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ELECTRICALLY COMMUTATED FLUID MOTOR

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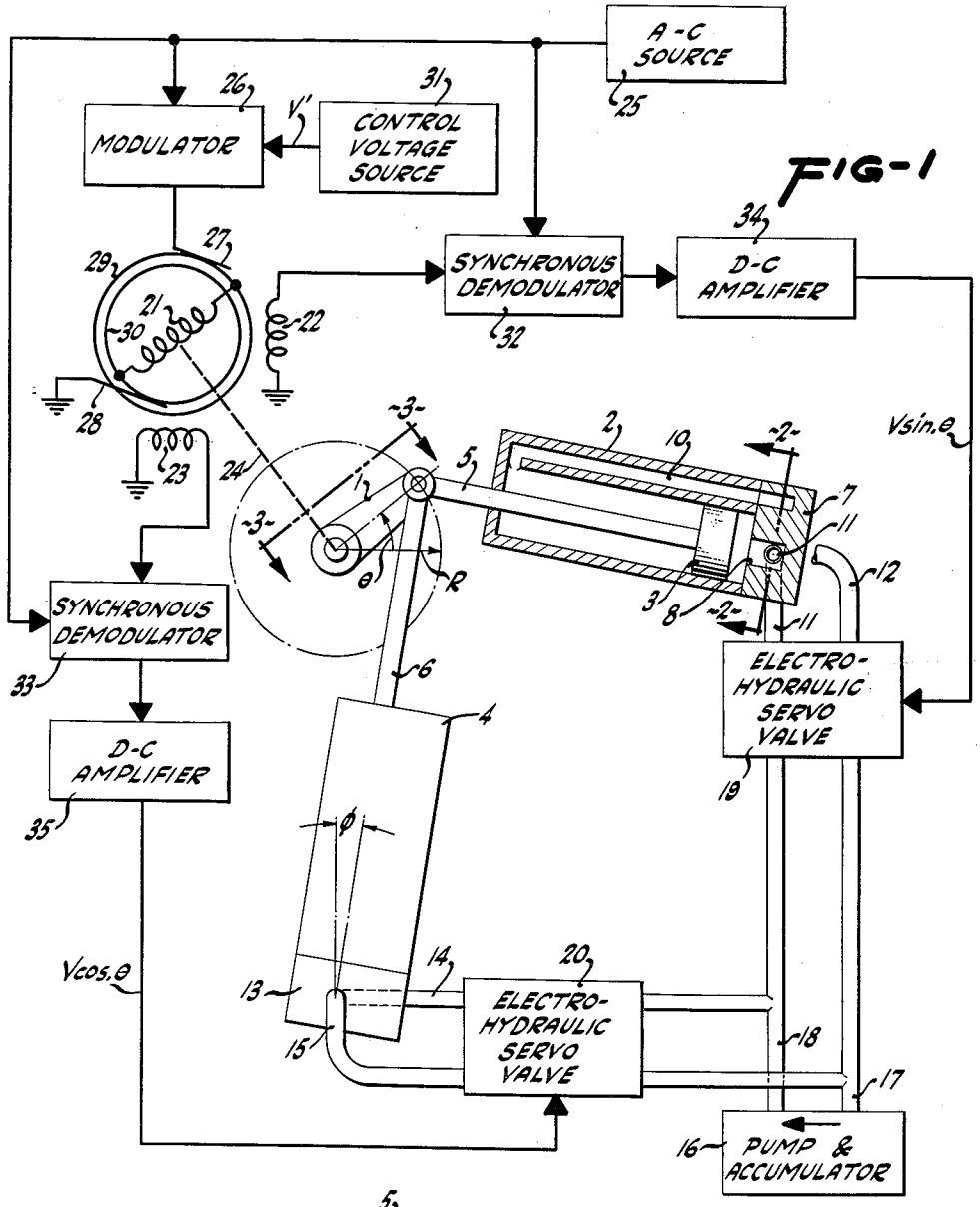


FIG-1

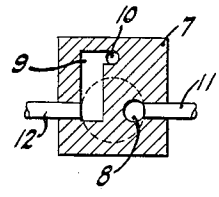


FIG-2

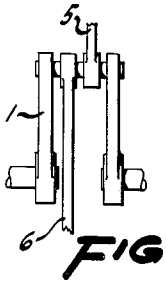


FIG-3

INVENTOR.
GLEN D. ROLLS

BY

Lippincott, Ralls & Hendrickson
ATTORNEYS

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ELECTRICALLY COMMUTATED FLUID MOTOR

Glen D. Rolls, Redwood City, Calif., assignor to Textron Inc., Belmont, Calif.

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This invention relates to motors operated by hydraulic or other fluid for continuously rotating a rotary part, e.g., a crackshaft, and in particular to such a motor in which the fluid supply to fluid-driven reciprocators is commutated by electrically controlled valves.

Briefly, two double-acting, fluid-driven reciprocators are mechanically connected in driving relation to a rotary part and in quadrature phase relation to each other. Two electrically controlled valves are connected in fluid-controlling relation to the two reciprocators. The two valves are controlled by two electric signals that vary cyclically in synchronism with the rotation of the rotating part and in phase quadrature with each other. Thus, the flow of fluid to the two reciprocators is commutated to provide continuous rotation of the rotary part. Further, the electrically controlled valves may be of the pressure-control type that provides an output pressure differential proportional to an input electric signal, in which case the motor described will provide a constant output torque at the rotary part. Alternatively, the valves may be of the flow-control type that provides an output flow rate proportional to an input electric signal, in which case the motor will provide a constant speed at the rotary part.

The invention may be understood better from the following illustrative description and the accompanying drawings.

FIG. 1 of the drawings is a schematic representation and circuit diagram of a preferred embodiment of the invention.

FIG. 2 is a section taken along the line 2—2 of FIG. 1.

FIG. 3 is a section taken along the line 3—3 of FIG. 1.

Referring to the drawings, crankshaft 1 is a rotary part, which may be connected to any load that is to be driven by the motor. A first, fluid-driven reciprocator comprises a double-acting hydraulic cylinder 2 containing a reciprocating piston 3; and a second, fluid-driven reciprocator comprises an identical double-acting hydraulic cylinder 4, also containing a reciprocating piston. For clarity of illustration, the drawing shows cylinder 2 in longitudinal section and cylinder 4 in side elevation. It will be understood that the two reciprocators may be, and preferably are, identical. The two reciprocating pistons are connected to crankshaft 1 by two connecting rods 5 and 6. Thus, both pistons are mechanically connected in driving relation to the crankshaft and in quadrature phase relation to each other. In the illustrated embodiment, quadrature phase relation is achieved by spacing the two cylinders ninety degrees apart in relation to the crankshaft, but it will be understood that other well-kniwn arrangements for achieving a ninety-degree phase relation of two reciprocators might be employed.

Rotary fluid joints are attached to the outer ends of cylinders 2 and 4 for introducing and extracting hydraulic fluid. The cylinders are pivoted upon these rotary joints so that they may oscillate as the crankshaft 1 rotates. This permits the use of straight, unarticulated connecting rods 5 and 6. The nature of the rotary joint is shown somewhat schematically in FIGS. 1 and 2. The outer end of cylinder 2 is covered by an end cap 7 provided with a first fluid passage 8 that opens into the outer end of the cylinder, for the introduction of fluid into the space behind piston 3 for forcing the piston outward, i.e., toward the left as viewed in FIG. 1, and a second fluid

passage 9 leading to a further passage 10 that opens into the front end of the cylinder, for introducing fluid in front of piston 3 to force the piston back, i.e., toward the right as viewed in FIG. 1 . The same passages serve for the extraction of fluid from the space into which the piston is moving. Pipe 11 extends laterally into one side of end cap 7 and opens into space 8. Pipe 12 extends into the opposite side of end cap 7 and opens into the passage 9. The ends of the two pipes 11 and 12 are in axial alignment, and the end cap 7 is pivoted for oscillation about the axis of these pipes. Conventional fluid seals of known type may be employed to prevent any leakage of hydraulic fluid through the rotary joints. Similarly, the outer end of the cylinder 4 is closed by an end cap 13. Pipes 14 and 15 extend into opposite sides of end cap 13, and cylinder 4 is pivoted for oscillation about the common axis of the ends of these two pipes.

A conventional hydraulic power supply, i.e., a pump and accumulator 16, receives fluid from return pipe 17 and supplies fluid under pressure through pipe 18. Two electrically controlled valves 19 and 20 are connected in fluid-controlling relation to the two cylinders 2 and 4. More specifically, valve 19 is an electrohydraulic servo valve arranged to establish a fluid connection from pipe 18 to either of the pipes 11 or 12, selectively, under the control of an electric signal, and a return connection from the other of the pipes 11 and 12 to the return pipe 17. Similarly, valve 20 is an electrohydraulic servo valve arranged to establish a fluid connection from pipe 18 to either of the pipes 14 and 15, selectively, under the control of another electric signal, and to establish a return fluid connection from the other of the pipes 14 and 15 to the pipe 17.

Electrohydraulic servo valves suitable for this application are elready well known in the art, and require no further description. Two examples of such valves are disclosed in U.S. Patent No. 2,904,055, entitled "Hydraulic Amplifier Valve with Feedback," issued to Robert R. Witherell on September 15, 1959. FIG. 1 of this patent shows such a valve of the flow-control type that provides an output flow rate proportional to an input electric signal. FIG. 2 shows such a valve with the addition of pressure feedback from the load, whereby the valve can be designed to give an output pressure differential proportional to the input electric signal. Either type of valve may be used for the present invention. If the flow-control type is used, the motor herein described will provide a constant speed at the crankshaft 1, and if the pressure feedback type of valve is employed, the motor herein described will provide a constant torque at the output shaft 1. Other valve characteristics, e.g., a function of both flow rate and pressure that varies in proportion to the input electric signal, may be obtained with variations in valve design that are known to those skilled in the art, and will result in a motor characteristic expressed by a similar function of speed and torque. Hence, a wide range of motor characteristics is obtainable by varying the design of the electro-hydraulic servo valves to obtain various valve characteristics, in a manner already known to those skilled in the art.

For properly commutating the fluid supply to the two reciprocators to achieve the continuous rotation of crankshaft 1, the two valves 19 and 20 should be supplied with two electric signals that vary cyclically in synchronism with the rotation of crankshaft 1, and in phase quadrature with each other. Selecting as an arbitrary reference point the angular position of chankshaft 1 when piston 3 is at top dead center, and expressing all other positions of crankshaft 1 in terms of an angle θ measured from the selected reference point, the input electric signal supplied to valve 19 should be proportional to sin θ and the input electric signal supplied by

valve 20 should be proportional to cos θ. The amplitudes of these two signals should be proportional to a variable V, which determines the output speed of the motor or the output torque of the motor, depending upon the characteristics of the servo valves 19 and 20, as hereinbefore explained.

For example, assume that valves 19 and 20 are of the pressure-control type, and that the connecting rods 5 and 6 are sufficiently long in relation to the radius R of the crankshaft that the angle ϕ, arising from the oscillation of cylinders 2 and 4, is small enough to be negligible. It is then evident that the pressure acting upon piston 3 is proportional to V sin θ and that the torque provided at the crankshaft by piston 3 is proportional to RV $\sin^2 \theta$. The other piston provides a torque proportional to RV $\cos^2 \theta$, and $\sin^2+\cos^2$ being equal to 1, the total output torque is a constant proportional to RV.

From similar considerations, if the valves 19 and 20 are of the flow-control type, the linear velocity of piston 3 will be proportional to V sin θ, the linear velocity of the other piston will be proportional to V cos θ, and the angular velocity of crankshaft 1 will be a constant proportional to V/R.

A preferred means for supplying the electric signals V sin θ and V cos θ comprises a synchro-resolver having a rotor winding 21, and having two stator windings 22 and 23 disposed in quadrature phase relation to each other. The rotor winding 21 is mechanically connected to the crankshaft 1, as indicated by broken line 24, so that the rotor winding and the crankshaft rotate in synchronism. Alternating current is supplied to the rotor winding from an A.C. source 25 through a modulator 26, brushes 27 and 28, and slip rings 29 and 30. A control-voltage source 31 supplies a variable voltage V′ to the modulator for varying the amplitude of alternating current transmitted to the rotor winding. The control-voltage V′ controls, and is proportional to, the amplitude of the cyclically varying electric signals supplied to the servo valves.

From the foregoing, it is evident that rotor winding 21 is supplied with an alternating current having an amplitude proportional to V′. The frequency of this alternating current is immaterial, but preferably is higher than the maximum angular velocity of crankshaft 1 and rotor winding 21. As the rotor winding 21 rotates, its magnetic flux linkage with stator winding 22 varies as sin θ and its magnetic flux linkage with winding 23 varies as cos θ. Hence, there is induced in winding 22 an alternating voltage of the frequency supplied by source 25, which is amplitude-modulated with the function V′ sin θ. Similarly, there is induced in winding 23 a voltage amplitude-modulated with the function V′ cos θ. Windings 22 and 23 are connected to the inputs of synchronous demodulators 32 and 33, respectively. These synchronous demodulators have reference voltage inputs connected to alternating current source 25, and hence provide at their outputs electric signals proportional to the modulation functions V′ sin θ and V′ cos θ. Preferably amplified by D.C. amplifiers 34 and 35, these output signals from the two synchronous demodulators become the desired input V sin θ and V cos θ for controlling servo valves 19 and 20.

Although other means for developing the electric signals V sin θ and V cos θ will occur readily to those skilled in the art, the circuit shown is advantageous in that control of the output speed or torque is easily achieved by varying the control voltage V′, and in the long life and reliability of the synchro-resolver and other parts employed.

In its broader aspects, this invention is not limited to the specific embodiment herein illustrated and described; various changes and modifications can be made without departing from the inventive principles herein disclosed.

What is claimed is:

1. An electrically commutated fluid motor comprising a rotary part, two fluid-driven reciprocators mechanically connected in driving relation to said rotary part and in quadrature phase relation to each other to continuously rotate said rotary part in one direction in spite of the repeated direction reversal of the motion of said reciprocators, two electrically controlled valves connected in fluid-controlling relation to said two reciprocators, means for supplying to one of said valves a first electric signal synchronized with the continuous rotation of said rotary part, and means for supplying to the other of said valves a second electric signal in quadrature phase relation to said first signal so that said reciprocators continuously rotate said rotary part in the direction determined by said quadrature phase relation.

2. An electrically commutated fluid motor comprising a crankshaft, two double-acting hydraulic cylinders each containing a reciprocating piston, means connecting said pistons in driving relation to said crankshaft and in quadrature phase relation to each other to continuously rotate said crankshaft in one direction in spite of the repeated direction reversal of the motion of said reciprocating pistons, two electrohydraulic servo valves connected in fluid-controlling relation to said two cylinders, means for supplying to one of said valves an electric signal proportional to the sine of the angular position of said crankshaft, and means for supplying to the other of said valves an electric signal proportional to the cosine of the angular position of said crankshaft so that said reciprocating pistons continuously rotate said crankshaft in the direction determined by said quadrature phase relation.

3. An electrically commutated fluid motor comprising a crankshaft, two double-acting hydraulic cylinders each containing a reciprocating piston, said two cylinders being spaced ninety degrees from each other relative to said crankshaft to continuously rotate said crankshaft in one direction in spite of the repeated direction reversal of the motion of said reciprocating pistons, connecting rods connecting said pistons to said crankshaft, rotary fluid joints attached to said cylinders for introducing and extracting hydraulic fluid, each cylinder being pivoted upon said joints for oscillation as the crankshaft rotates, two electrically controlled valves connected in fluid-controlling relation to the rotary joints of the two cylinders, means for supplying to one of said valves an electric signal proportional to the sine of the angular position of said crankshaft, and means for supplying to the other of said valves an electric signal proportional to the cosine of the angular position of said crankshaft so that said reciprocating pistons continuously rotate said crankshaft in the direction determined by said quadrature phase relation.

4. A constant-torque, electrically commutated hydraulic motor comprising a rotary part, two double-acting hydraulic reciprocators mechanically connected in driving relation to said rotary part and in quadrature phase relation to each other to continuously rotate said rotary part in one direction in spite of the repeated direction reversal of the motion of said reciprocators, two electrohydraulic servo valves connected in hydraulic pressure-controlling relationship to said two reciprocators, each of said valves being of the perssure-control type that provides an output pressure differential proportional to an input electric signal, means for supplying to one of said valves an electric signal proportional to the sine of the angular position of said rotary part, and means for supplying to the other of said valves an electric signal proportional to the cosine of the angular position of said rotary part so that said reciprocators continuously rotate said rotary part in the direction determined by said quadrature phase relation.

5. A constant-speed, electrically commutated hydraulic motor comprising a rotary part, two double-acting hydraulic reciprocators mechanically connected in driving relation to said rotary part and in quadrature phase relation to each other to continuously rotate said rotary part in one direction in spite of the repeated direction re-

versal of the motion of said reciprocators, two electrohydraulic servo valves connected in hydraulic flow-controlling relationship to said two reciprocators, each of said valves being of the flow-control type that provides an output flow rate proportional to an input electric signal, means for supplying to one of said valves an electric signal proportional to the sine of the angular position of said rotary part, and means for supplying to the other of said valves an electric signal proportional to the cosine of the angular position of said rotary part so that said reciprocators continuously rotate said rotary part in the direction determined by said quadrature phase relation.

6. An electrically commutated fluid motor comprising a rotary part, two fluid-driven reciprocators mechanically connected in driving relation to said rotary part and in quadrature phase relation to each other, two electrically controlled valves connected in fluid-controlling relation to said two reciprocators, a synchro-resolver having a rotor winding and two quadrature-phased stator windings, means mechanically connecting said rotor winding and said rotary part together for rotation in synchronism with each other, means for supplying alternating current

to said rotor winding, two synchronous demodulators each connected to a different one of said two stator windings, and means electrically connecting each of said demodulators to a different one of said two valves, whereby the two valves receive two electric signals that vary cyclically in synchronism with the rotation of said rotary part and in phase quadrature with each other.

7. A motor as in claim 6, said means for supplying alternating current comprising an alternating current source, a modulator connected between said source and the rotor winding of the resolver, and means for supplying a variable control voltage to said modulator for varying the amplitude of the alternating current transmitted to the rotor winding.

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