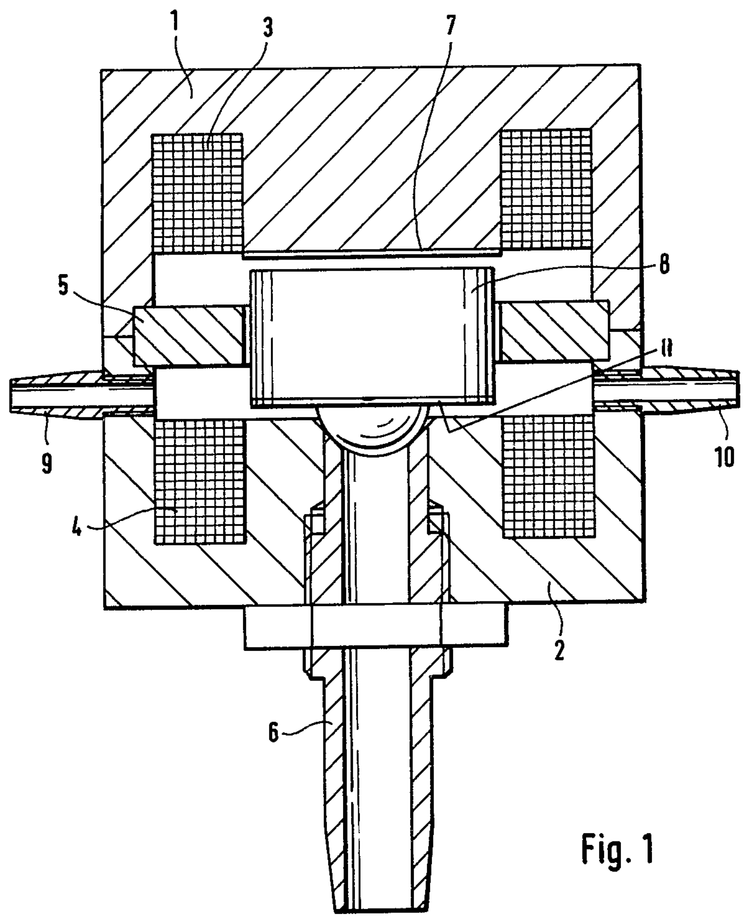


Fig. 1

GB 2 079 412 A

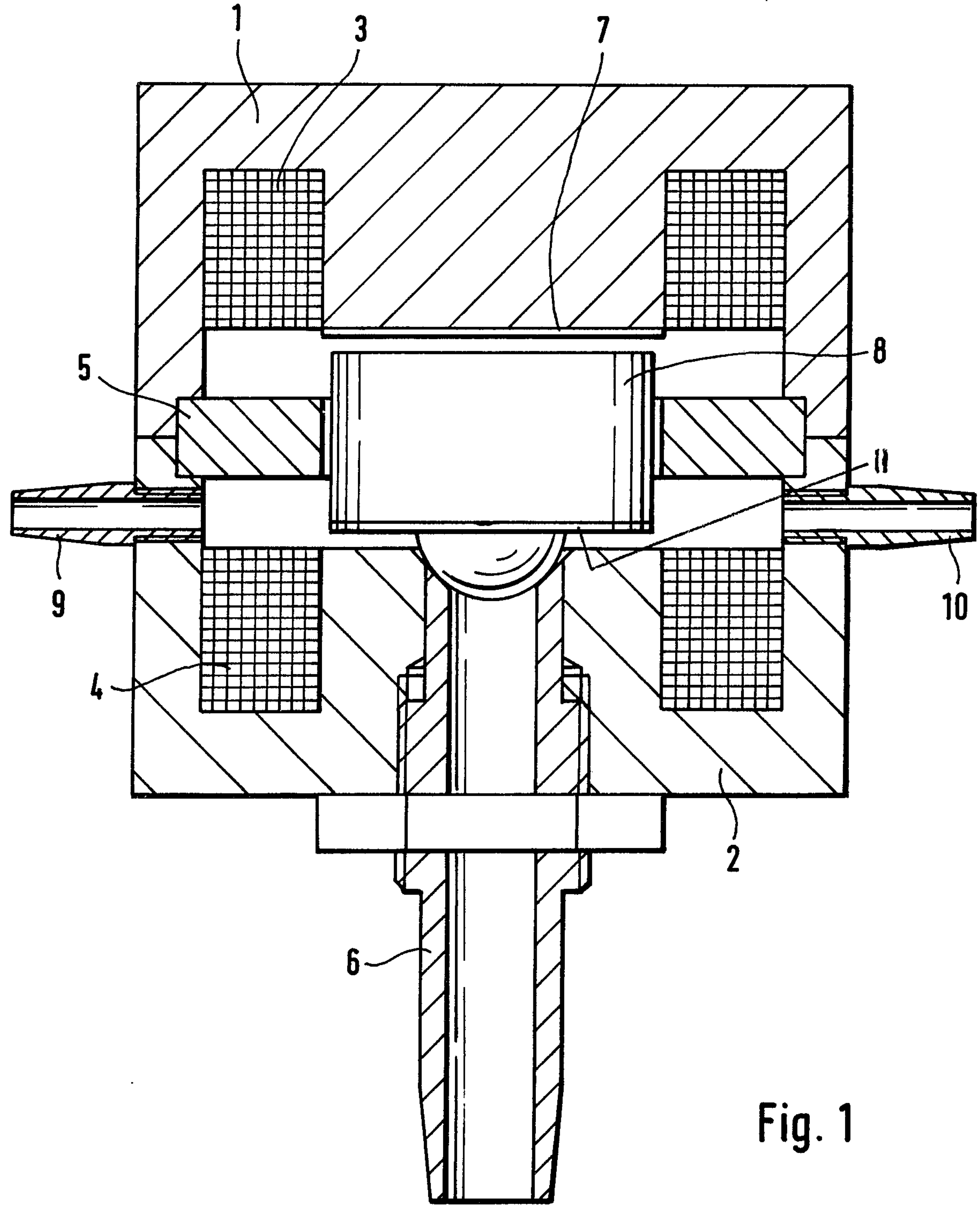


Fig. 1

2/2

Fig. 2

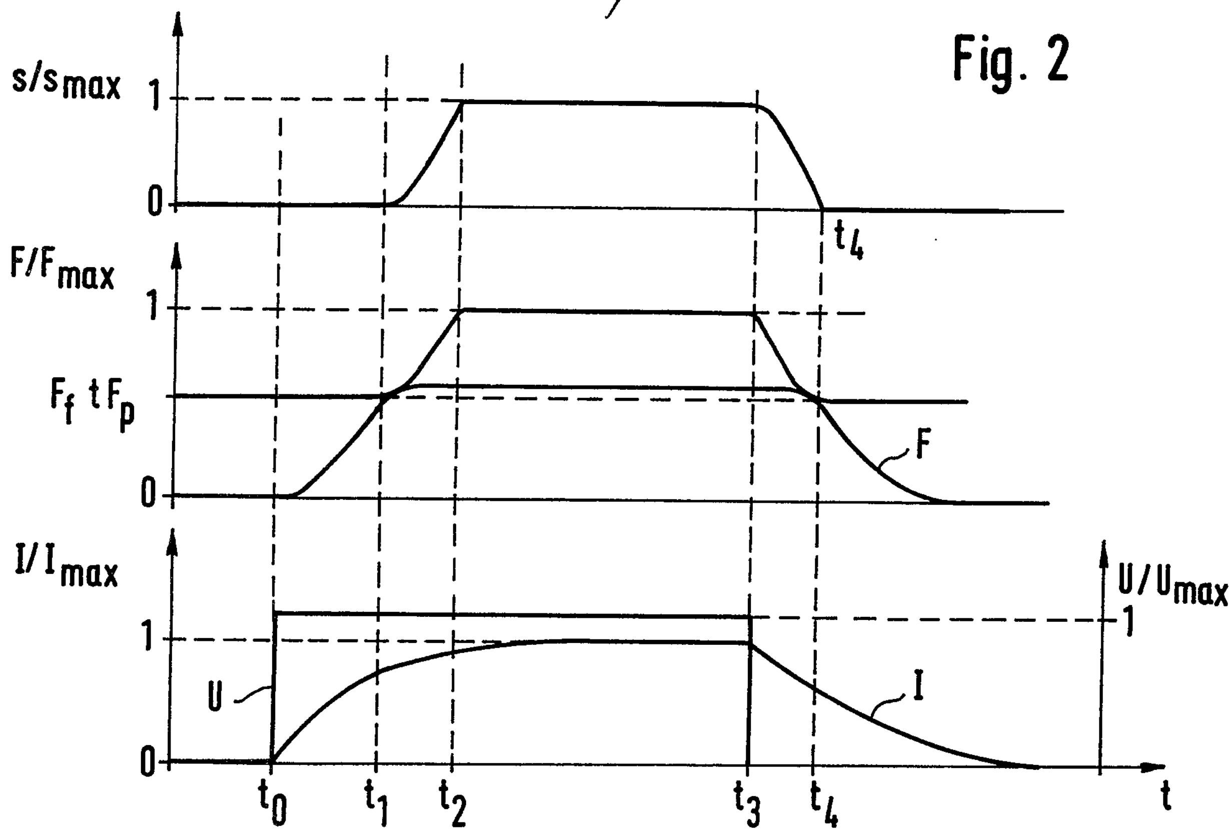
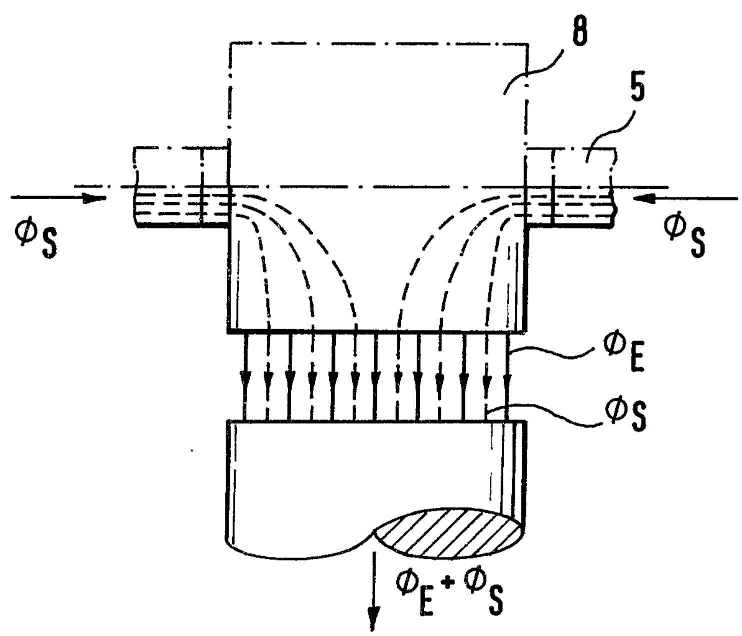

s/smax
1
0
t4
F/Fmax
1
Ff t Fp
F
0
I/Imax
U/Umax
1
1
U
I
0
t0
t1
t2
t3
t4
t

Fig. 3


8
5
ΦS
ΦS
ΦE
ΦS
ΦE + ΦS

SPECIFICATION

Solenoid valve

The present invention relates to a solenoid valve.

Electro-magnetically operated (or solenoid) valves are known in which a cone or a ball valve member is pressed into a valve seat by means of a spring and, when in this position, effects a tight seal and thus interrupts a flow. In order to put the flow into operation, the valve member is withdrawn from the seat by an electro-magnet against the force of the spring by means of a plate of ferromagnetic material which is connected to the ball. The flow continues for as long as the electromagnet holds the plate. Although valves of this kind have been under develoment for a long period of time, they have disadvantages which are of a fundamental nature and which thus cannot be eliminated structurally.

Basically, they have a considerable dead time. This is shown by the graph of Figure 2 of the accompanying drawings, in which the characteristic of the voltage, the current, the attractive force, the acceleration, the speed and the travel are plotted against the time axis.

If a constant voltage U is applied to the magnet coil at the instant $t = 0$, as is usually the case during practical use, the current increases in accordance with an exponential function.

$$I = I_{max}\,(1 - e^{-t/\tau}) \text{ to a maximum valve } I_{max} = U/R$$

wherein R is the ohmic resistance of the coil t is the time constant of the coil, and $\tau = L/R$ when L represents the self-inductance of the coil.

Consequently, the attractive force increases from zero approximately in accordance with a function

$$F = k\,I^2/l$$

in which l is the gap width and *k* is a constant in which the iron cross section and the number of turns of the coil appear, and the magnetic resistance in the iron is ignored. The magnetic attractive force, increased by the pressure force, reaches the value of the spring force F_f at the instant t_l, and the ball is then raised. The pressure force is expressed by the equation

$$F_p = p \cdot A.$$

in which A is the effective surface area. The spring force increases linearly from this instant onwards, and the attractive force increases over-proportionally since, on the one hand, the current is increasing and, on the other hand, the air gap is decreasing. The pressure force is reduced over a short distance. The maximum attractive force is reached at the upper stop at the instant t_2. If the voltage is switched off at the instant t_3, and a free-running diode is provided, the current normally decays exponentially. However, in this instance, the time constant decreases during the travel of the ball, since the air gap is increasing. The attractive force decreases in proportion to the square of the current and with the reciprocal value of the air gap, and the ball is accelerated towards the seat with which it comes into contact at the instant t_4. The counter-pressure *p* of the fluid commences to build up again shortly before the ball comes into contact with the seat.

It follows from this that considerable delay times occur during opening and closing. These delay times vary to the extent to which the operating voltage, ohmic resistance of the coil and the counter-pressure fluctuate.

Moreover, the attractive force has to be maintained during the open period by a flowing current, so that there is a considerable loss of power.

These disadvantages are largely avoided in the subject of the invention, that is to say, a valve having a permanent-magnetic adjusting member. Figure 1 of the accompanying drawings is a diagram of the arrangement. The shell-type cores (1) and (2) of ferromagnetic material, preferably of high saturation induction, contain coils (3) and (4) which are wired such that a current flowing therethrough produces like poles at the inner, mutually facing planar surfaces. The lines of magnetic flux emanate outwardly from the poles to the concentric casing formed by the shells. In order to concentrate the lines of force, a ring (5) made from the same ferromagnetic material as that of the shell cores is fitted in the central portion and is coated with a thin layer of a material having a low coefficient of friction. The lower shell-type core (2) is axially drilled and is provided with a screwed-in valve seat (6) of non-magnetic material. The inner pole surface of the shell-type core (1) carries a thin plate (7) of non-magnetic material. An axially magnetized permanent magnet cylinder (8) of, for example, cobalt/samarium, is fitted into the cavity between the poles of the shell-type cores and the inner wall of the ring (5). The bottom of the cylinder carries a throttling or valve member in the form of a steel disc whose central portion is of conical or, preferably, part-spherical, construction and is sealingly pressed into the valve seat by the cylinder (8) when the latter is in its bottom position. When in this position, the planar annular base surface of the valve member is only at a short distance from the pole surface of the shell-type core (2). An inlet tube (9) and an outlet tube (10) are fitted in the bottom shell-type core above the coil. By way of example, a flow of fluid can flow continuously through the tubes and is tapped when the valve is opened.

The magnet system has the following characteristics:

1) When the magnet (8) is in its central position, the plane of symmetry of the ring (5) is at the same time the plane of symmetry of the magnetic field. When the coils are non-energized, no force is exerted on the magnet when the latter is in this position. The magnet is in unstable equilibrium.

2) When the magnet moves towards one of the poles of the shell-type cores, the attractive force increases at this side, while the attractive force decreases at the other side. In the case of a very small air gap, the attractive force reaches a very high value which can be calculated from the flux permeating the end face of the magnet:

$$F = \frac{0.5\,B_L^2 A}{\mu_o}$$

in which B_L signifies the air gap induction, A signifies the cross sectional area, and μ_o represents the permeability of a vacuum.

If we reckon with the induction, realisable nowadays, of $B_L = 1$ T, and an available cross section of $0.5\ cm^2 = 0.5 \cdot 10^{-4}\ m^2$, then $F = 0.5 \cdot 1.0 \cdot 0.5 \cdot 10^{-4}/1.26 \cdot 10^{-6} \approx 20$ N.

The equation $p = F/A$ applies between the pressure *p* against which the valve could still seal, the holding force and the effective surface area A of the valve member. An effective surface area of $0.13\ cm^2$ results for a contact circle of 4 mm of the valve member in the valve seat. Thus, the calculated force counter-balances a pressure of

$$\frac{20\ N}{10 \cdot 0.13\ cm^2} \approx 15\ bar$$

In order to assess the effect of the windings on the magnet, and for the sake of simplicity, the half of the system below the plane of symmetry will be considered.

Figure 3 of the accompanying drawings shows the facts. The flux $Ø_S$ produced by the coil enters the outer surface of the cylindrical magnet and exits at the bottom end face. It is superimposed on the impressed inherent flux $Ø_E$ and, together therewith, produces the force

$$F = C_1 (Ø_E + Ø_S)^2 - C_1 Ø_E^2$$

$$= C_1 (Ø_S^{\ 2} + 2\,Ø_E Ø_S),$$

in which C_1 represents a constant. This takes into account that the reversible permeability of the permanent magnet is virtually equal to 1.

If we now also include the upper half of the system, the quadratic terms cancel one another with the opposite polarity of the coils, and the mixed term is doubled.

$$F = 4\,C_1 \quad Ø_E Ø_F \quad \text{with } C_1 = \frac{A}{\mu_o}$$

now applies, in which $Ø_S$ represents the flux produced by each coil when the magnet is in its central position. The fluxes in the two halves of the magnet system vary opposingly when the magnet moves, so that the sum remains constant, at least in the first approximation. The following advantages are obtained compared with known solenoid valves:

1) A spring is not required, since, when the valve is in its closed position, the magnetic attractive force is sufficient to withstand the pressure.

The open state is also maintained by the attractive force of the permanent magnet. Thus, pulses are sufficient for controlling the valve, so that the energy requirement can be reduced to a considerable extent.

2) By adjusting the tube with the valve seat screwed into the bottom shell-type core, the force under which the valve member is held in its closed state can be set such that it just reaches the required value. As a result of this adjustment, the current required for release is brought to a minimum value and the dead time is reduced.

3) In order to prevent chattering of the valve seat and valve member and to prevent damage thereto, the direction of flow can be reversed after half the distance of the valve member has been travelled, thereby decelerating the movement. The operation can be optimised with respect to time by the choice of the amplitude and duration of the pulses.

It is also concievable for the valve member and cylinder 8 to be replaced by a ball. In this case, the ball would also have to serve as the magnet and would need to be made of a diametrically magnetised magnetically hard material; and the valve seat should be made from a soft-like magnetic material, so that it is included in the magnetic flux. Further, to achieve the minimum possible reluctance and, at the same time, adequate mobility of the magnetic ball, the upper pole should be provided with a recess adapted to the ball.

CLAIMS

1. A solenoid valve having a seat of a concave surface and a valve member of a convex surface to engage the surface of the seat, wherein the valve member is connected to or comprises a permanent magnet which moves in a cavity delineated by two cylindrical coils and a ferromagnetic ring between the cylindrical poles of two ferromagnetic shell-type cores and which surround the coils, one of which poles carries the valve seat, which permanent magnet moves under the influence of a current flowing through the coils and in accordance with the direction of the current and thereby closes or opens the valve.

2. A solenoid valve as claimed in claim 1, wherein in the case where the valve member is connected to the permanent magnet, the latter is cylindrical.

3. A solenoid valve according to claim 1, wherein the valve member constitutes the magnet and is in the form of a ball of diametrically magnetised magnetically hard material; with the valve seal being formed of magnetically soft material.

4. A solenoid valve according to claim 3, wherein the pole of the shell-type core remote from the valve seat bears a recess adapted to the ball so that the magnetic reluctance is reduced and mobility of the ball is increased.

5. A solenoid valve as claimed in claim 1 or 2, wherein the valve is such that it can be controlled by pulse signals.

6. A solenoid valve substantially as hereinbefore described with reference to the accompanying drawings.

Printed for Her Majesty's Stationery Office, by Croydon Printing Company Limited, Croydon, Surrey, 1982.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.