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[31] 42/83,880

[54] **ELECTRO-HYDRAULIC SERVOMOTOR**
10 Claims, 5 Drawing Figs.

[52] **U.S. Cl.** **91/6.5,**
91/180, 91/380, 91/448, 91/39
[51] **Int. Cl.** **F01b 3/00,**
F01l 33/02, F15b 9/10
[50] **Field of Search** 91/380,
368, 75, 180 (Cursory), 375 (Cursory)

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ABSTRACT: This invention relates to an electro-hydraulic servomotor wherein a hydraulic motor can exactly follow the rotation of an electric motor. No relative rotation occurs between a servovalve chamber and a valve spool closely mounted within said chamber. The valve spool is axially moved by the electric motor, thereby enlarging the opening degree of the oil ports of the hydraulic motor, and the rotation of said hydraulic motor moves said valve spool in the reverse direction to said axial displacement of said valve spool, thereby controlling the opening degree of said oil ports of said hydraulic motor.

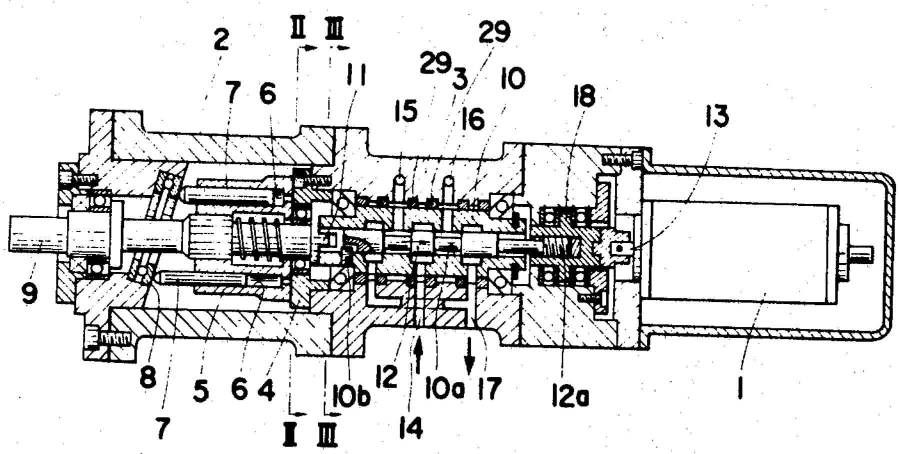

FIG. 1

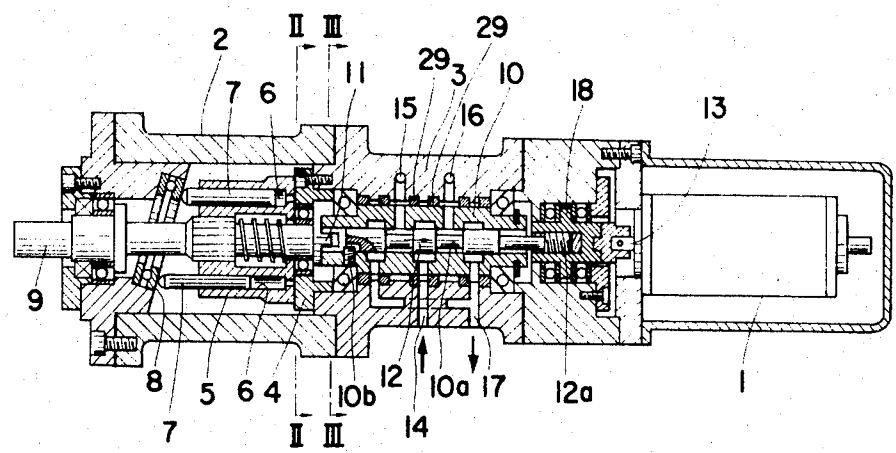

FIG. 2

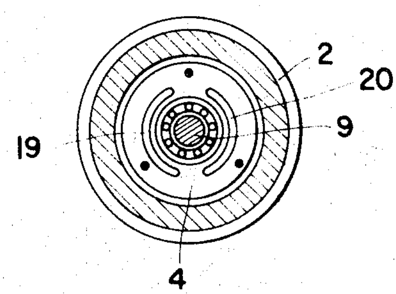

FIG. 3

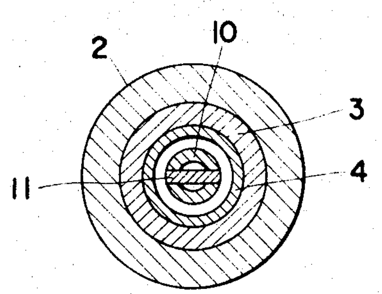

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FIG. 4

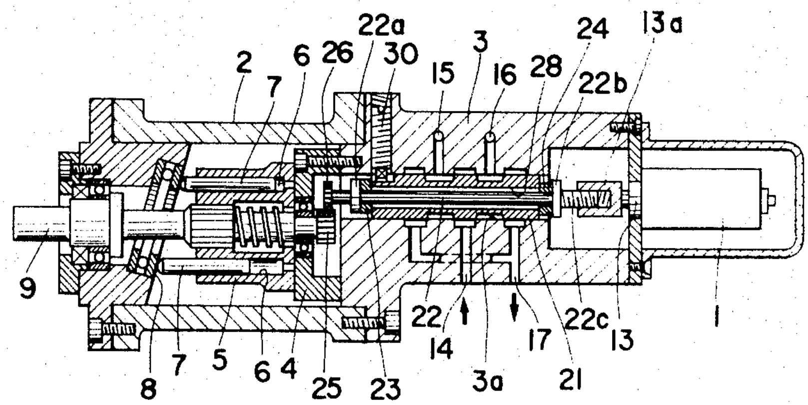
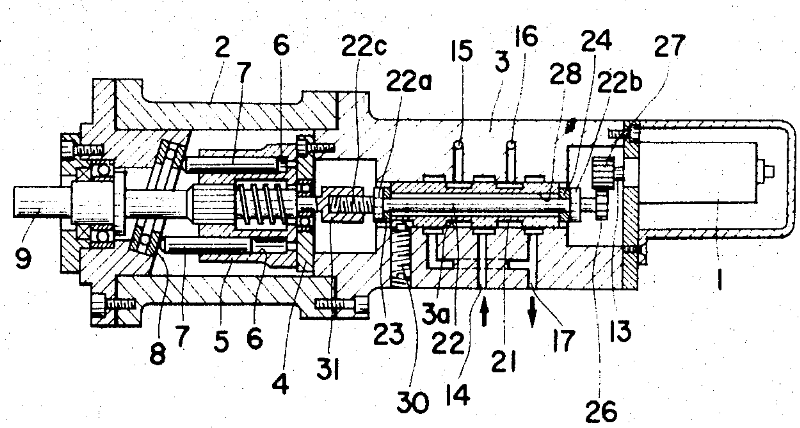


FIG. 5



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ELECTRO-HYDRAULIC SERVOMOTOR

BACKGROUND OF THE INVENTION

Recently with a spectacular advance in the automatic control of machine tools, and the like, a servomotor which can quickly respond to the r.p.m. indication and at the same time can withstand a heavy load is widely in demand.

As is well known, in an electric motor, like an electric pulse motor or a synchronous motor, the control of revolution is easy, but the motor cannot be used at high speed revolutions over a certain r.p.m. under a heavy load.

Meanwhile, in the case of a hydraulic motor, the motor may be used even at high speed revolutions under a heavy load, but it is not so easy for revolution control as the electric motor. Thus, both kinds of servomotors are found to have relative merits and demerits.

In view of this situation, the so-called electro-hydraulic servomotor has come into practical use, combining the good controllability features of the electric motor, such as an electric pulse motor or a synchronous motor, with the high speed and high output of the hydraulic motor.

The electro-hydraulic motor, as is well known, works as follows: the revolution of the electric motor is converted into an axial displacement taking place at the same time as the rotation of the valve spool or to a rotational displacement of the pilot valve. By either displacement, the oil port is opened to supply the pressurized oil to the hydraulic motor or to discharge the oil out of the motor, thereby the revolution of the hydraulic motor is made to follow that of the electric motor.

The construction of the conventional electro-hydraulic motor, however, is such that either the valve spool or the pilot valve is closely mounted within the valve chamber of the servovalve; thereby either the valve spool or the pilot valve is rotated by the electric motor; and thus either the valve spool or the pilot valve can rotate or slide in relation to the valve chamber of the servovalve. Under this construction, considerable power is needed to move the valve spool or the pilot valve.

The valve spool must be closely mounted within the valve chamber of the servovalve, or otherwise the hydraulic motor will not be able to follow the rotation of the electric motor with any degree of accuracy. Thus, great resistance should be overcome in order to realize a close mounting of either the valve spool or the pilot valve within the valve chamber of the servovalve due to the relative rotation of either the valve spool or the pilot valve to the valve chamber of the servovalve. Particularly when the oil viscosity is high, the resistance against the valve spool imposes an increased torque on the electric motor, resulting in a control failure of the electric motor.

Meanwhile, it is conceivable to make the valve spool rotate or slide relative to the valve chamber of the servovalve by the rotating output of the hydraulic motor and provide such feedback as to nullify the axial displacement of the valve spool. Under this arrangement, however, the rotation of the valve spool would be synchronized with that of the hydraulic motor and accordingly the relative rotation of the valve spool to the valve chamber of the servovalve would be high-speed, or the absolute amount of this relative motion would be great. While the radial difference between the valve chamber of the servovalve and the valve spool, closely mounted within the valve chamber, is less than several microns, the valve spool and the valve chamber of the servovalve cannot be true circle. Moreover, the valve spool and the valve chamber of the servovalve cannot be precisely concentric. It follows, on one hand, that the valve spool would be worn out and accordingly it would be difficult to make the rotation of the hydraulic motor follow that of the electric motor with high accuracy, and on the other hand, that a strong shearing force acts on the film of pressurized oil and in consequence the temperature rise of the pressurized oil is very much promoted.

SUMMARY OF THE INVENTION

The primary object of this invention is to provide an electro-hydraulic motor in which no relative rotation takes place between a valve chamber and a valve spool closely mounted within said valve chamber. Only a relative displacement in the axial direction takes place between them, so that the valve spool can work smoothly.

Another object of this invention is to provide an electro-hydraulic motor in which the oil port of the hydraulic motor is opened by a feeble or small torque of the electric motor. The rotation of the hydraulic motor can follow with high accuracy the rotation of the electric motor and a large torque of the hydraulic motor can be produced.

Still another object of this invention is to provide an electro-hydraulic motor in which the valve spool is allowed to cause only an axial displacement, thereby preventing any heat generation through the shearing of the pressurized oil.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and effects of this invention will be obvious from the following description with reference to the attached drawings, in which:

FIG. 1 shows a longitudinal section of one embodiment of this invention;

FIG. 2 shows a sectional view of FIG. 1 taken along the line II–II;

FIG. 3 shows a sectional view of FIG. 1 taken along the line III–III;

FIG. 4 shows a longitudinal section of another embodiment of this invention; and

FIG. 5 shows a longitudinal section of still another embodiment of this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIG. 1, 1 is an electric pulse motor, a synchronous motor, or other electric motor with controllable speed; 2 is a hydraulic motor; and 3 is a servovalve linking the electric motor 1 and the hydraulic motor 2.

The hydraulic motor 2 shown here is a well known axial plunger type motor illustrated as an example. This motor comprises a valve plate 4 fixed to the servovalve 3, a cylinder block 5 rotating in contact with said valve plate 4, an output shaft 9 splined to said cylinder block 5, an odd number of cylinders 6 provided within said cylinder block 5 axially disposed and circumferentially spaced around the axis of said output shaft 9, pistons 7 slidably mounted in the respective cylinders 6, and a rotatable inclined plate 8 which contacts the tips of said pistons 7.

As shown in FIG. 2, said valve plate 4 has two arcuate circulation grooves 19 and 20 provided opposite to each other around said output shaft 9. One of said circulation grooves 19 communicates with the port 15 of the servovalve 3, while the other 20 communicates with the port 16 of the servovalve 3 through passages not shown. The respective cylinders 6 provided in the cylinder block 5 communicate at one time with the circulation groove 19 and at another time with the circulation groove 20 according to the rotation of the cylinder block 5, whereby at any time some of the cylinders communicate with the circulation groove 19, while some of the cylinders communicate with the circulation groove 20.

Within the servovalve 3, a sleeve 10 is supported on bearings. The sleeve is rotatable but not shiftable in the axial direction. The left end of the sleeve 10 in FIG. 1 engages with a coupling 11 provided at the right end of the output shaft 9. Thus, the sleeve 10 can rotate together with the output shaft 9. The sleeve 10 has a valve chamber 10*a* bored therein. A valve spool 12 is mounted within this valve chamber 10*a* slidably in an axial direction. The valve spool 12 engages with a key member 10*b* screwed into the sleeve 10, whereby it can be shifted axially relative to the sleeve 10, but cannot be rotated relative to the sleeve 10.

The right end of the valve spool **12** in FIG. **1** is provided with a male screw member **12***a*, which is threadedly received in the female screw member **18** connected to the rotating shaft **13** of the electric motor **1**. Said female screw **18** is rotatably supported by a thrust bearing within the block.

An inlet oil passage **14** is provided in the servovalve housing **3** and opens to the valve chamber **10***a* bored in the sleeve **10**. At the neutral position of the valve spool **12**, *i.e.*, the halt condition of the electro-hydraulic servomotor, said passage **14** communicates with neither the port **15** nor the port **16**. When the valve spool **12** moves rightward from the position indicated in FIG. **1**, the inlet oil passage **14** is opened to communicate with the port **15**. As stated before, since the port **15** communicates with the circulation groove **19** (FIG. **2**), the pressurized oil supplied from the passage **14** to the port **15** goes into the circulation groove **19** to be delivered to the cylinders **6** which communicate with the circulation groove **19**.

When the valve spool **12** shifts leftward from the position of FIG. **1**, the inlet passage **14** is opened to communicate with the port **16**. Since the port **16** communicates with the circulation groove **20** (FIG. **2**), the pressurized oil supplied from the passage **14** to the port **16** reaches the groove **20**, to be delivered to the cylinders **6** which communicate with the groove **20**.

The servovalve **3** is further provided with an oil discharge passage **17**, which opens to the valve chamber **10***a* bored in the sleeve **10**. At the neutral position of the valve spool **12**, said oil discharge passage **17** communicates with neither the port **15** nor the port **16**.

When the valve spool **12** moves rightward from the position indicated in FIG. **1** the port **16** is opened to communicate with the oil discharge passage **17** and the pressurized oil within the cylinders **6** communicating with the groove **20** will drain out of the groove **20** and be discharged into the reservoir tank through the discharge passage **17** through the port **16**.

When the valve spool **12** moves leftward from the position of FIG. **1**, the port **15** is opened to communicate with the oil discharge passage **17** and the pressurized oil within the cylinders **6** communicating with the groove **19** will pass through the groove **19** and be discharged into the reservoir tank via the port **15** and the discharge passage **17**.

There are sealing members **29** of synthetic resin, etc. provided between the internal bore of the servovalve **3** and the external surface of the sleeve **10** to prevent the pressurized oil from leaking to the adjacent ports and passageways.

The performance of this electro-hydraulic servomotor is to be explained in the following.

An electric pulse motor is used at the electric motor **1**. When an electric pulse is given to the electric motor **1**, the rotating shaft **13** of said motor **1** begins to turn. Accordingly, the female screw member **18** turns along with the rotating shaft **13**. When the electric pulse motor begins to turn, the valve spool **12** is at the neutral position shown in FIG. **1**, with the output shaft **9** at rest. The sleeve **10** engaging with the output shaft **9** through the coupling **11** is also at rest. The valve spool **12** is retained against rotation relative to the sleeve **10** by means of the key member **10***b*. Therefore, when the female screw member **18** turns, the male screw member **12***a*, which is threadedly engaged with said female screw member **18**, is axially moved together with the valve spool **12**. The motion of the valve spool **12** thereby is not a relative rotation to the sleeve **10** but merely a simple displacement in an axial direction. Thus, the screwed engagement of female screw member **18** with male screw member **12***a* is utilized as the means for converting the rotation of the electric motor **1** to an axial displacement of the valve spool **12**. As the axial moving force of the valve spool **12** in this case is amplified, even a feeble torque of the electric motor **1** is enough to cause a very accurate displacement of the valve spool **12** with the least possible energy loss due to the viscosity of the pressurized oil and without the possibility of the pulse failing to be given to the electric motor.

If the axial displacement of the valve spool **12** is as indicated by the arrow in FIG. **1** rightward, the pressurized oil passage **14** communicates with the port **15** and the pressurized oil introduced at the passage **14** goes from the port **15** to the circulation groove **19** to be delivered to the cylinders **6** communicating with said groove **19**. As a result, the pistons **7** mounted in the cylinders **6** which communicate with said groove **19**, tend to be projected outwardly of the cylinder block **5** and the tips of said pistons **7** push against the inclined plate **8**, causing the cylinder block **5** to rotate in the same direction as the rotation of the rotating shaft **13**.

When the cylinder block **5** is rotated, the pressurized oil in the cylinders **6** communicating with the circulation groove **19**, is permitted to drain out through the groove **20** and through the port **16** to be discharged into the reservoir tank through the discharge passage **17**, while the pistons **7** mounted in the cylinders **6** communicating with the circulation groove **20**, are pushed by the inclined plate **8**, upon the rotation of the cylinder block **5**, back into the cylinders **6**.

Upon rotation of the cylinder block **5**, the output shaft **9**, splined to said block **5** is rotated, thereby causing the rotation of the sleeve **10** through the coupling **11**. Since the valve spool **12** is retained against rotation relative to the sleeve **10** by means of the key member **10***b*, the rotation of the sleeve **10** is accompanied by that of the valve spool **12**.

When the electric pulse ceases to be given to the electric motor **1** and in consequence the motor **1** comes to a halt, the still continuing rotation of the cylinder block **5** and the output shaft **9** maintains the rotation of the valve spool **12**. The rotating male screw member **12***a* will therefore move leftward to the original neutral position of FIG. **1** within the female screw member **18** which has now stopped rotating with the electric motor. The valve spool cuts the communication of the oil passage **14** with the port **15** and that of the oil discharge passage **17** with the port **16**. Thereupon, the rotation of both the cylinder block **5** and the output shaft **9** stops, no relative rotation between the valve spool **12** and sleeve **10** taking place even at this time.

If under continuous rotation of the electric motor **1** at constant speed the rotation of the output shaft **9** is slower than that of the rotating shaft **13**, the valve spool **12** makes an axial displacement in the direction of enlarging the opening degrees of the ports **15** and **16** and increasing the flow of pressurized oil to the hydraulic motor and as the result the supply and discharge of oil to the cylinders **6** are increased to promote increased rotation of the cylinder block **5**. When the rotation of the output shaft **9** is faster than that of the rotating shaft **13**, the valve spool **12** makes an axial displacement in the direction of narrowing the opening degrees of the ports **15** and **16** and decreasing the flow of pressurized oil to the motor and as the result the supply and discharge of oil to the cylinders **6** are decreased to reduce the speed of rotation of the cylinder block **5**. Thus, the speed of rotation of the output shaft **9** is at all times controlled to follow the speed of the rotating shaft of the electric motor **1**.

FIG. **4** illustrates another embodiment according to this invention, in which the identical parts to FIG. **1** are denoted by the identical symbols.

In the embodiment of FIG. **4**, the servovalve **3** is bored to form a valve chamber **3***a*, within which the valve spool **21** is mounted slidably in an axial direction. The valve spool **21** engages with a key member **30** screwed into the body of the servovalve **3**. Said valve spool is therefore axially movable relative to the internal bore of the servovalve **3**, but not rotatable. The valve spool **21** has an axial through hole **28** bored therein and into this through hole **28** a working shaft **22** is inserted rotatable relative to the valve spool **21**. At both ends of the valve spool **21** there are installed bearings **23** and **24** which rotatably support said working shaft **22**. Outside of said bearings **23** and **24** there are flanges **22***a* and **22***b* fixed to the working shaft **22**. Thus, the working shaft **22** can both rotate and make displacement in an axial direction. While the valve spool **21** moves axially therewith, the valve spool **21** does not rotate.

At the right end of the working shaft **22** there is provided the male screw member **22c**, which is threadedly received in the female screw member **13a** formed on the rotating shaft of the electric motor **1**. At the left end of the working shaft **22** a gear **26** is rigidly mounted and this gear meshes with and is axially slidable relative to a wide gear **25** fixed to the output shaft **9**.

In the embodiment of FIG. **4**, when an electric input like the electric pulse is imparted to the electric motor **1**, the rotating shaft **13** of the electric motor begins to rotate. Accordingly, the female screw member **13a** turns along with the rotating shaft **13**. When the electric pulse motor begins to rotate the cylinder block **5** and the output shaft **9** splined to said block **5** are at rest, so that the working shaft **22** on which is rigidly mounted the gear **26** meshing with the gear **25** rigidly mounted on the output shaft **9** does not rotate at first. Therefore, as the female screw member **13a** turns, the male screw member **22c**, cooperatively engaged with said female screw member **13a**, will be axially displaced together with the working shaft **22**.

When the working shaft **22** is displaced in an axial direction, the valve spool **21** disposed between the flanges **22a** and **22b** is also displaced axially together with the working shaft **22** and the oil passage **14** and the oil discharge passage **17** are made to communicate either with the port **15** or with the port **16**, thereby causing a rotation of the cylinder block **5**.

When the cylinder block **5** rotates, the output shaft **9** splined with said block **5** also rotates and as the result the working shaft **22** will be rotated through the meshing gears **25** and **26**. If there is a speed difference between the rotation of the working shaft **22** and that of the rotating shaft **13** of the electric motor **1**, the male screw member **22c** threaded into the female screw member **13a** will shift the valve spool **21** together with the working shaft **22** in the axial direction, thereby changing the opening degrees of ports **15** and **16** and controlling the flow of pressurized oil, with the result that the rotation of the output shaft **9** can follow that of the rotating shaft **13** of the electric motor **1**.

The valve spool **21** is prevented by the key member **30** from being rotated. As there are bearings **23** and **24** inserted between the valve spool **21** and the working shaft **22**, the valve spool **21** will not rotate relative to the valve chamber **3a** of the servovalve **3**, but instead will merely be axially displaceable whenever the working shaft **22** is turned by the gear **26** and makes an axial displacement.

In the embodiment of FIG. **4**, as compared with that of FIG. **1**, the composition of the servovalve **3** is simplified and the equipment is made compact. With the working shaft provided within the valve spool **21**, the sealing of pressurized oil is also simplified. Moreover the working shaft **22** is reduced both in diameter and in weight, so with the load on the electric motor **1** is greatly reduced. It is thus possible to make the rotating shaft **13** of the electric motor **1** turn correctly following the frequency of the electric input.

FIG. **5** illustrates still another embodiment of this invention, the identical parts to FIG. **4** being denoted by the identical symbols. In the embodiment of FIG. **5**, the rotating shaft **13** of the electric motor **1** has fixed thereon a wide gear **27**, which meshes with a gear **26** fixed to the working shaft **22**. The male screw member **22c** provided at the left end of the working shaft **22** is threadedly received in the female screw member **31**, formed at the right end of the output shaft **9**.

In the embodiment of FIG. **5** when an electric input like the electric pulse is given to the electric motor **1**, the rotating shaft **13** of the electric motor **1** begins to turn. Through the gears **27** and **26** the working shaft **22** is rotated. When the electric pulse motor begins to turn, both the cylinder block **5** and the output shaft **9** splined therewith are at rest. The rotation of the working shaft **22** causes the male screw member **22c**, threaded into the female screw member **31**, to be axially displaced along with the working shaft **22**.

When the working shaft **22** is shifted, while rotating, in the axial direction, the valve spool **21** disposed between the flanges **22a** and **22b**, will likewise be displaced axially along with the working shaft **22**, thereby supplying and discharging the pressurized oil to the cylinders **6** of the cylinder block **5** to rotate the cylinder block **5**. The valve spool **21** being retained against rotation by means of the key member **30**, the valve spool **21** does not rotate relative to the valve chamber **3a** of the servovalve **3**, but merely makes an axial displacement therein as illustrated in the embodiment of FIG. **4**.

If there is a speed difference between the rotation of the output shaft **9** and that of the working shaft **22**, the male screw member **22c**, threaded into the female screw member **31**, causes the valve spool **21** to be axially displaced together with the working shaft **22**, thereby changing the degree of opening of the ports **15** and **16** and thus controlling the flow of pressurized oil, with the result that the rotation of the output shaft **9** can follow that of the rotating shaft **13** of the electric motor **1**.

As explained above, this invention makes it possible for the rotation of the hydraulic motor to follow with high accuracy the rotation of the electric motor by converting the rotation of the electric motor with controllable angle or speed of rotation to an axial displacement of the valve spool and effecting the supply and discharge of pressurized oil to the hydraulic motor through this axial displacement of the valve spool. Particularly, according to this invention, no relative rotation is permitted to occur between the axially moving valve spool and the sleeve mounted about said valve spool or the valve chamber of the servovalve. In consequence the valve spool can be very accurately moved by an extremely small or feeble rotating torque. Therefore, the response of the valve spool is extremely rapid, making it possible for the hydraulic motor to follow the rotational angle or speed of the electric motor with extremely high accuracy. Besides, there being no relative rotation between the valve chamber and the valve spool mounted closely within the valve chamber, the temperature rise of the pressurized oil is small.

Thus, unlike the conventional electro-hydraulic servomotors of the prior art, the servomotor of the present invention is free from the inconveniences and disadvantages of being affected by the viscosity of the pressurized oil requiring a large power consumption in order to move the valve spool. In this invention there is no possibility of the pulse failing to be given to the electric motor.

While the above descriptions are concerned with the preferred embodiment of this invention, it will be evident to those skilled in the art that various changes and modifications may be made therein without departing from the invention; and the appended claims intend to cover all such changes and modifications as fully within the true spirit and scope of the invention.

I claim:

1. An electro-hydraulic servomotor comprising an electric motor having a drive shaft and rotatable in response to electric signals, a hydraulic rotary motor having an output shaft, a source of fluid pressure, servovalve means controlled by said electric motor for operating said hydraulic rotary motor through control of the supply of fluid pressure from said source, said servovalve means having a valve chamber provided with ports for the supply and discharge of the pressurized fluid to said hydraulic motor, a spool valve disposed within said chamber and retained from relative rotation therewith but axially shiftable within said chamber to control the selection and degree of opening of said ports, a screw threaded connection means associated with said spool valve and rotatable under the influence of relative rotation of the drive shaft of said electric motor and the output shaft of said hydraulic motor to cause axial displacement of said spool valve whereby the hydraulic motor is effectively controlled to follow very closely the rotational speed of the electric motor.

2. An electro-hydraulic servomotor as defined in claim **1**, wherein said electric motor is an electric pulse type motor rotatable through a predetermined angle by responding to electric pulses.

3. An electro-hydraulic servomotor as defined in claim 1, wherein said hydraulic rotary motor is of the hydraulic plunger type motor.

4. An electro-hydraulic servomotor as defined in claim 1, wherein said valve chamber is formed within a sleeve rotatably mounted within the body of the servovalve means and connected at one end to the output shaft of said hydraulic rotary motor with said spool valve slidably mounted within said sleeve and retained from relative rotation with respect to said sleeve.

5. An electro-hydraulic servomotor as defined in claim 4, wherein said screw threaded connection means is interposed between the drive shaft of said electric motor and the spool valve.

6. An electro-hydraulic servomotor as defined in claim 4, wherein said sleeve is provided with a port for introducing fluid under pressure from said fluid pressure source, a first pair of ports for supplying said fluid to said hydraulic rotary motor and a second pair of ports for discharging said fluid from said hydraulic rotary motor, and wherein said spool valve is provided with spaced lands thereon to simultaneously control said fluid supplied to said hydraulic motor and discharged therefrom by controlling said ports.

7. An electro-hydraulic servomotor as defined in claim 1, wherein said spool valve slidably mounted within said valve chamber is keyed against rotation relative to the body of said servovalve means and is provided with an axially extending working shaft rotatably mounted therethrough and axially slidable along with said spool valve, said working shaft having gear means at one end thereof slidingly engaging gear means carried by the output shaft of said hydraulic rotary motor, and wherein said screw threaded connection means is interposed between the other end of said working shaft and the drive shaft of said electric motor so that when the electric motor is rotated said spool valve is shifted axially through said working shaft with respect to said valve chamber to control pressure fluid to and from said hydraulic rotary motor.

8. An electro-hydraulic servomotor as defined in claim 7, wherein said body of said servovalve means is provided with a port for introducing fluid under pressure from said fluid pressure source, a first pair of ports for supplying said fluid to said hydraulic rotary motor and a second pair of ports for discharging said fluid from said hydraulic rotary motor, and wherein said spool valve is provided with spaced lands thereon to simultaneously control said fluid supplied to said hydraulic motor and discharged therefrom by controlling said ports.

9. An electro-hydraulic servomotor as defined in claim 1, wherein said spool valve slidably mounted within said valve chamber is keyed against rotation relative to the body of said servovalve means and is provided with an axially extending working shaft rotatably mounted therethrough and axially slidable along with said spool valve, said working shaft having gear means at one end thereof slidingly engaging gear means carried by the drive shaft of said electric motor, and wherein said screw threaded connection means is interposed between the other end of said working shaft and the output shaft of said hydraulic rotary motor, so that when said electric motor is rotated the spool valve is shifted axially through said working shaft with respect to said valve chamber to control pressure fluid to and from said hydraulic rotary motor.

10. An electro-hydraulic servomotor as defined in claim 9, wherein said body of said servovalve means is provided with a port for introducing fluid under pressure from said fluid pressure source, a first pair of ports for supplying said fluid to said hydraulic rotary motor and a second pair of ports for discharging said fluid from said hydraulic rotary motor, and wherein said spool valve is provided with spaced lands thereon to simultaneously control said fluid supplied to said hydraulic motor and discharged therefrom by controlling said ports.