

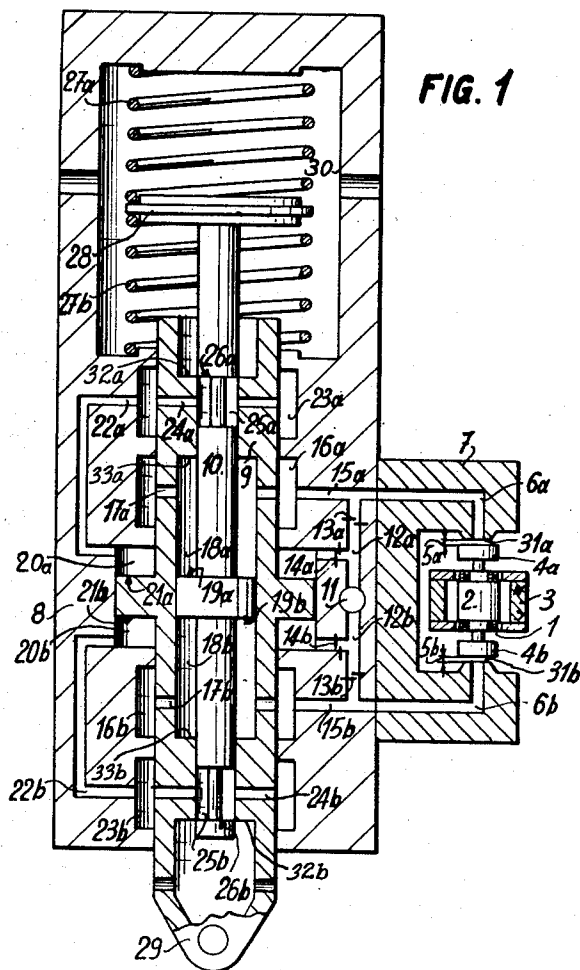
Feb. 5, 1963

V. RAEER
HYDRAULIC RELAY

3,076,442

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2 Sheets-Sheet 1



INVENTOR
VICTOR RAEER
By *Emory L. Graft*
ATTY

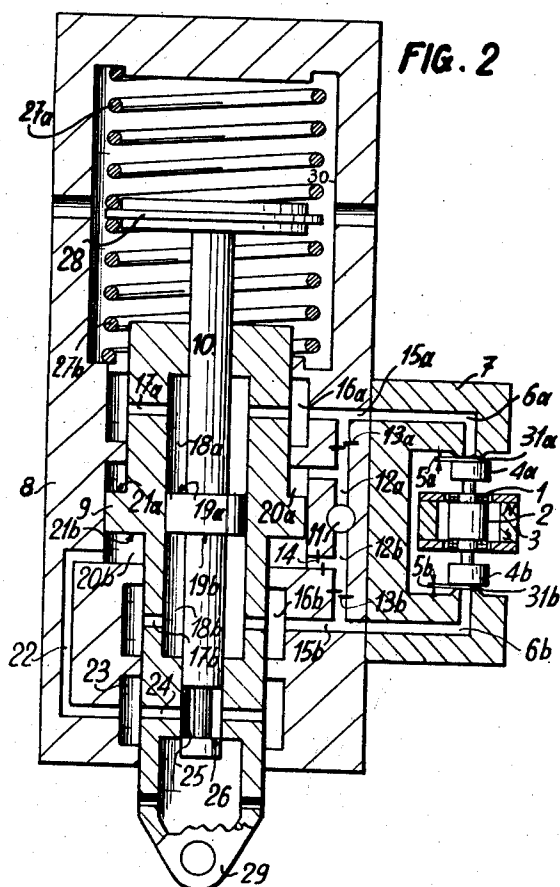
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INVENTOR
VICTOR RAEER
By *Emory H. Groff*
Att'y

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HYDRAULIC RELAY

Victor Raeber, Vevey, Switzerland, assignor to Ateliers de Constructions Mecaniques de Vevey S.A., Vevey, Vaud, Switzerland, a corporation of Switzerland

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Automatic regulators adapted to be continuously adjusted are frequently used for industrial purposes. They include systems operating after the manner of a relay, which systems are controlled by an input magnitude of a predetermined nature, the lever of energy of which is low and transforms said magnitude into an output magnitude having a high level of energy and the nature of which may be different. Furthermore, they are fed with an auxiliary energy which provides for the transformation and amplification of the energy received.

A number of characteristic features which allow defining the grade of a relay are as follows:

The amplification factor should be high, said amplification factor being defined as the ratio between the levels of energy of the output magnitude and of the input magnitude of the system considered;

The static accuracy, to wit the output magnitude should be a univocal that is, unequivocal, reciprocal function of the input magnitude;

The dynamic delay should be as low as possible, which means that if the input magnitude varies, for instance in a sinusoidal manner, but with a same phase shifting, said phase shifting should be negligible;

The relay should absorb a minimum amount of auxiliary energy.

The above-mentioned properties are contradictory, since, for instance, an amplifying factor which is too considerable may lead to an unallowable dynamic delay.

The present invention has for its object a hydraulic relay, chiefly for use with an automatic regulator, adapted for the transformation and amplification of an input signal into an output signal of a higher energy.

Said hydraulic relay has for its novel characteristic feature the fact that it includes a casing inside which are arranged at least two pistons slidably engaging each other, the output signal being provided by the location of the outer piston, which location is governed hydraulically by the inner piston, the movements of which are controlled in their turn, through hydraulic means, by the input signal, the inner piston cooperating with the outer piston after the manner of a timing slide valve with a set of adjusting ridges provided between the two pistons in a manner such that the volumes of the control chambers formed between the two pistons may remain practically constant, which reduces thus the phase shifting arising between the input and the output signals.

The arrangement of the above-defined relay is such that it allows a high static accuracy, a high ratio of amplification, without this leading to any substantial dynamic delay and without the relay requiring a large expenditure of auxiliary energy.

The accompanying drawing illustrates diagrammatically and by way of a mere exemplification two embodiments of the hydraulic relay executed in accordance with the present invention. In said drawings:

FIG. 1 is a sectional view of a first embodiment and

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FIG. 2 is a view, similar to FIG. 1, of the second embodiment.

Various embodiments of this improved relay are possible, but the present description is restricted to an input magnitude of an electric character. In this case, the input magnitude is constituted by the stress produced by an electric current passing through a solenoid subjected to a magnetic field.

The improved relay includes a main body or casing 8 inside which are arranged two pistons 9 and 10 slidably engaging each other, coaxially or otherwise. Inside the casing 8 are formed a number of annular chambers 20a, 20b, 16a, 16b, 23a, 23b. The outer piston 9 is provided with at least two transverse surfaces 21a and 21b facing opposite directions and defining inside the casing 8 a divided primary piston chamber including the two compartments 20a and 20b, which form operative compartments communicating each through the agency of branch pipes 12a or 12b respectively, with a pipe 11 feeding liquid under pressure into said chambers. The feeding of said operative chambers or compartments 20a, 20b is performed starting from the branch pipes 12a and 12b through the diaphragms 14a and 14b. We intend that "diaphragm" signifies a device which partially closes a pipe, for example a short length plug having an axial calibrated hole drilled in the same axis as the axis of the pipe. The diaphragm induces a pressure drop in the oil circuits. This pressure drop depends only, for a given type of oil, on the discharge, which is set elsewhere by a control device. In the drawings, said diaphragms are illustrated in a highly diagrammatic manner by two short lines perpendicular to the axis of the channel carrying them. Each connecting branch pipe 12a or 12b opens into the channel 15a or 15b feeding the chamber 16a or 16b respectively. The oil flow through said channels 15a and 15b is controlled in a manner similar to that disclosed for the chambers 20a and 20b by the diaphragms 13a and 13b respectively.

First and second inner chambers 18a and 18b are formed between the outer piston 9 and the inner piston 10. The latter is provided with two transverse surfaces facing opposite directions 19a and 19b and which limit the chambers 18a and 18b just referred to. These chambers 18a and 18b are fed with oil under pressure by the channels 15a and 15b respectively through the passages 17a and 17b extending through the wall of the piston 9. Furthermore, a third auxiliary chamber 25b and a fourth auxiliary chamber 25a are formed between the two pistons 9 and 10 at the ends of the latter, each of said auxiliary chambers communicating with the corresponding operative outer chambers 20a and 20b respectively through the channels 22a and 22b formed in the wall of the casing and the transverse passageways 24a and 24b extending through the wall of the piston 9.

Each chamber 25a, respectively 25b, is located within the walls of a slot machined in the inner piston 10 and that of an axial hole bored in the outer piston 9. These chambers possess control surfaces resulting from the disposition of the faces 26a and 32a, respectively 26b and 32b.

Depending on the relative axial positions of the inner piston 10 and the outer piston 9, the chambers 25a, respectively 25b, may be connected with the exhaust or, on the contrary, isolated from the exhaust.

The lower end of the outer piston 9 extends so as to form an element 29 which allows using the output move-

ment for any desired purpose. The output signal is given, in fact, by the location of the outer piston 9. Said element 29 may control, for instance, a distributing slide valve, which is not illustrated.

The upper section of the inner piston 10 extends upwardly and carries a plate 28 subjected to the antagonistic action of two compression springs 27a and 27b housed inside a recess 30 formed in the upper section of the casing 8. The two antagonistic elastic forces exerted by said springs on the plate 28 urge the inner piston 10 into a mean position with reference to the casing 8 of the relay.

To one side of the main casing 8 is arranged an auxiliary body 7 carrying an electromagnet constituted by a winding 1 wound over a core 2 which is axially movable. A permanent magnet 3 surrounds said core 2 which carries at its opposite ends the corresponding valves 4a and 4b. The allowed stroke of said masses is reduced, since it is limited by the terminal openings 31a and 31b of the nozzles 6a and 6b formed in the body 7 in alignment with the axis of the core 2. Slight clearances 5a and 5b are left to either side between the terminal openings 31a and 31b of the nozzles and the cooperating valves 4a and 4b. Said nozzles 6a and 6b form a passage for the exhaust through the branch pipes 12a and 12b respectively out of the diaphragms 13a and 13b and of the channels 15a and 15b.

The casing 8 and the body 7 being stationary as also the permanent magnet 3, the operation of the relay which has just been described is as follows:

Assuming first there is no electric current flowing through the winding 1, the oil under pressure is fed through the pipe 11 and passes through the diaphragms 13a, 13b and 14a, 14b. The oil is subjected to a reduction in pressure as it passes through each of said diaphragms, which reduction depends on the throughput and on the size of the diaphragms. The chambers and the channels 18a and 18b, 16a and 16b, 17a and 17b, 15a and 15b and 6a and 6b are subjected to oil pressure. Since the core 2 of the electromagnet is not energized and the sizes of the nozzles are furthermore the same as is also the case for the diaphragms 13a and 13b and for the clearances 5a and 5b, the pressure at 6a will be equal to the pressure at 6b and, consequently, the pressures in the chambers 18a and 18b are also identical. The inner piston 10 is subjected to a vertical thrust directed downwards resulting from the oil pressure in the chamber 18a. This thrust acts on the face 19a and is equal to the product of the area of this face by the pressure. On the other hand, the same inner piston 10 is subjected to a vertical thrust directed upwards and due to the oil pressure in the chamber 18b. This pressure acts on the face 19b and, as above, it is equal to the product of the area of the faces by the pressure. The design is such that the area 19a and 19b are equal. The thrusts are also equal, but in opposed directions, and their sum is zero. Therefore the inner piston 10 is subjected to no thrust resulting from oil pressure. It is located in the middle of its stroke as set by the characteristics of the two springs 27a and 27b which rest, on the one hand, on the casing 8 and on the other hand by the intermediary of a plate on the inner piston 10. For a single well-determined position, the sum of the two efforts induced by the two springs 27a and 27b is zero, as one, 27a, acts on the piston 10 vertically in a downward direction and the other spring 27b acts vertically in an upward direction. This position corresponds to the middle of the stroke of the piston 10.

The outer piston 9 stands also at the middle of its stroke in a position obtained when the pressures in the chambers 20a and 20b fed through the diaphragms 14a and 14b produce on the transverse surfaces 21a and 21b thrusts of equal values but of opposite signs.

As the cross-sections of the diaphragms 14a and 14b are equal, the pressures prevailing in said chambers 20a and 20b are also equal.

The throughputs passing between the cooperating ridges 26a, 26b, and 32a, 32b and the diaphragms 14a and 14b are identical and since the diaphragms are equal, it is necessary that the overlapping of both pairs of cooperating ridges 26a, 26b, and 32a, 32b may be identical.

In fact, let us assume that the piston 10 is in the middle of its stroke and the piston 9 displaced upward. The face 26a is at a lower location than the face 32a and the chamber 25a is isolated from the exhaust. The face 26b is higher than the face 32b and the chamber 25b is connected with the exhaust.

The oil coming from the pipe 11 flows through the pipe 12a and the diaphragm 14a, reaches the chambers 20a, 32a and 25a. As this latter is isolated from the exhaust, the discharge is low. Therefore the loss of head through the diaphragm 14a is low, approximately zero. The pressure in the chamber 20a almost equals the feeding pressure in pipe 11. The oil which passes through the diaphragm 14b reaches the chambers 20b, 23b and 25b. This latter chamber is connected to the exhaust. The oil escapes through the opening and the discharge is high. As a result, the loss of head through the diaphragm 14b is high, almost equal to the feeding pressure in the pipe 11. The pressure in the chamber 20b is practically zero.

To sum up, when the inner piston is displaced upwards in respect to the outer piston 10, the pressure in the chamber 20a is high, whereas it is low in the chamber 20b. As a result, the hydraulic thrusts on the faces 21a and 21b are unequal, producing a vertical thrust directed downwards. This resulting thrust induces a displacement of the piston 9 in respect to the inner piston 10. This displacement will stop when the otherwise overlapping of the surfaces 26a, 32a and 26b, 32b (FIG. 1) are once more in the same plane.

It may be said that by the effect of diaphragms 14, working chambers 20, set of surfaces 26 and connecting piping, the outer piston 9 always follows the displacement of the inner piston 10. The speed of the movement depends on the dimensions of diaphragms 14, chambers 20, surfaces 26 and on the oil pressure in pipe 11.

Assuming now the electromagnet winding 1 is fed with a predetermined intensity in a direction such that its core 2 and the valves 4a and 4b are urged upwardly. The effect of this movement is on the one hand to reduce the clearance 5a, and therefore to reduce the oil flow through the diaphragm 13a, consequently increasing the pressure in the nozzle 6a, the pipes 15a and 17a and the chambers 16a and 18a, and on the other hand to increase the clearance 5b, thus increasing the oil flow through the diaphragm 13b, in this way reducing the oil pressure in the nozzle 6b, the pipes 15b and 17b and the chambers 16b and 18b. The thrust induced by the oil pressure on the face 19a increases, whereas the thrust decreases on the face 19b. The balance of the hydraulic thrusts is cancelled. There is a vertical downward thrust. The inner piston 10 will therefore move vertically downward, thus increasing the compression of the spring 27a. This movement will stop when the balance of all the vertical forces acting on the inner piston 10 is re-established, which happens when the increase in compression of the spring 27b added to the decrease in compression of the spring 27a results in a vertical upward thrust exactly equal to the hydraulic thrust directed downwards.

Due to the effect of springs 27a and 27b, there is an axial location of the inner piston 10 determined for each value of the hydraulic thrust. Therefore there is a univocal and reciprocal relation between the pressure differences in the chambers 18a and 18b and the axial position of the piston 10 in respect to the casing 8.

It should be remarked that the oil pressure acting inside the nozzles 6a, 6b exert a thrust on the core 2 of the electromagnet. These thrusts are of equal values and of opposite signs if the clearances 5a and 5b are equal. When an electric current flows through the winding, it

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produces a vertical stress, which latter shifts the valves 4a and 4b until the difference between the thrust exerted by the oil escaping through the nozzles 6a and 6b ensures a compensation of said stress. The pressures prevailing in the nozzles 6a, 6b are functions of the electrically produced attraction exerted on the core 2 and, consequently, of the intensity feeding the electromagnet 1—2. There is a univocal reciprocal relationship between the value of the oil pressure prevailing in the nozzles 6a, 6b and in the chambers 18a, 18b and the intensity of the current in the electromagnetic winding 1; there is also a direct relationship between the axial position of the inner piston and the pressures prevailing in the chambers 18a, 18b cooperating with the latter.

It has been precedingly shown that the outer piston follows the movements of the inner piston. In brief, there is a univocal and reciprocal relationship between the movements of the attaching member 29 constituting the output signals and the electric current forming the input signal. The relay described operates thus as a transformer and it also acts as an amplifier, since the work available at the output end depends on the volumes of the chambers 20a and 20b cooperating with the outer piston and on the pressure of oil. The work obtained may be considerable, while the work required at the input end is equal to the product of the force acting on the core 2 by the axial shifting of the latter. Now, the force required for shifting the core 2 is small and depends on the cross-section of the nozzles and on the oil pressure at such a point. Said cross-section is much smaller than that of the chambers 20a, 20b. Furthermore, the stroke allowed for the core 2 is small, since the clearances 5a, 5b are very small and the input work is therefore a product of two small factors, so that it is apparent that the arrangement described operates as an amplifying relay.

As far as the delay is concerned, it has already been mentioned hereinabove that the delay between the movements of the inner and outer pistons depends on the size of the diaphragms 14a and 14b, of the chambers 20 and of the cut-off faces 26a and 26b. It is possible to select said sizes in a manner such as to obtain the work required by reducing the consumption of auxiliary energy and by limiting the dynamic delay to an allowable value.

In order to examine the dynamic delay provided between the movements of the inner piston and the input signal, it will be first assumed that the outer piston is locked and held fast in a position corresponding to the middle of its stroke, while the electromagnet is suddenly fed with a predetermined intensity in a direction such that its core 2 is subjected to a vertical upwardly directed stress. Practically at the same moment, the pressure rises in the chamber 18a and falls in the chamber 18b. The delay between the pressure rise in the chamber 18a and the displacement of the core 2 of the solenoid is dependent on the pressure wave velocity following the change in discharge induced by the displacement of the face 5a. The wave velocity is very high and therefore the pressure increase in the chambers 18a and 18b is in the phase with the pressure increases in the nozzles 6a and 6b, respectively. The inner piston 10 begins a downward movement. This movement will require a given time depending on the speed with which:

The chamber 18a is filled with oil passing across the diaphragm 13a in which the throughput decreases by reason of the increase in the pressure in the nozzle 6a;

The chamber 18b is emptied of the oil escaping through the nozzle 6b, taking into account the increase in throughput across the diaphragm 13b, by reason of the lowering of the pressure in the nozzle 6b.

The delay occurring between the input signal and the execution of the movement by the inner piston 10 could be considerable. It is ascribable chiefly to the modifications in volume in the chambers 18a and 18b, modifications following a relative displacement of the piston 10 to piston 9, but the design of the pistons is such that the

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outer piston 9 exactly follows the displacement of the inner piston 10, thus keeping constant the volumes in chambers 18a and 18b for any position.

In fact, considering again the previous example, let us assume that the current which acts on solenoid 1 is such that it induces a vertical downward movement of the inner piston 10 equal to approximately 10 mm. As soon as a movement of the inner piston 10 begins, the overlapping of the surfaces 26a, 32a and 26b and 32b is modified, the outer piston 9 follows the movement of the inner piston 10, thus maintaining constant the volume in chambers 18a and 18b.

In fact, if the face 19a falls by, say 10 mm., the opposite face of the same chamber 33a falls also by 10 mm. As a result, the volume in chamber 18a remains unchanged in spite of the displacement of the inner piston 10, as there is at the same time an equal displacement of the outer piston 9.

This particular position results in suppressing any source of appreciable delay between the input signal and the output signal and therefore decreases considerably the dynamic delays.

Other embodiments of the hydraulic relay described hereinabove are possible. In the above description, the example is that of an embodiment having a plane of symmetry for the inner parts. It is also possible to design the relay in another manner, as illustrated in FIG. 2, while the operation of the relay remains the same. The difference between the two embodiments illustrated in FIGS. 1 and 2 consists in that there is only one set of cut-off surfaces 26 instead of two and a single diaphragm 14 instead of two. The chamber 20a is therefore different from the chamber 20b in the case of FIG. 2. Apart from said difference, the second embodiment of the relay includes the same parts as that described with reference to FIG. 1 and the similar parts carry the same reference numbers in both cases.

Assuming, for instance, the cross-section of the chamber 20a according to FIG. 2 is equal to one half the cross-section of the chamber 20b, it is then necessary, in order to obtain equilibrium, for the pressure at 20b to be equal to one half the pressure at 20a. The operation of the relay is otherwise identical with that described with reference to FIG. 1.

As a further modification, the input magnitude may be other than an electric magnitude. As a matter of fact, it is possible to design a mechanical element acting on the members 4a and 4b controlling the throughput of the nozzles 31, while the operation of the electromagnet 1 is replaced by an outer force forming the input magnitude.

In the two embodiments described hereinabove, the inner piston 10 and the outer piston 9 are arranged co-axially inside one another; however, it is also possible to arrange said pistons 9 and 10 eccentrically inside one another.

As to the elastic elements 27 constituted by springs, in the case of the embodiments illustrated, they may as well be replaced by other elastic elements such as cushions of a compressed gas or by electromagnetic fields acting in opposite directions on a core which would then replace the plate 28.

All these elastic elements may also be provided with means for their adjustment, so that it is possible to shift the mean position of the inner piston 10, or else, to adjust the stress required for a shifting of the piston 10 in either direction.

I claim:

1. A hydraulic relay adapted to transform and amplify an input impulse into an output impulse of higher energy, said relay including, a casing having an axial bore, an outer piston slidable in said axial bore and having opposite transverse faces medially disposed to provide a divided primary piston chamber, one end of which communicates through a passage in said casing with a fluid

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pressure inlet and the other end of which also communicates with said fluid pressure inlet by another passage in said casing, said outer piston having internal axial bores of large and small diameters, to provide first and second fluid chambers, and a third fluid chamber, respectively, an inner piston including a stem of two different diameters, the larger of which is provided with a medial enlargement having opposite transverse faces, respectively, defining the inner limits of said first fluid chamber and said second fluid chamber which chambers are respectively in communication with said primary inlet, the smaller diameter of said inner piston having an enlargement cooperating with the third fluid chamber, fluid passage means in the casing establishing communication between said third fluid chamber and said primary fluid pressure inlet, and electromagnetically controlled conduit means also communicating with said fluid pressure inlet.

2. A hydraulic relay according to claim 1, wherein, the inner piston has its stem provided with a head, and a coil spring medially engaging said head in a ported chamber of the casing.

3. A hydraulic relay according to claim 1, wherein, the stem of said inner piston is provided with a second portion of smaller diameter to provide in cooperation with the outer piston a fourth chamber, passages in the outer piston communicating with said fourth chamber, and passage-forming means in said casing leading to said fluid pressure inlet from said passages in the outer piston.

4. A hydraulic relay adapted to transform and amplify an input signal into an output signal of higher energy, including, a casing, inner and outer coaxially disposed telescopic pistons within the casing and slidable one within the other, means on the outer piston to provide a divided outer piston chamber including a set of transverse surfaces, first and second inner chambers of substantially equal volume formed between said two pistons, a set of control surfaces arranged between the two pistons and defining a third and fourth control chamber therebetween, hydraulic means actuated by the input signal to control the movement of the inner piston to adjust the position of the outer piston as it responds to the output signal, whereby the outer piston follows the movement of the inner piston and the volume of said first and second inner chambers formed between the two pistons remains practically constant so that the phase shifting between the input and output signals is reduced.

5. A hydraulic relay as set forth in claim 4, wherein said third and fourth auxiliary chambers communicate on one hand with said divided outer piston chamber and, on the other hand, with the exhaust through the corresponding set of said control surfaces in such a manner that the pressure effects produced by said auxiliary chambers are added to simultaneously produce a shifting of the outer piston by the same amplitude as the inner piston.

6. A hydraulic relay for controlling a mechanism and designed to transform and amplify an input signal into an output signal, the energy level of which is higher, said relay including, a casing having an axial bore of at least two different diameters, an outer piston having at least two different outer surface diameters corresponding to the bore diameters in the casing, at least two outer chambers between said outer piston and casing, the volumes of which depend on the relative axial position of said outer piston in respect to the casing, said outer piston having a plurality of internal co-axial bores of at least two different diameters, at least one of said internal bores having a shoulder providing a female control surface, one end of the outer piston having means to transmit its movements as an output signal to the mechanism controlled by the relay, an inner piston sliding freely within the outer piston and having different surface diameters corresponding with said bores in the outer piston, first and second inner chambers between said inner and outer pistons whose volumes depend on the relative position of the outer and inner pistons, at least one groove formed in said inner piston, the said groove forming between the

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outer and the inner pistons a third chamber for the control fluid, one edge of said groove having a shoulder cooperating with the inner cylindrical part of said outer piston to provide a male control surface, the axial location of which corresponds with that of said female control surface, a set of grooves disposed between said relay casing and the outer piston to allow a free passage, whatever the position of the pistons, of the control fluid feeding said first and second inner chambers between said two pistons, one end of said inner piston extended and including a plate, at least one spring biased against said plate and at the same time against said relay casing, grooves and channels in said casing having diaphragms for feeding said first and second two inner chambers with fluid under pressure, the pressures in said first and second two inner chambers being transmitted through said channels to input signal means controlled by an electric current, solenoid means controlling said input signal means to control the pressures in said first and second inner chambers, each of said two variable volume outer chambers also being fed with fluid under pressure through diaphragms, fluid supply channels feeding each of said two outer chambers, and transverse passageways formed through the outer piston and connecting with said groove in the inner piston, said passageways controlled by said cooperating male and female control surfaces.

7. A hydraulic relay for controlling a mechanism and adapted to transform and amplify an input signal into an output signal, the energy level of which is higher, said relay including, a casing provided with an axial bore having at least two different diameters, an outer piston slidably disposed in said casing and whose various outer surface diameters correspond to said diameters in said casing, at least two variable volume outer chambers between said piston and the relay casing whose volumes depend on the relative axial position of the outer piston in respect to the casing, said outer piston being co-axially formed with at least two different inner diameters, at least one of said inner diameters forming with a plane perpendicular to the axis a sharp female control surface, one end of said outer piston having means to transmit its movements in the form an output signal, to the mechanism controlled by the relay, an inner piston slidable in said outer piston and having different surface diameters corresponding with the inner diameters in said outer piston of the outer and inner pistons, at least one groove inner pistons whose volumes depend on the relative position of the outer and inner pistons, at least one groove formed in said inner piston by one of said inner piston diameters, said piston groove forming between said outer and inner pistons at least one control passage for the control fluid, one edge of said piston groove forming with the inner cylindrical part of said outer piston a sharp male control surface, the axial location of which corresponds to that of said female control surface, a set of passages formed between said casing and said outer piston to allow a free passage of the control fluid feeding said first and second chambers between the two pistons regardless of the relative position of said pistons, at least one spring biasing against said inner piston and said casing, said first and second chambers between the inner piston and outer piston each being fed with fluid under pressure through diaphragms disposed in channels in said casing, control means, including a solenoid and actuated by an electric current for producing said input signal, said control means regulating the pressures in said first and second chambers through said channels, and the smaller of said two variable volume chambers between the relay casing and the outer piston is fed directly with fluid under pressure, whereas the other of said variable volume chambers is fed through one of said diaphragms in said channels, and said larger chamber feeding, through said channels to said piston groove, the chamber formed by said groove in the inner piston and said male and female control surfaces.

8. A hydraulic relay as set forth in claim 6 wherein,

said input signal means includes valves actuated to control at least one pressure in at least one of the variable volume chambers between the inner and outer pistons.

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