

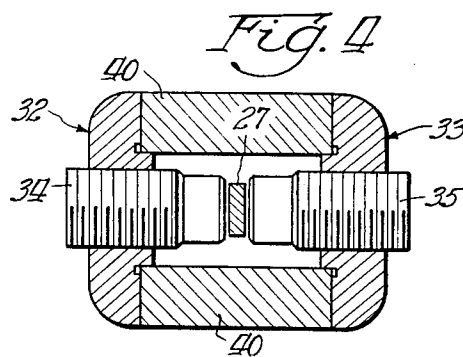
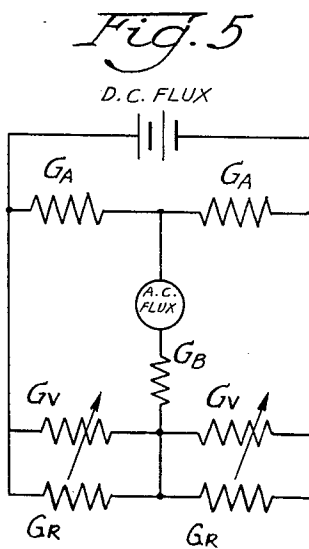
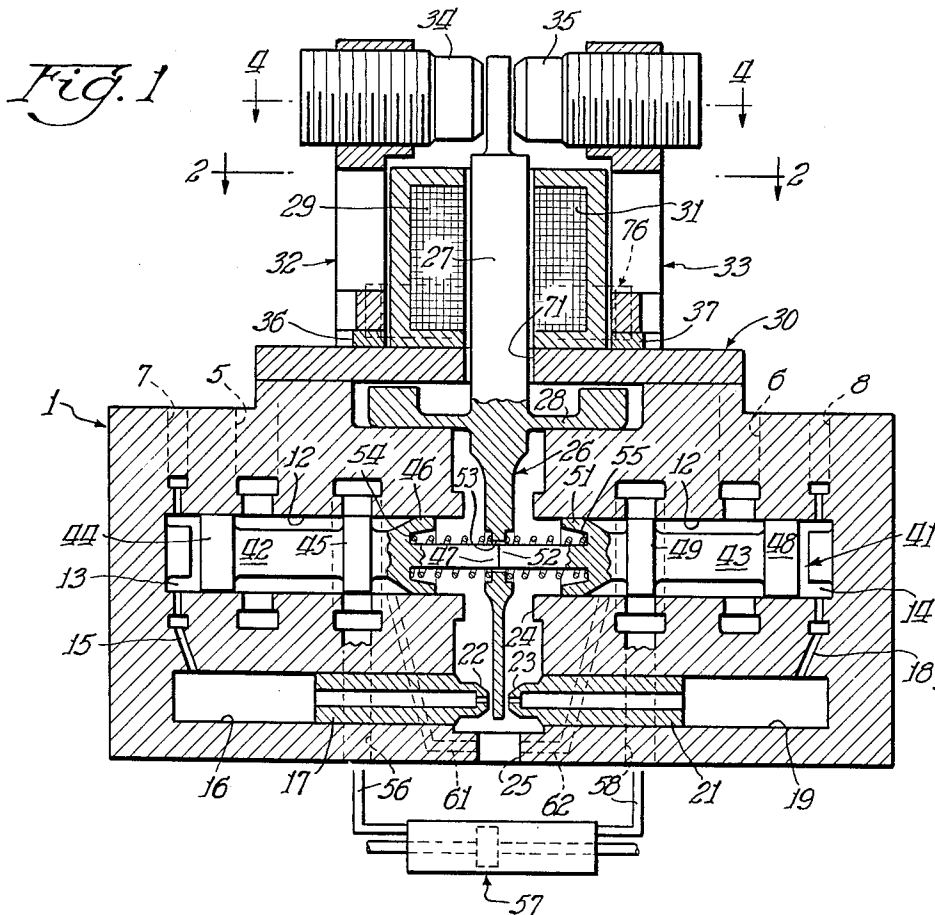
Oct. 9, 1962

H. Q. STEDMAN, JR., ET AL
TORQUE MOTOR WITH NULL BALANCE

3,058,038

Filed Nov. 20, 1959

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

Fig. 2

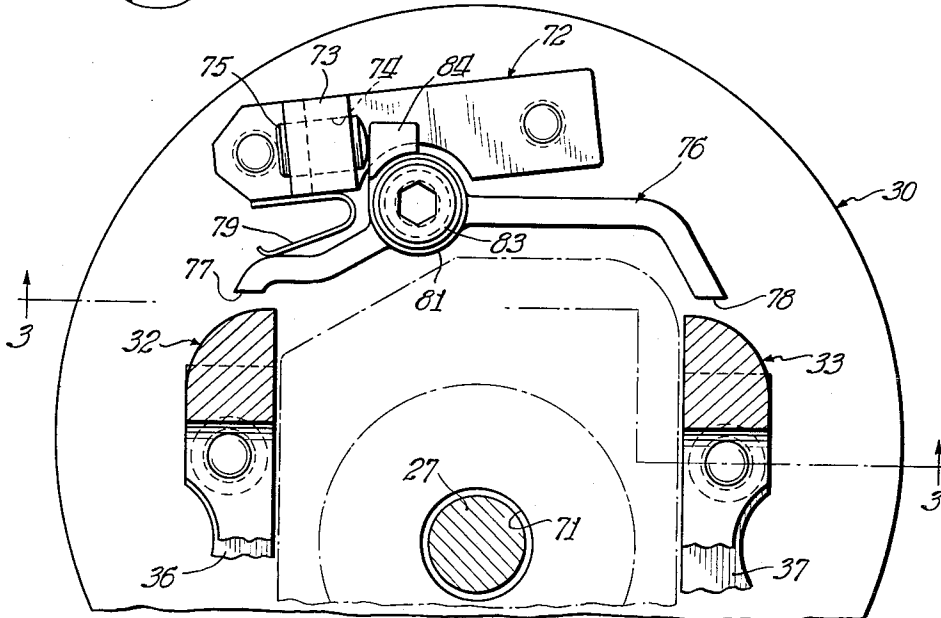
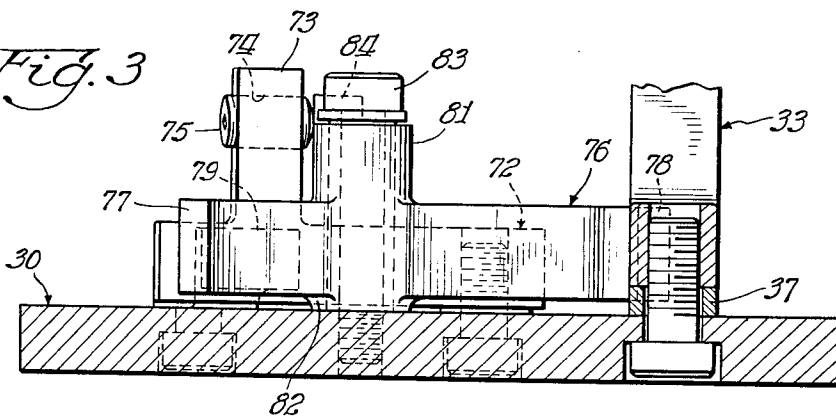


Fig. 3



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3,058,038

TORQUE MOTOR WITH NULL BALANCE

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This invention relates to mechanisms for adjusting the operation of electrical torque motors, such as are commonly used in electrohydraulic servo valves.

The object of this invention is to provide a new and improved adjustable torque motor in which the adjustment may be effected by simple, economical and non-critical means.

Other objects and features of the invention will be readily apparent to those skilled in the art from the specification and appended drawing illustrating a certain preferred embodiment in which:

FIGURE 1 is a sectional view taken vertically through a torque motor and servo valve associated therewith;

FIGURE 2 is a sectional view along the plane of line 2-2 of FIGURE 1;

FIGURE 3 is a sectional view along the plane of line 3-3 of FIGURE 2;

FIGURE 4 is a sectional view along the plane of line 4-4 of FIGURE 1; and

FIGURE 5 is a schematic representation of a magnetic circuit of the torque motor of the present invention.

It will be readily understood by those skilled in the art that the foregoing figures are somewhat schematic, for the purpose of facilitating the description and understanding of the invention.

The valve has a body, indicated in general by the numeral 1, with spaced fluid passages 5 and 6 adapted to receive and conduct pressurized fluid, at a pressure of the order of 3,000 p.s.i., to spaced portions of an elongated opening 12 in the body portion 1. Fluid at a lower pressure, which may be of the order of 300 to 700 p.s.i., is supplied to other spaced passages 7 and 8 in the body which respectively communicate with opposite end portions 13 and 14 of the opening 12. End portion 13 is in fluid communication, through a passage 15, with an opening 16 in the body 1, in which there is disposed a nozzle 17. Similarly, end portion 14 of the opening 12 is in communication, through a passage 18, with an opening 19 in the body 1, in which there is disposed a nozzle 21. The nozzles 17 and 21 have ends 22 and 23, respectively, which project into a central opening 24 extending vertically, in the view of FIGURE 1, through the body 1. A port 25 is provided in the body 1 communicating the opening 24 with a sump for the hydraulic fluid, port 25 therefore serving as the "return" port.

Disposed within the opening 24 is an elongated flapper 26. Flapper 26 has one end portion disposed between the nozzles 17 and 21 and closely adjacent the ends 22 and 23 thereof, the spacing being such that when the flapper is being moved toward one of said ends the flow of fluid therethrough is progressively restricted, while the flow of fluid through the opposite nozzle is progressively increased. The opposite end of the flapper 26 is integrally connected to an armature 27 of an electro magnetic material. Integral with the flapper 26—armature 27 unit is a flexible sealing diaphragm 28 of material such as beryllium copper or spring steel. The seal 28 is generally circular in configuration, and is fixedly and sealably connected to the body 1 in such a manner that the armature 27 is isolated from any fluid in the opening 24.

The armature 27 is part of an electro magnetic torque motor constructed in accordance with the present invention. While this torque motor will be described in greater detail hereinafter, it comprises electrical coils 29 and

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31—which are preferably bifilar wound to reduce inductance to a minimum—and pole pieces of electro magnetic material indicated in general by the numerals 30, 32 and 33. In addition, there is provided a pair of top pole pieces of electro magnetic material 34 and 35 which are threadably mounted in intimate magnetic relationship with pole pieces 32 and 33 respectively, this adjustable mounting being such that the pole pieces 34 and 35 are closely spaced from the associated end of the armature 27. Disposed between the generally circular pole piece 30 and the side pole 32 is a flux restrictor 36 of a non-magnetic material such as aluminum or copper; a similar flux restrictor 37 is disposed between the plate-like bottom pole 30 and the side pole 33. In addition, as illustrated in FIGURE 4, there is provided a pair of permanent magnets, each indicated by the numeral 40, preferably of material such as—for example—Alnico 5, in intimate mechanical and magnetic contact, respectively, with the opposite sides of the pole pieces 32 and 33.

Referring once again to the elongated opening 12 in the body 1, disposed therein is a shuttle assembly, which is indicated in general by the numeral 41. The shuttle assembly comprises two identical cylindrical shuttles 42 and 43 which are oppositely directed. Shuttle 42 has spaced lands 44 and 45, a flow shield 46 and an elongated nose 47. Similarly, shuttle 43 has lands 48 and 49, a flow shield 51 and a nose 52. When the device is in operation, fluid in the end portions 13 and 14 of the opening 12 force the shuttles 42 and 43 inwardly so that the noses 47 and 52 thereof are in engagement, as illustrated in FIGURE 1. In this position the noses 47 and 52 extend into and meet within an aperture 53 which extends through the flapper 26, the dimension of aperture 53 being such that the flapper 26 does not engage either of the shuttles regardless of the flapper position. Disposed between the flapper 26 and the flow shield 46 on the shuttle 42 is a spring 54; similarly, disposed between the flapper 26 and the flow shield 51 is a spring 55, springs 54 and 55 surrounding the nose portions of their associated shuttles as illustrated in FIGURE 1. In the illustrated position of the shuttles 42 and 43, the land 45 on the shuttle 42 prevents fluid flow between the opening 12 and a fluid passage 56 which serves as a utilization port for connection to one side of a device controlled by the valve, and which is schematically illustrated as a double acting piston 57. Similarly, the land 49 on the shuttle 43 in the illustrated position prevents fluid flow between the opening 12 and a fluid passage 58 which serves as a utilization port connecting the valve with the opposite side of the piston 57.

It should also be noted that within the body 1 there is provided a fluid passage 61 which connects the return port 25 with that portion of the opening 12 which is between the land 45 and the flow shield 46 on the shuttle 42. Similarly, there is provided a fluid passage 62 in the body 1 connecting the return port 25 with that portion of the opening 12 between the land 49 and the flow shield 51 on the shuttle 43.

As previously indicated, when high pressure fluid is supplied to the unit, filtered high pressure fluid flows through the passages 5 and 6 to the opening 12, filling the space between land 44 and 45 on the shuttle 42 and the space between lands 48 and 49 on the shuttle 43. Filtered, lower pressure fluid is supplied to the passages 7 and 8; this fluid enters the end portions 14 and 13 of the opening 12 forcing the shuttles 42 and 43 into engagement, as previously indicated, against the bias of springs 54 and 55. This lower pressure fluid also flows through passages 15 and 18 and through nozzles 17 and 21 where it impinges upon the end portion of flapper 26, then flowing through the return port 25.

If a differential control current flow occurs in the coils

29 and 31, the differential flux produced thereby, in combination with the D.C. flux provided by the magnets 40 will cause the armature 27 to move either clockwise or counterclockwise. Assuming armature 27 is moved in a counterclockwise direction, the flexible seal 28 will permit the flapper 26 to be moved in such a direction that the end portion thereof approaches the end 23 of the nozzle 21. As the flapper 26 approaches the nozzle 21, fluid flow therethrough is progressively inhibited; simultaneously, fluid flow through nozzle 17 becomes progressively less inhibited. As a result, the fluid pressure in end portion 13 of opening 12 will decrease while fluid flow pressure in end portion 14 will increase. The shuttle means 41, comprising the shuttles 42 and 43, will therefore be moved toward the left in the view of FIGURE 1. The springs 54 and 55, as explained in the copending application of Harvey F. Gerwig et al., Serial No. 649,862, entitled "Transfer Valve," filed April 1, 1957, are preferably of the constant compression type so that movement of the shuttle means 41 toward the left effects a linearly increasing force on the flapper 26 tending to return it toward its neutral position, indicated in FIGURE 1. In other words, a mechanical feedback opposes the deflection of the flapper caused by the torque motor. The movement of the shuttle means 41 increases the feedback force on the flapper 26 until the flapper is returned to nearly its neutral position; the flapper will remain off-set only enough to hold sufficient differential pressure across the shuttle means 41 to compress the feedback spring 55. As the shuttle means 41 are displaced toward the left, the high pressure fluid in passage 6 will be supplied through the fluid passage 58 to the right end, in the view of FIGURE 1, of the double acting piston 57. Fluid to the left of the piston will be expelled through the fluid passage 56 and into the opening 12.

As may be readily visualized from FIGURE 1, when the shuttle means 41 are displaced to the left of the position illustrated, fluid entering the opening 12 from the fluid passage 56 will be between the land 45 and the flow shield 46. The flow shield 46 is, in effect, a land which engages the walls forming the opening 12 with only a sliding fit so that fluid cannot pass therebetween. The interiorly facing surface of the flow shield 46 is generally cup-shaped so as to provide a seat for the spring 54. (The flow shield 51 is identical with the flow shield 46.) The fluid, therefore, between the land 45 and flow shield 46 will pass through the fluid passage 61 to the return port 25. It is important to notice that the land 45 will completely uncover its associated port, connecting the fluid passage 56 with the opening 12, before the flow shield 46 will block fluid flow through fluid passage 61. It is also important to note that the fluid ejected from the double acting piston 57 will flow through passage 56 and passage 61 to the return port 25 without in any way impinging upon the flapper 26, in view of the shielding effect of flow shield 46.

The shuttle means 41 will be displaced to the degree required by the torque motor. The fluid pressures in end portions 13 and 14 are substantially equalized when the flapper 26 is returned to its "almost neutral" position, described before. The shuttle means 41 will remain in this displaced position until the differential current supplied to the electrical coils 29 and 31 will effect the opposite movement of the flapper 26, at which time the shuttle means 41 will be returned to the position illustrated, or some other position as desired. It may be readily apparent that the shuttle means 41 may be positioned within the opening 12 as desired. The operation of the device when the armature 27 is moved in a clockwise direction, as distinguished from the counterclockwise direction as discussed above, will be readily apparent to those skilled in the art.

From the foregoing description of the general nature of the electrohydraulic servo valve and its associated torque motor it will be appreciated that relatively minute

movements of a very precise nature must be imparted to the flapper 26 to effect proper operation of the valve. It is, therefore, essential that the initial positioning and subsequent movement of the armature 27, which controls the flapper 26, be precisely as desired.

Discussing now the particularities of the torque motor incorporating the principles of the present invention by which such precise positioning of the armature 27 is effected, the pole pieces 32 and 33 are of electro magnetic material such as, for example, of nickel and iron in substantially equal proportions. Each pole piece has a rectangular opening therein near its lower portion; the section of the pole piece defining the lower edge of this opening rests upon its associated flux restrictor 36 or 37. The upper portion of each pole piece is provided with an opening having threads therein adapted to cooperate with the threaded portions of pole pieces 34 and 35. Inasmuch as the adjustability of position of these pole pieces is critical, the cooperating threads are very fine, and are preferably of the order of 36 threads per inch. This permits the achievement of a precise relationship between the ends of the pole pieces and the associated end of the armature so that the resulting air gap is as desired. Suitable means (not shown) are provided for holding the pole pieces 34 and 35 in the desired position by preventing rotation thereof after their initial, desired positioning is achieved.

As previously indicated, the flux restrictors 36 and 37 are of non-magnetic material, and may be, for example, aluminum. In a typical installation these flux restrictors may be of the order of 0.030 to 0.040 inch thick. This thickness is determined in conjunction with the area of the lower edge of the side pole piece to provide a reluctance as nearly equal to the top pole air gap reluctance as practical. The bottom pole piece 30 is of electro magnetic material such, for example, as of nickel and iron in substantially equal proportions. It will, therefore, be seen that the flux restrictors 36 and 37 act as reluctances in the magnetic circuit between the bottom pole 30 and the side poles 32 and 33. This reluctance is in addition to that provided by the air gap between the armature and the pole pieces 34 and 35, a further additional element of reluctance being provided by the air gap between the bottom pole piece 30 and the armature 27. This latter air gap is provided by the spacing between the walls of a circular opening 71 in the bottom pole 30 and the cylindrical wall of that portion of the armature 27 which extends through this opening.

Under ideal conditions, the previously described construction will operate satisfactorily. As a practical matter, however, in actual installations various factors are present affecting the magnetic characteristics of the unit and it is, therefore, necessary to provide an adjustment feature which will effect any rebalancing of the unit as desired.

Attention is now directed particularly to FIGURES 2 and 3. In these figures there is illustrated a bracket 72 of non-magnetic material, such as aluminum, fixed to the bottom pole 30 by suitable means, such as the illustrated bolts. This bracket has an upstanding portion 73 provided with a threaded aperture 74. Disposed within aperture 74 is a threaded adjustment screw 75. The cooperating threads on the screw 75 and aperture 74 are, of necessity, relatively fine and they are preferably of the order of 40 or more threads per inch. Also mounted upon the bottom pole 30 is an adjustment arm of electro magnetic material indicated in general by the numeral 76. Arm 76 has end portions, respectively numbered 77 and 78, a leaf spring 79 being mounted upon the bracket 72 and engaging the arm 76 to maintain it under spring bias. Arm 76 is provided with an upper cylindrical flange 81 and a lower, shorter cylindrical flange 82. The flange 82 engages the pole piece 30 and arm 76 is, therefore, in series magnetically with pole piece 30. A bolt 83 extends through a cylindrical opening in the arm 76 and serves to hold it to the pole piece 30, the relationship

being such, however, that the arm 76 is rotatable about the bolt 83. Arm 76 is further provided with a projection 84 integral therewith which extends outwardly from arm 76 so as to be engaged by the adjusting screw 75. The normal spacing between the end portions 77 and 78 and their associated pole pieces 32 and 33, respectively, is, for example, of the order of 0.015 to 0.020 inch. It is apparent that upon rotation of adjusting screw 75 the arm 76 will rotate so that one of these end portions of arm 76 will approach its associated pole piece while the opposite end portion will simultaneously move away from its associated pole piece.

The magnetic circuitry of the elements described is diagrammatically illustrated in FIGURE 5. In this figure the permanent magnets 40 are illustrated diagrammatically as "D.C. flux" while the coils 29 and 31 diagrammatically appear as "A.C. flux." The two air gaps at the top of the armature and, respectively, between the armature 27 and the pole pieces 34 and 35 are illustrated as G_A . The air gap between the armature 27 and the bottom pole piece 30 is illustrated as G_B . The flux restrictors 36 and 37 (which magnetically operate as air gaps) are illustrated as G_R and are combined with the variable reluctance aspect of the present invention which is illustrated as G_V . It will be seen from FIGURE 5 that the variable reluctance G_V is in parallel with the first reluctance G_R and provides an alternate path for magnetic flux. The D.C. flux produced by the magnets 40 follows two paths through the torque motor. One of these paths is through the adjustable top poles and the top of the armature; in other words, through the two G_A reluctances illustrated in FIGURE 5. The other path followed by the D.C. flux includes the side pole pieces, the bottom pole piece and is affected by the position of the adjustment arm 76; in other words, in FIGURE 5 this is illustrated as the path for the D.C. flux through the two G_R , G_V reluctances illustrated. It will be apparent that as arm 76 is rotated by rotation of adjusting screw 75, so that one end of arm 76 is brought closer to the associated side pole while the other end is moved away from its associated side pole, the magnetic path at each of the flux restrictors is distorted. In other words, the reluctance is increased where the adjusting air gap is increased, while the reluctance is decreased where the adjusting air gap is decreased. Since the flux restrictors G_R , G_V are reluctances in parallel with the armature air gap reluctances G_A , the relative flux density of the armature air gaps can be controlled in this manner. The A.C. flux is, of course, generated by the coils. The side through which the A.C. flux passes is determined by the differential current in the coil which can polarize the armature in either direction. This A.C. flux will follow the armature, pass from the top of the armature through one of the air gaps G_A into one of the top poles, down one of the side pole pieces, through the G_R , G_V reluctance to the bottom pole piece, and back to the bottom of the armature through the annular air gap G_B in the bottom pole piece. The difference in the flux in the two top air gaps causes the force on the armature, the armature being acted upon by a force proportional to any flux density imbalance at the two armature air gaps.

It will therefore be seen that the torque motor of the present invention has inherently incorporated therein a null adjusting device which is simple, accurate, requires no special tools, requires no disassembly of the unit and operates in a relatively non-critical fashion.

While certain preferred embodiments of the invention have been specifically disclosed, it is understood that the invention is not limited thereto, as many variations will be readily apparent to those skilled in the art and the invention is to be given its broadest possible interpretation within the terms of the following claims.

We claim:

1. In a torque motor, the combination comprising electrical coil means, pole pieces of magnetic material asso-

ciated therewith, permanent magnet means adapted to produce flux, an armature movable in response to operation of said electrical coil means and being normally separated from said pole pieces by air gaps, reluctance providing means separate from said air gaps defining a first reluctance, a second reluctance providing means positioned magnetically in series with said pole pieces and said armature, said first reluctance being adapted to be balanced with said second reluctance providing means, a third reluctance means adjustably positioned in series magnetically with said armature and said pole pieces providing an alternate route for flux around one of said first and second reluctance means, whereby the total reluctance may be adjusted within close limits.

2. The device defined in claim 1 in which said third reluctance means comprises means for adjustably providing an air gap between one of said pole pieces and another of said pole pieces, said last mentioned means including a bar of magnetic material pivotally mounted with respect to said one pole piece.

3. The device defined in claim 1, wherein said air gaps between said armature and said pole pieces are adjustable to vary the reluctance provided thereby.

4. In a torque motor the combination comprising electrical coil means, side pole means of magnetic material, top pole means of magnetic material, bottom pole means of magnetic material, permanent magnet means adapted to produce flux, an armature movable in response to operation of said electrical coil means, said armature extending closely adjacent said top and bottom pole means and being separated therefrom by air gaps, the air gap between said top pole means and said armature being adjustable, reluctance providing means distinct from said air gaps separating an adjacent pair of said pole means, and means of magnetic material in engagement magnetically with one of said pair of pole means and adjustably positionable with respect to the other of said pair of pole means effective to provide an alternate path for flux in parallel with said reluctance providing means whereby the effect of said reluctance providing means is variable by changing the position of said adjustably positionable means of magnetic material.

5. In a torque motor the combination comprising electrical coil means, side pole means of magnetic material, top pole means of magnetic material, bottom pole means of magnetic material, permanent magnet means adapted to produce flux, an armature movable in response to operation of said electrical coil means, said armature extending closely adjacent said top and bottom pole means and being separated therefrom by air gaps, means positioning said pole means with respect to said armature and magnet means to provide a first flux path through said top pole means and a second flux path in parallel with said first flux path through said side and bottom pole means, means providing reluctance separate and remotely situated from said air gaps in said second flux path, and adjustable means of low reluctance material effective to provide a flux path of variable reluctance in parallel with said reluctance providing means whereby the effect of said reluctance providing means may be varied by operation of said adjustable means.

6. The device defined in claim 5, in which said reluctance providing means provides reluctance substantially equal to the reluctance of the air gap between said armature and top pole means, and in which said adjustable means are selectively movable toward and away from said reluctance providing means.

7. In a torque motor the combination comprising electrical coil means, side pole means of magnetic material, top pole means of magnetic material, bottom pole means of magnetic material, permanent magnet means adapted to produce flux, an armature movable in response to operation of said electrical coil means, said armature extending closely adjacent said top and bottom pole means and being separated therefrom by air gaps, means posi-

tioning said pole means with respect to said armature and magnet means to provide a first flux path through said top pole means and a second flux path in parallel with said first flux path through said side and bottom pole means, means providing reluctance between said side and bottom pole means substantially equal to the reluctance of the air gap between said armature and top pole means, and adjustably positionable means of low reluctance material effective to provide an alternate flux path between said side and bottom pole means in engagement with one and movable toward and away from the other whereby the effect of said means providing reluctance is variable by changing the position of said adjustably positionable means of low reluctance material.

8. In a torque motor the combination comprising electrical coil means, side pole means of magnetic material, top pole means of magnetic material, bottom pole means of magnetic material, permanent magnet means adapted to produce flux, an armature movable in response to operation of said electrical coil means, said armature extending closely adjacent said top and bottom pole means and being separated therefrom by air gaps, means positioning said pole means with respect to said armature and magnet means to provide a first flux path through said top pole means and a second flux path in parallel with said first flux path through said side and bottom pole means, means providing reluctance between said side and bottom pole means substantially equal to the reluctance of the air gap between said armature and top pole means, and adjustably positionable means of low reluctance material effective to provide an alternate flux path between said side and bottom pole means in engagement with said bottom pole means and movable toward and away from said side pole means in the position adjacent said reluctance providing means whereby the effect of said reluctance providing means is variable by changing the position of said adjustably positionable means of low reluctance material.

9. The device defined in claim 8, in which said means providing reluctance comprise a pair of members of relatively high reluctance material respectively disposed be-

tween said bottom pole means and opposed side pole means, and in which said adjustably positionable means comprises a generally U-shaped arm having end portions respectively adjacent said pair of members of high reluctance material and movable toward and away therefrom.

10. In a valve of the type having a shuttle moved in response to changes in the position of a flapper and in which the flapper position is varied by movement of an armature, the improvement comprising electrical coil means adapted to produce flux, side pole means of magnetic material closely adjacent said coil means, top pole means of magnetic material closely adjacent said coil means, bottom pole means of magnetic material closely adjacent said coil means, permanent magnet means adapted to produce flux, an armature of magnetic material extending between said coil and pole means, means mounting said armature for pivotal movement, said armature being pivoted in response to operation of said electrical coil means to effect movement of the flapper and being normally separated from said top and bottom pole means by relatively small air gaps, a pair of metallic members respectively disposed between said bottom pole means and said side pole means adapted to provide reluctance substantially equal to the reluctance of the air gap between said armature and top pole means, a generally U-shaped adjusting arm of magnetic material in engagement with said bottom pole means having spaced end portions respectively adjacent said pair of metallic members, and means mounting said adjusting arm for pivotal movement thereof whereby said end portions are respectively movable simultaneously toward and away from said metallic members to vary the effective reluctance of said metallic members.

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