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[54] ELECTRO HYDRAULIC MOTORS

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[51] **Int. Cl.**.....**F15b 21/02**

[58] **Field of Search**.....91/35, 39, 491, 481

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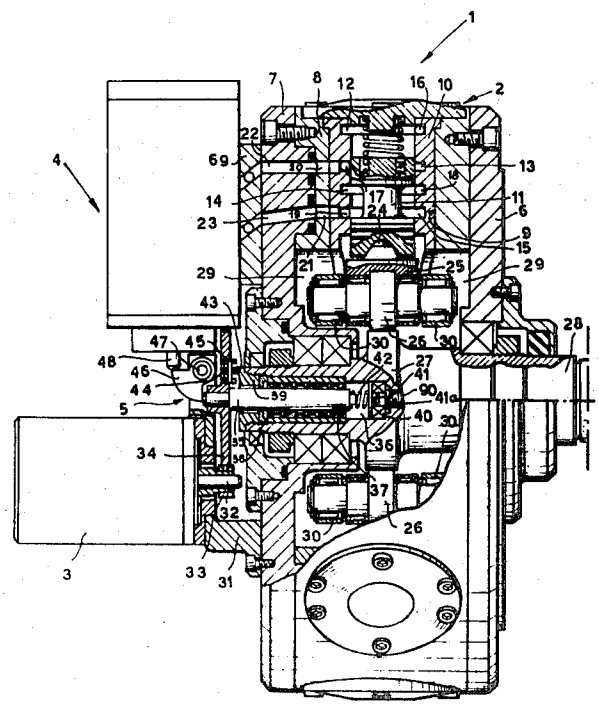
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[57] **ABSTRACT**

An electro-hydraulic motor is described in which a rotary hydraulic motor is slaved to a stepping pilot motor by the operation of a fluid distributor valve which is controlled by a differential device responsive to the angular discrepancy between the shafts of the pilot and hydraulic motor. In this invention, the differential device consists of a toothed wheel coupled to the electric pilot motor to drive a shaft which is slidable coaxially and rotatable relative to the hydraulic motor shaft: a frontal cam carried by the latter shaft cooperates with a roller mounted on a face of the toothed wheel to cause proportional axial displacement of the differential shaft, which is transmitted to the spool of the distributor valve, preferably mounted at right angles to the hydraulic motor shaft.

10 Claims, 2 Drawing Figures

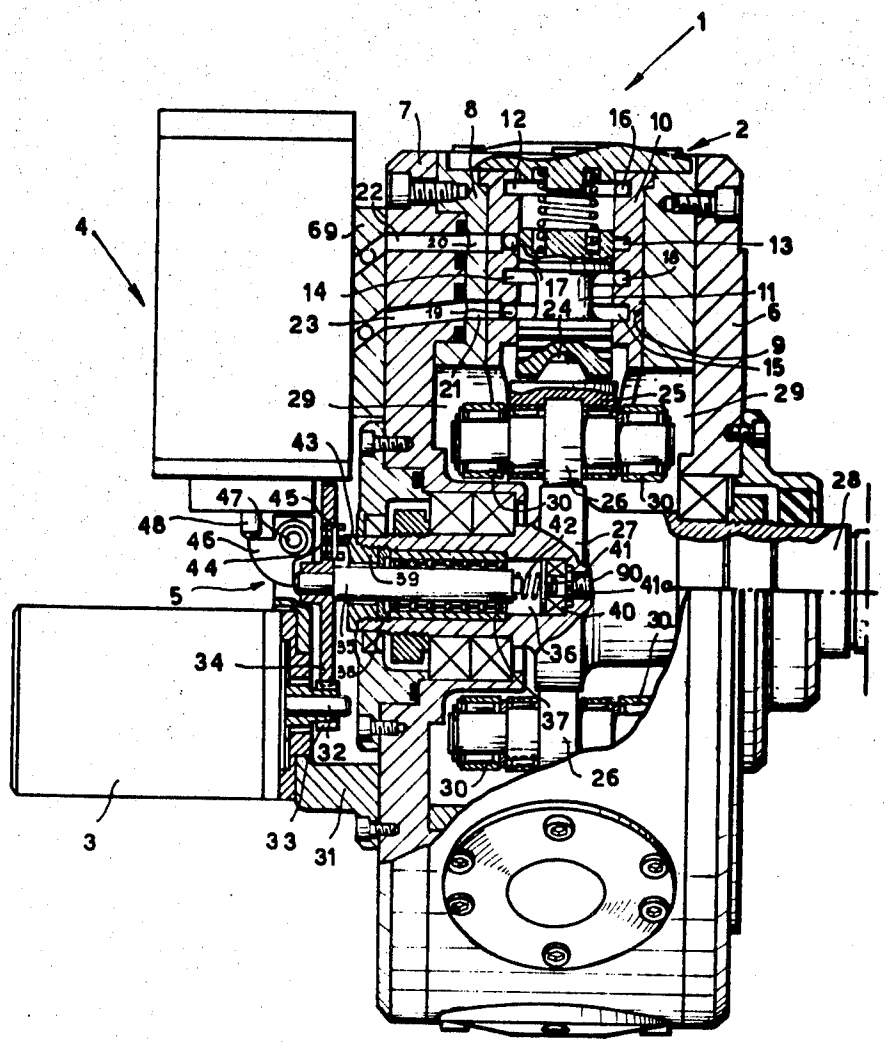


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SHEET 1 OF 2

Fig. 1



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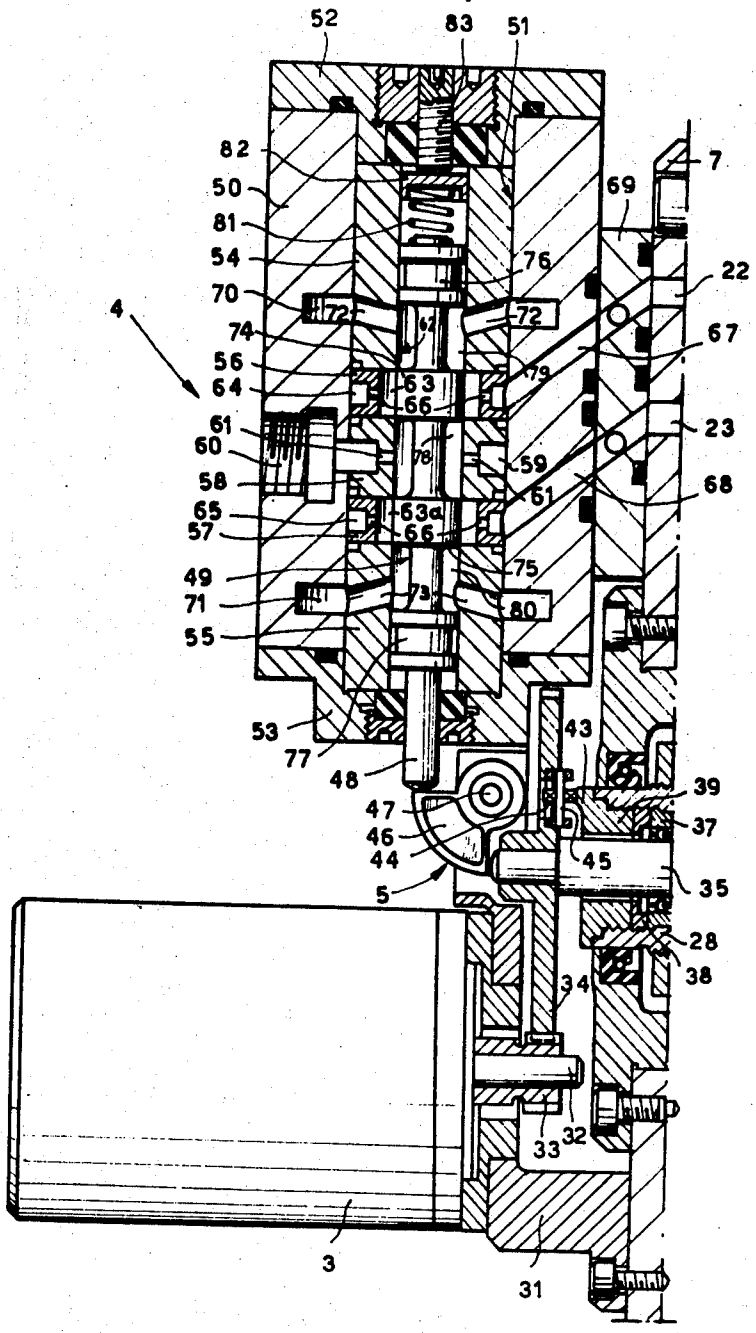
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Fig. 2


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ELECTRO HYDRAULIC MOTORS

This invention relates to electro-hydraulic motors for controlling the movement of slides and the like in machine tools, particularly machine tools having numerical control.

More specifically, the invention relates to an electro-hydraulic motor of the type comprising a stepping electric pilot motor, a rotary hydraulic power motor, a distributor valve for regulating the supply of working fluid to the hydraulic motor and a differential device adapted to displace a movable stem of the distributor valve proportionally to the angular discrepancy existing between the shaft of the electric pilot motor and the shaft of the hydraulic motor.

Electro-hydraulic motors of this type are very useful for operating slides in machine tools under numerical control. Such motors can be used as angular position servos and can control machine tools in a simple open loop. As a consequence the use of such motors avoids the necessity, in machine tool control systems, for feedback means, generally formed by a position indicator independently detecting the position of the slide, and by an associated feedback loop.

In general known electro-hydraulic motors include, as already stated, a stepping electric pilot motor which converts the electrical digital incoming impulses into angular steps. The angular steps of the pilot motor are used as a mechanical control input to a rotary hydraulic servo-system which operates in a closed control loop and which supplies a torque output sufficiently amplified to carry out the desired movement of the slide or other moving member controlled by the electro-hydraulic motor in the machine tool.

The hydraulic servo-system comprises a rotary hydraulic power motor and a distributor valve which controls the supply and exhaust of the working fluid of the motor. The distributor valve has a stem which is parallel to the shaft of the hydraulic motor and is connected both to the shaft of the electric pilot motor and to the shaft of the hydraulic motor.

In such known systems the distributor valve stem usually rotates about its axis with an angular speed proportional to that of the electric pilot motor, according to a fixed transmission ratio and is connected to the shaft of the hydraulic motor by means of a screw coupling (i.e., the stem of the distributor valve being threaded and screwing into a nut housed in the valve body, rotation of the valve stem causing the stem to move axially relatively to the nut). The screw coupling forms a differential device which causes the hydraulic servo system to effect axial displacement of the distributor valve stem in proportion to the difference existing at any given moment between the angular positions of the distributor (and, therefore, of the shaft of the electric pilot motor) and the shaft of the hydraulic motor. The distributor therefore controls the supply of working fluid to the hydraulic motor to cause the latter to follow constantly the movement of the electric pilot motor.

The known electro-hydraulic motors of the above mentioned type have numerous disadvantages.

The distributor valve is generally disposed with its axis parallel to the axis of the hydraulic motor. In consequence, even if the valve is directly supported by the outside body of the hydraulic motor, conduits of a certain length are necessary to interconnect hydraulically

the distributor valve and the hydraulic motor. The variation of volume of the fluid contained in the said conduits during the operation of the hydraulic motor and the dilation of these conduits under pressure lessen the overall rigidity of the system, increase its time constants and distort the output. Moreover this positioning of the distributor valve relative to the hydraulic motor makes the whole electro-hydraulic motor bulky and difficult to mount on a machine tool.

The fact that the distributor valve stem rotates on its own axis inside the casing of the distributor valve causes a rapid wear on the valve itself.

Finally, the use of a differential device formed by a screw coupling causes difficulties both in the construction of the differential device itself and in replacement thereof should it be desired to vary the gain of the hydraulic servo system. The mating male and female parts of the screw coupling must be manufactured to a high degree of precision for accurate control, and this makes for high production costs. In order to vary the gain of a servo system having this type of differential device the pitch of the screw coupling must be charged. It is therefore necessary to provide an electro-hydraulic motor of this type with a series of screw-type differential devices, of different pitch, each of which is in itself of high cost.

An object of this invention is to minimize the above mentioned disadvantages in an electro-hydraulic motor of the type stated.

It is a further object to provide an electro-hydraulic motor of high efficiency and precision, with good accessibility to facilitate construction, servicing and repair.

According to the invention there is therefore provided an electro-hydraulic motor of the type stated, characterized in that the differential device is formed by a toothed wheel coupled directly to the electric pilot motor and fitted on a shaft coaxial with the shaft of the hydraulic motor, means supporting the said shaft for rotation and axial displacement relative to the hydraulic motor shaft, a frontal cam rotatable with the latter shaft and facing the toothed wheel, and cam-follower means interposed between the frontal cam and the toothed wheel and supported by the latter; and further characterized in that the distributor valve is placed transversely to the shaft of the hydraulic motor and is directly connected to the latter through the interposition of a variable shock-absorbing laminar member so that the distributor valve is connected hydraulically to respective supply/exhaust conduits of the hydraulic motor, transmitting means being provided between the shaft of the differential device and the stem of the distributor valve to transform the axial movements, in either sense, of the said shaft into corresponding axial movements of the stem, and elastic means being provided to maintain said shaft and the stem always in contact with the said transmitting means.

Further characteristics and advantages of this invention will be apparent from the following description, given by way of non-limiting example, with reference to the accompanying drawings, in which:

FIG. 1 is a side elevational view, partially in section, of an electro-hydraulic motor according to one embodiment of the invention, and

FIG. 2 is an axial section, on an enlarged scale, of part of the motor of FIG. 1.

Reference numeral 1 indicates generally an electro-hydraulic motor comprising an hydraulic drive motor 2, an electric pilot stepping motor 3, a distributor valve 4 hydraulically connected to the hydraulic motor 2, and a differential device 5 mechanically interconnecting the hydraulic motor 2 and the distributor valve 4.

The hydraulic motor 2 is of the type described and claimed in U.S. Pat. No. 3,583,286.

The hydraulic motor 2 has a substantially cylindrical shape and is formed by two parallel circular plates 6 and 7 between which an annular body 8 is interposed.

The annular body 8 has a number of radial bores 9 distributed uniformely around the body 8 and each housing a sleeve 10 in which a piston 11 is mounted for fluid-tight sliding movement. Each sleeve 10 is provided with a number of axially spaced circumferential annular grooves 12, 13, 14 and 15, each of which communicates with respective tangential conduits indicated diagrammatically at 16, 17, 18 and 19.

The annular body 8 is provided with two internal annular conduits 20 and 21, extending over the entire circumference of the body 8, which are in direct communication with the tangential conduits 19 and 17 respectively and which are employed alternatively, according to the sense of rotation of the hydraulic motor 2, as inlets and exhaust passages for working fluid under pressure. To this end the annular conduits 20 and 21 in turn communicate with respective conduits 22 and 23 in the plate 7, leading to respective ports on the outside of the hydraulic motor 2.

Each piston 11 is connected at its radially inner end, and through a spherical coupling 24, to a stirrup 25 which supports a roller 26 for rotation about an axis parallel to the axis of the annular body 8. Each roller 26 is in rolling contact with a twin-lobe cam 27 which is integral with a shaft 28. The shaft 28 is rotatably supported by the plates 6 and 7, coaxially with the latter.

The lateral forces imparted by the cam 27 to each roller 26 are transmitted to respective tracks 29 formed on the inside surface of the annular body 8, by way of rollers 30 coaxial with the respective roller 26 and connected to the latter by short shafts on each side of the roller 26.

The hydraulic motor 2, the operation of which is described in the previously mentioned U.S. Pat. No. 3,583,286 is particularly suitable for use as an electro-hydraulic motor for the control of movement of members such as slides, worktables and tool-carrying turrets in machine tools having numerical control.

In fact the hydraulic motor 2 has a very low moment of inertia, since its rotating parts are formed solely by the shaft 28 and the cam 27. Consequently the hydraulic motor 2 is capable of high frequencies of operation and high dynamic accelleration, and has good stability. Moreover, since lateral forces on the pistons 11 due to the contact between the rollers 26 and the cam 27 are discharged on the tracks 29 through the rollers 30, the hydraulic motor 2 operates with very regular rotation, even at a very low rotational speeds.

The hydraulic motor 2 is controlled by the electric pilot motor 3. An external bracket 31 is secured to the plate 7 and rigidly supports the outer casing of the electric motor 3. The electric motor 3 has an output shaft 32 disposed parallel to the shaft 28. The shaft 32 projects from the electric motor 3 on the side of the latter which faces the plate 7 of the hydraulic motor 2 and carries at its outer end, externally of the electric motor 3, a toothed wheel 33. The toothed wheel 33 meshes with a toothed wheel 34 fitted on one end of a shaft 35 coaxial with the shaft 28.

The shaft 35 is mounted for rotation and axial sliding movement inside a cylindrical bore 36 formed in one end of the shaft 28, through the interposition of a circulating ball bearing 37. The bearing 37 is maintained inside the cylindrical bore 36 by a spacer 38 which is in turn retained by a metal ring 39 screwed into the open end of the bore 36.

A thrust bearing 40 is located at the blind end of the bore 36 through the interposition of a small plate 41*a*. The thrust bearing 40 supports a small plate 41. A helical spring 42 is interposed between the small plate 41 and the inner end of the shaft 35. Inside the shaft 28 a screw 90 is threaded coaxially into the shaft 28 and is adjustable from the outside. The screw 90 cooperates with the small plate 41*a* for adjustment of the axial position of the bearing 40 inside the bore 36, in order to vary the pre-loading of the spring 42.

The outer annular end surface of the retaining ring 39, which is coaxial with the shaft 35, is formed with a frontal cam 43. The frontal cam 43 cooperates with a roller 44 mounted on a small shaft 45 mounted on and extending radially of the toothed wheel 34.

The end of the shaft 35 connected to the toothed wheel 34 projects beyond the latter and cooperates with a right angled quadrant thrust-transmitting lever 46 mounted for rotation on a pin 47 carried by the bracket 31. The lever 46 is rotatable about the pin 47 in a plane passing through the axes of the distributor valve 4 and the shaft 28 and acts as a transmitting means, cooperating on one side with said end of the shaft 35 and on the other with the end of a stem 48 of the distributor valve 4. The stem 48 is therefore in contact, through the quadrant lever 46, with the rotating-translating device formed by the toothed wheel 34 and by the shaft 35. The wheel 34, and therefore the shaft 35, is rotated at an angular speed which has a fixed relation to that of the output shaft 32 of the electric motor 3. The toothed wheel 34 and the shaft 35 occupy an axial position which is a function of the angular discrepancy existing between the said rotation-translating device and the shaft 28 of the motor 2, as determined by the cooperation of the roller 44 with the frontal cam 43.

Collectively the frontal cam 43, the roller 44 the relatively small shaft 45, the toothed wheel 34 and the shaft 35 form the differential device 5.

The distributor valve 4 includes a distributor spool 49, (FIG. 2) and an external casing 50 having an internal coaxial cylindrical through bore 51 closed at its ends by two annular end plates 52 and 53 sealingly connected to the casing 50.

Within the bore 51, at the opposite axial ends of the latter, two tubular sleeves 54 and 55 are located, each being a tight fit in the bore 51. Three coaxial annular bodies 56, 57 and 58 are held tightly between the two sleeves 54 and 55, the two bodies 56 and 57 being identical and placed symmetrically on either side of the body 58.

The annular body 58 has an internal diameter equal to that of the sleeves 54 and 55 and has, in its external surface, which is in contact with the surface of the bore 51, an annular groove 59. The groove 59 commu-

nicates with the outside through a radial port **60** in the external casing **50**. The port **60** forms the inlet opening of the valve **4**. On the bottom of the groove **59** some radial passages **61** of small cross-section are provided to put the inlet port of the valve **4** into communication with the bore **62** extending through the sleeves **54** and **55** and the annular bodies **56**, **57** and **58**, in which the distributor spool **49** slides.

The annular bodies **56** and **57** have an internal diameter which is larger than that of the annular body **58** and the tubular sleeves **54** and **55**, the bodies **56** and **57** delimiting with their inner surfaces respective cylindrical chambers **63** and **63***a*. The annular bodies **57** and **56** have on their outside surfaces respective annular grooves **64** and **65** respectively in communication, through radial passages **66** of small section in the annular bodies **56** and **57**, with the cylindrical chambers **63** and **63***a* respectively. The grooves **64** and **65** communicate with respective conduits **67** and **68** within the external casing **50** of the valve **4**. The conduits **67** and **68** communicate, through a laminar shock-absorbing plate **69** connected to the valve **4**, with the conduits **22** and **23** respectively of the hydraulic motor **2**. The plate **69** is variable in the sense that it can be replaced by different plates **69**.

The distributor valve **4**, is positioned with the axis perpendicular to the axis of the shaft **28** of the hydraulic motor **2** and is supported by the plate **7** of the latter with the interposition of the plate **69**. The latter is sandwiched tightly between the plate **7** and the external casing **50** of the distributor valve **4** and is immediately replaceable in the event of damage or failure. On the inside of the external casing **50**, at the respective parts of the cylindrical bore **51** in which the tubular sleeves **54** and **55** are located, there are formed two grooves **70** and **71**. The grooves **70** and **71** communicate with the bore **62** through substantially radial ducts **72** and **73** in the walls of the tubular sleeves **54** and **55** respectively. The grooves **70** and **71** additionally communicate with exhaust outlets (not illustrated) which open into the outside of the valve casing **50**.

The distributor spool **49**, which is slidable within the bore **62**, has, in addition to the stem **48**, two pistons **74** and **75** each having a cross-section equal to that of the bore **62** and disposed, when at rest, in correspondence with the chambers **63** and **63***a* respectively. The axial length of the pistons **74** and **75** is substantially equal to that of the respective chambers **63** and **63***a*.

The distributor spool **49** is supported for sliding movement in the bore **62** by two cylindrical lands **76** and **77**, formed integrally with the stem **48**. The lands **76** and **77** are slidable within the bores of the tubular sleeves **54** and **55** respectively.

The two pistons **74** and **75** and the two lands **76** and **77** define between them, with the surface of the bore **62**, three annular chambers **78**, **79** and **80**.

In the previously mentioned position of rest, the chamber **78** is limited externally by the annular body **58** and communicates with the outside through the passages **61**, the groove **59** and the port **60**. The annular chambers **79** and **80** communicate at the same time, through the ducts **72** and **73** respectively, with the grooves **70** and **71**, and therefore, with the outside through the exhaust outlets (not shown).

The stem **48** passes through an opening in the end plate **53**, which is provided with a suitable packing, and is rounded at its free end, where, as previously stated, it cooperates with the lever **46**. The distributor spool **49** bears resiliently against the end plate **52** by way of a helical spring **81** and a small cup **82**. The cup **82** bears against the end of a screw **83** coaxial with the casing **50** and passing through the end plate **52** for control externally of the casing **50**.

The electro-hydraulic motor operates as follows:

The electric stepping motor **3** receives incoming digital electrical impulses and in response to them causes angular stepwise rotations of the shaft **32** and of the toothed wheel **33**. The latter, meshing with the toothed wheel **34**, causes rotation of the wheel **34** with a transmission ratio which, in this example, is **1** to **5**.

The rotation of the toothed wheel **34** and, therefore, of the shaft **35**, causes rolling of the roller **44** on the frontal cam **43** and, therefore, an axial displacement of the shaft **35**. The axial translation of the shaft **35** is transmitted, through the quadrant lever **46**, to the stem **48** of the distributor spool **49** of the distributor valve **4**.

The distributor spool **49** is initially in the condition of rest, with the pistons **74** and **75** aligned with the annular bodies **56** and **57**. In this position hydraulic fluid supplied to the port **60** enters the groove **59** and flows through the passages **61** into the chamber **78**. The fluid cannot, however, enter the chambers **63** and **63***a* as the chamber **78** is closed at both ends by the pistons **74** and **75**.

Upon any axial displacement of the shaft **35** the stem **48** is displaced axially by the lever **46**. Upon shifting of the stem **48** the pistons **74** and **75** are shifted axially so that the annular chamber **78** is put in communication with the chamber **63** or the chamber **63***a*. Fluid supplied to the port **60** enters the conduit **67** or **68** and, after passing through the plate **69**, enters the conduit **22** or **23** respectively to drive the hydraulic motor **2** in one direction or the opposite direction.

The axial shifting of the stem **48** also puts one of the chambers **79** and **80** into communication with one of the conduits **67** and **68** of the hydraulic motor **2** which, according to the sense of rotation of the motor **2** acts as an exhaust conduit communicating with that one of the chambers **63** and **63***a* which is not in communication with the annular chamber **78**. Fluid exhausted from the said chamber **63** or **63***a* reaches the outside of the valve **4** through the conduit **72** or **73**, the groove **70** or **71** and one of the exhaust outlets of the distributor valve **4**.

The hydraulic motor **2** therefore rotates in one sense or in the other according to the direction of rotation of the shaft **32** of the electric motor **3**. The rotation of the shaft **28** of the hydraulic motor **2** causes rotation of the frontal cam **43** carried by the said shaft **28** which rotates in the same sense as the toothed wheel **34**.

The initial relative angular displacement between the toothed wheel **34** and the shaft **28** of the hydraulic motor **2** tends to diminish by the effect of the counter-reaction due to the differential device **5**. The latter controls the opening of the ports of the valve **4** and therefore controls the supply of working fluid to the hydraulic motor **2** so as to annul the phase discrepancy existing between the toothed wheel **34** and the shaft **28**.

Two advantages are obtained by placing the distributor valve **4** transversely to the axis of the shaft **28** of the

hydraulic motor 2 and not parallel to it. Firstly, the external casing 50 of the valve 4 can rest on the exterior of the hydraulic motor 2 and can be supported by the latter in such a way as to permit hydraulic inter-connection of the valve 4 and the motor 2 without using intermediate conduits, but directly through the plate 69, thus minimizing the quantity of working fluid between the valve 4 and the hydraulic motor 2, which would otherwise impede accurate control of the hydraulic motor 2.

Secondly, by virtue of the transverse disposition of the distributor valve 4, it is possible to adopt as differential device 5 the combination of the frontal cam 43, the roller 44 the small shaft 45, the toothed wheel 34 and the shaft 35. The differential device 5 acts on the stem 48 of the distributor valve 4 through the interposition of the quadrant lever 46, and consequently can impart only a movement of translation and not a rotational movement. In this way it is possible to prolong considerably the life of the distributor valve 4 since it does not rotate.

Regulation of the axial position of the distributor valve spool 49 is effected without jumps and without vibrations since the servo-control mechanism, including the shaft 35, the toothed wheel 34, the roller 44, the frontal cam 43, the distributor spool 49 and the lever 46, is compressed between the opposing springs 42 and 81, which effectively eliminate wear-producing play among the components of said mechanism. The springs 42 and 81 are, moreover, pre-loaded and their preloading can be regulated from the outside through the action of the screws 83 and 90 respectively.

With regard to the elements forming the differential device 5, the use of the frontal cam 43 affords considerable advantages compared with the use of the mating screw elements generally used for the same purpose in known electro-hydraulic motors: the cam 43 is easily replaceable and easily and economically manufactured, and the overall gain of the whole system is readily variable by simply replacing the frontal cam 43 by another frontal cam having a different profile. Finally, the efficiency of the whole system is high since frictions are minimized by the use of ball bearings and of a circulating ball bearing in the differential device.

It will be appreciated that details of practical embodiments of the invention can be widely varied from the illustrated example, without departing from the scope of this invention.

We claim:

1. An electro-hydraulic motor of the type comprising a first stepping electric pilot motor and a rotary hydraulic power motor having respective shafts, a distributor valve having a movable stem which regulates the supply of working fluid to the hydraulic motor, and a differential device connected to said movable stem of the distributor valve to displace the latter proportionally to the angular discrepancy existing between the shaft of the electric pilot motor and the shaft of the hydraulic motor, wherein the improvement consists in: the differential device comprising a first toothed wheel coupled directly to the shaft of the electric pilot motor, a shaft of the differential device coaxial with the shaft of the hydraulic motor and on which a second toothed wheel meshing with the first toothed wheel is mounted: means supporting said shaft of the differential device for rotation and axial displacement relative to the hydraulic motor shaft and facing the second toothed wheel, and cam-follower means interposed between the frontal cam and said toothed wheel and supported by the latter; the distributor valve being disposed transversely of the shaft of the hydraulic motor and connected hydraulically to the hydraulic motor; transmitting means interconnecting said shaft of the differential device and the stem of the distributor valve and transforming axial movements, in either sense, of the said shaft of the differential device into corresponding axial movements of said stem; and elastic means acting on the said shaft of the differential device and said stem to maintain them always in contact with said transmitting means.

2. Motor according to claim 1, in which the shaft of the hydraulic motor has a cylindrical bore and including a circulating ball bearing in said bore supporting the shaft of the differential device radially.

3. Motor according to claim 2, including a thrust bearing located at the axially inner end of said bore in the hydraulic motor shaft and a spring located between such thrust bearing and the shaft of the differential device.

4. Motor according to claim 2, wherein the axially outer end of said cylindrical bore is threaded and carries a correspondingly threaded tubular member arranged coaxially with the shaft of the differential device, the said frontal cam being formed integrally on the axially outer end of said member.

5. Motor according to claim 1, wherein the cam-follower means comprise a rotatable roller the axis of which extends radially with respect to the second toothed wheel and a small shaft carrying said roller and supported by the said toothed wheel on the surface of the latter facing the frontal cam.

6. Motor according to claim 1, wherein the transmitting means comprise a right angled lever pivotally mounted on the hydraulic motor for rocking movement about an axis perpendicular to the plane containing the axes of the shaft of the differential device and the stem of the distributor valve, the said lever being in contact on one side with the outer end of said shaft of the differential device and on the other side with the outer end of the said stem outside the distributor valve.

7. Motor according to claim 3, wherein the transmitting means comprise a right-angled lever pivotally mounted on the hydraulic motor for rocking movement about an axis perpendicular to the plane containing the axes of the shaft of the differential device and the stem of the distributor valve, the said lever being in contact on one side with the outer end of said shaft of the differential device and on the other side with the outer end of the said stem outside the distributor valve, and wherein the distributor valve has an end plate, the elastic means for maintaining the shaft of the differential device and the stem of the distributor valve always in contact with the right-angled lever comprising two helical springs the first of which is the spring located within said cylindrical bore of the hydraulic motor shaft between the inner end of the shaft of the differential device and the thrust bearing, and the second of which is interposed between the end of the distributor valve stem opposite to that cooperating with the right-angled lever and the end plate of the distributor valve.

8. Motor according to claim 7, including presettable means varying the pre-loading of the said springs.

9. Motor according to claim 8, wherein said presettable means varying the pre-loading of the springs comprise a first screw passing through said end plate of the distributor valve a plate through which said first screw, cooperates with an end of the spring disposed inside the valve and a second screw disposed coaxially with the shaft of the hydraulic motor and mounted inside the latter in cooperation with the thrust bearing supporting the shaft of the differential device to vary the axial position of the said bearing inside the bore of the hydraulic motor shaft, means being provided for adjusting the said first and second screws from the outside.

10. Motor according to claim 1, including a replaceable shock-absorbing member through which the distributor valve is connected to the hydraulic motor.

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