March 2, 1965 D. B. HARNEY ET AL 3,171,630

WELL PUMP

Filed March 14, 1963 2 Sheets-Sheet 1

Fig. 1

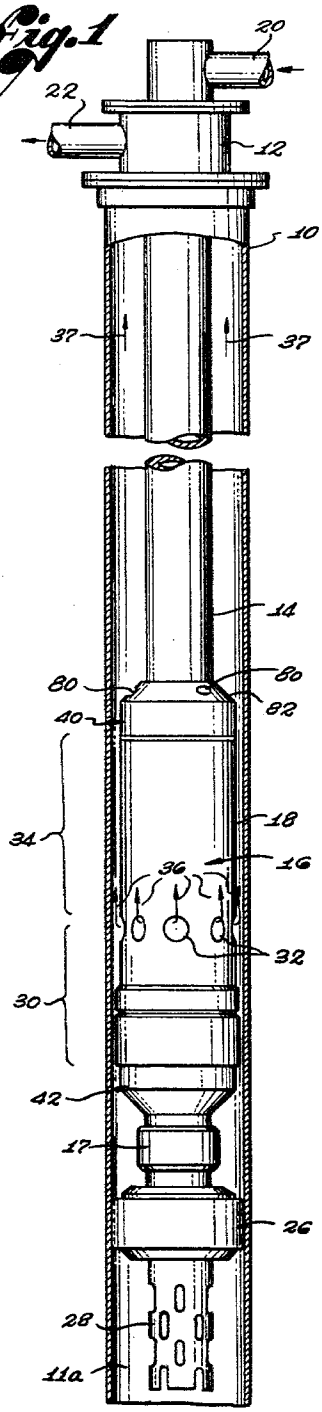
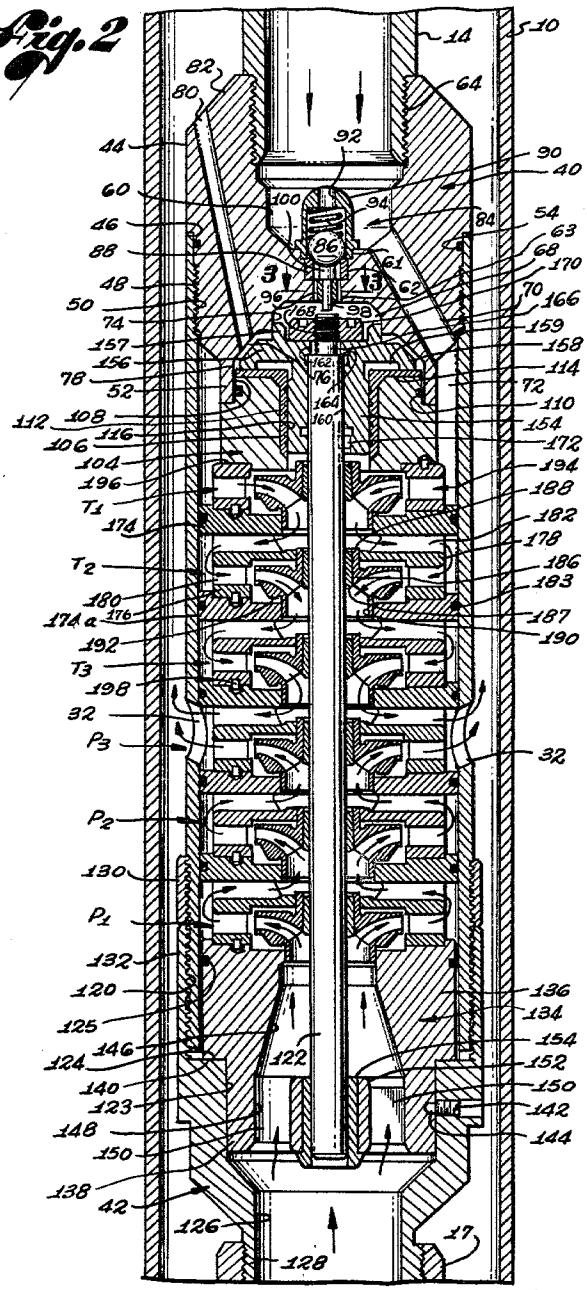


Fig. 2



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Fig. 4

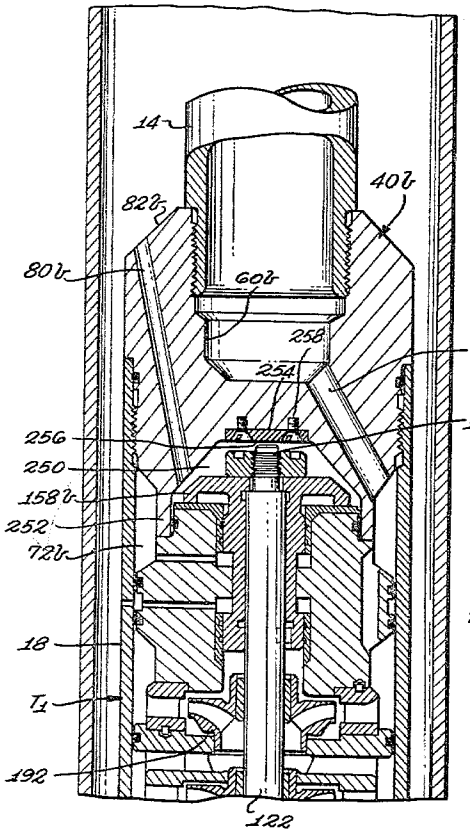
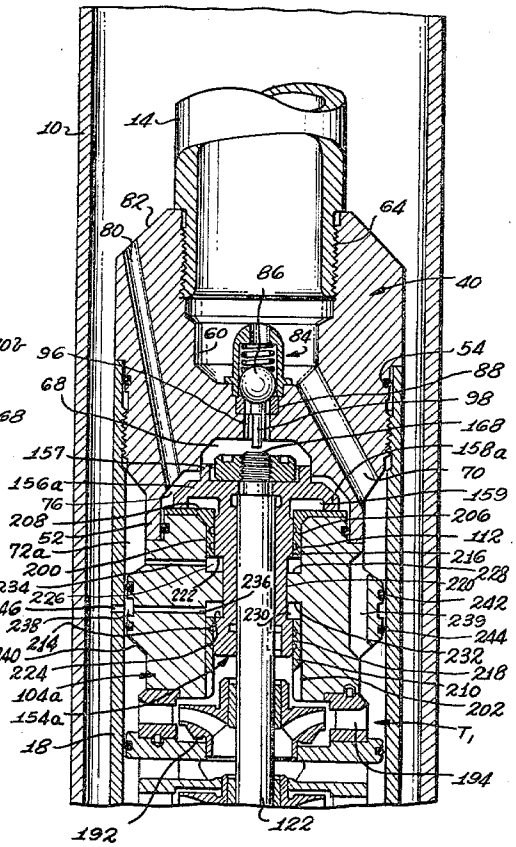


Fig. 5



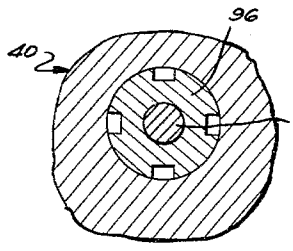


Fig. 3

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3,171,630
WELL PUMP

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This invention relates generally to fluid driven pumps, and more particularly to fluid turbine driven centrifugal type pump units for submerged, so-called bottom hole pumping operations within deep wells.

Such fluid driven turbo-pump units, to which this invention relates, employ a fluid reaction turbine and a fluid reaction or centrifugal type pump means coaxially coupled together to form a single compact, minimum-diametered unit with the runners of the turbine and the impellers of the pump mounted coaxially on a common shaft. In the installation of such a pumping unit in an earth bore hole, such as an oil or water well, it is common practice, if not a practical necessity, to suspend a unit coaxially of the well bore such that the impellers and shaft of the turbine and pump rotate about a substantially vertical axis.

Heretofore, numerous difficulties have been encountered in constructing such turbo-pump units, particularly for vertical operations as before mentioned, which would operate with satisfactory efficiency and durability under all varying pumping load requirements and conditions, particularly those encountered within the deep wells. Among such difficulties has been that of providing suitable bearing means for rotatably supporting the axial forces in the vertical shaft resulting from the weight and from the unbalanced axial fluid reaction forces imposed upon the common, rotatably mounted turbine runners and pump impellers, under varying operating conditions.

It is therefore a principal object of this invention to provide a turbo-pump unit having improved means for rotatably supporting the resultant axial thrust forces of its runners, impellers, and shaft.

It is another object of this invention to provide a means for automatically balancing out the axial thrust forces acting upon the turbine and pump impellers which act through the vertical shaft.

It is still another object of this invention to provide improved means for rotatably supporting the weight of a vertically positioned turbine and pump impeller assembly unit.

It is still another object of this invention to provide improved means for effecting improved automatic balancing out of variable unbalanced axial thrust of the rotating members of a turbine driven centrifugal pump unit, resulting from variations in pump loading conditions.

It is a further object of this invention to provide improved means for preventing wear and damage to the several impellers of the turbine and pump, which may result from variation in axial position thereof under varying load during pump starting and stopping intervals.

It is a still further object of this invention to provide a fluid-driven centrifugal pump unit having reduced running friction and bearing wear.

These and other objects, advantages, and features of novelty of this invention will be evident hereinafter.

In the drawings, which illustrate a preferred embodiment and mode of operation of the invention and in which like reference characters designate the same or similar parts throughout the several views:

FIGURE 1 is a view, partly in elevation and partly in longitudinal section, of a turbine driven pump unit assembly embodying the present invention and illustrating a manner of installation thereof in a typical oil well casing;

FIGURE 2 is an enlarged, longitudinal sectional view of the turbine driven pump unit shown in FIGURE 1;

FIGURE 3 is an enlarged, fragmentary cross sectional view taken on line 3—3 of FIGURE 2;

FIGURE 4 is a partial, enlarged, longitudinal sectional view of a modified form of a portion of the turbine driven pump unit shown in FIGURE 1; and

FIGURE 5 is a partial, enlarged, longitudinal sectional view of still another modification of a portion of the turbine driven pump unit shown in FIGURE 2.

Referring first primarily to FIGURE 1, the apparatus of the invention is shown in a typical installation in a well casing 10 having installed on the upper end thereof a typical casing head 12. Within the casing 10 and suspended from the casing head 12 upon suitable pipe or tubing 14 is a turbo-pump unit shown generally at 16 which embodies the features of the present invention. As illustrated herein, the turbo-pump unit 16 is of smaller outside diameter of the casing 10, thereby enabling it to be lowered into the casing by pipe or tubing 14 in a conventional manner, to the depth in the well from which the production fluid entering the well and contained in the lower portion of the casing is to be lifted. The upper end of the pipe or tubing 14 makes connection through the casing head 12 in conventional manner to an inlet pipe 20, which is in turn adapted to be connected to a source of power fluid, such as oil, water, gas, or the like, which may be supplied under suitable pressure through a fluid circulating pump, now shown.

The annulus 11 between the casing 10 and pipe 14 is connected at its upper end through the casing head 12 in conventional manner to a fluid outlet pipe 22, which is in turn adapted to be connected to a suitable receiver or storage means which may include means for separating and cleaning the thus received fluid and for returning a part thereof to the before mentioned circulating pump for re-introduction under pressure through the before mentioned inlet pipe 20 to serve as the before mentioned power fluid.

The housing 18 of the turbo pump unit 16 is coupled at its lower suction inlet end at 17 through a production packer which is more or less schematically illustrated at 26, to the upper end of a downwardly extending section of conventional strainer or perforated pipe 28. Packer 26 which may be of any conventional design, but preferably capable of being set and released in the well casing by manipulation of the suspending pipe or tubing 14, such as for example a conventional slip actuated hook wall production packer, serves to separate the annular space 11*a* in the lower portion of the well casing into which the strainer or perforated pipe 28 extends, from the annular space in the upper portion thereof containing the turbo-pump unit 16 and suspending pipe 14.

The lower portion of the turbo-unit housing 18, indicated generally at 30, in FIGURE 1 contains the centrifugal pump section which receives production fluid from the lower portion of the well below the packer 26 through the strainer or perforated pipe 28 and through coupling 17, and discharges the same therefrom after passing through the centrifugal pump to the exterior of the housing 18 above the packer 26 through a plurality of intermediately located, circumferentially spaced-apart discharge ports 32. The upper portion of the turbo-pump unit housing 18, indicated generally at 34 in FIGURE 1, contains the turbine drive section which receives power fluid under pressure at its upper end through pipe 14 and discharges the same after passing through the several turbine sections, together with the before mentioned production fluid from the centrifugal pump section, to the same intermediately located discharge ports 32. The thus com-

mingled fluid discharged through the ports 32 from both pump section 30 and turbine section 34 flows upwardly, as indicated by the arrows 36 and 37, through the annular space 11 within the casing to the casing head 12 and thence through the outlet pipe 22 to the storage and separating means, as hereinbefore mentioned.

Referring now primarily to FIGURE 2, the turbo-pump unit assembly 16 comprises the before mentioned elongated cylindrical housing 18, which is closed at its upper end by a turbine inlet head shown generally at 40 which is formed with an exterior, upper cylindrical section 44 having an outside diameter substantially equal to that of the housing 18, an intermediate section 46 of reduced outside diameter having external threads as shown at 48, which makes good connection with corresponding internal threads 50 on the upper end of the housing 18, and a lower downwardly extending skirted section 52 of still further reduced outside diameter. Suitable sealing means, such as an O-ring and groove as shown in 54 is provided between the inside wall surface of the housing 18 and the adjacent outside surface of the intermediate section 46 of the inlet head 40. The turbine inlet head 40 is so formed with a coaxial bore therethrough having an upper enlarged portion thereof 60 and upper intermediate reduced diameter section 61 a lower intermediate still further reduced diameter section 62 and a lowermost section 63 which opens into a downwardly facing cup shaped recess 68. The upper enlarged portion 60 of the bore makes screwed connection by means of threads 64 with the lower end of the suspending pipe 14. A plurality of downwardly, divergingly directed inlet passages, as shown at 70, extending through the turbine inlet head 40, interconnect the lower end of the bore portion 60 with the upper end of an annular spaced 72 formed between the outer cylindrical surface of the downwardly projecting annular skirted section 52 of the inlet head 40 and the adjacent inside surface of the housing 18.

The before mentioned downwardly facing cup shaped lower end portion 68 of the bore through the inlet head 40 is formed with a lower inside cylindrical wall portion 74, the lower end of which opens out into a generally downwardly facing frusto-conical shaped cavity 76 terminating in a lower cylindrical wall portion 78 which forms the inner side of the before mentioned skirted section 52 of the inlet head 40. A plurality of obliquely directed outlet ducts as shown at 80 circumferentially interspaced between the before mentioned passages 70, as shown in FIGURES 1 and 2, extending through the turbine inlet head 40, serves to interconnect the cavity 76 with the exterior of a turbine inlet head 40 at the upper exterior beveled end portion 82 thereof.

Seated coaxially within the bore portion 61, 62, and 63 of the turbine inlet head 40 is a control valve assembly shown generally at 84. The control valve assembly includes a ball valve 86 which normally seats on the upper inner edge of an annular valve seat member 88 which makes press fit within the lower intermediate bore portion 82 of the inlet head 40. Press fitted at its lower end into the intermediate bore portion 61 of the inlet head 40 is a ball valve cage 90 which is closed, except for an axial outlet opening 92 through its upper end. A helical spring 94 acting under compression between the upper inner end of the housing 90 and the top of the ball valve 86 serves to press the ball valve 86 downwardly upon its before mentioned annular seat. Also press fitted within the lowermost bore section 63 is a fluted guide bushing 96 having a coaxial bore through which axially slidably extends the shank 98 of a valve plunger or push rod. Integrally formed on the upper end of the shank 98 of the valve plunger is an enlarged head 100 which normally seats on the upper end of the bushing 96 and has formed on the upper end thereof a spherical depression which fits the curvature of and makes contact with the bottom portion of the spherical surface of the ball valve 86. The lower end of the shank 98 of the valve plunger or push rod extends downwardly into the cup shaped recess 68 with its lower end positioned closely adjacent the upper end of the turbo-pump shaft, for a purpose hereinafter more fully described.

Seated coaxially upwardly within the lower portion of the skirted portion 52 of the turbine inlet head 40 is an annular, upper retainer body 104 having a coaxial bore 106 and formed with an outer upper end portion 108 of reduced outside diameter which extends into coupling engagement with the inside cylindrical surface 78 of the skirted section 52. An O-ring seal and groove as shown at 110 is provided between the contiguous surfaces of the skirt portion 52 and the outer upper end portion 108. The bore 106 of the retainer body 104 has fitted therein a sleeve shaped bearing liner 112, said liner 112 having integrally formed at its upper end a radially, outwardly extending flange 114 which seats upon the annular upper end surface of the retainer body 104. The inner cylindrical surface of the bearing liner 112 is formed with a plurality of axially spaced-apart, semi-circular sectioned, inwardly facing annular grooves as shown at 116.

The pump inlet head indicated generally at 42 attached to the lower end of the housing 18 is formed with a coaxial bore therethrough having an upper threaded portion 120 thereof with an inside diameter slightly less than the outside diameter of the housing 18, an intermediate bore portion 123 or reduced inside diameter, forming thereby an upperwardly facing annular shoulder 124 and a lower bore portion 126 of still further reduced inside diameter terminating in an externally threaded connection 128. The upper bore portion 120 of the pump inlet head is provided with internal threads, with which corresponding external threads on the lower end of the housing 18 makes screwed coupled connection. An annular lock ring 130 carried on the said external threads on the lower end of the housing 18 is adapted to be screwed into jamming engagement with the upper end edge of the sleeve portion 132 surrounding the before mentioned upper bore portion 120 of the inlet head 42 and thereby serves to lock the screw connection between the pump inlet head 42 and the lower threaded end of the housing 18 in a longitudinally adjustable position relative to one another as required to clamp several turbine and pump assemblies axially together within the housing 18, as hereinafter more fully described.

Positioned within the lower end portion of the housing 18 and couplingly seated within the intermediate bore portion 123 of the inlet head 42 is a generally annular lower retainer body 134 formed with an upper annular portion 136 having an outside diameter slightly less than the inside diameter of the adjacent portion of the the housing 18 and with a lower annular portion 138 of reduced outside diameter relative to the upper portion 136, thereby forming at the juncture of the upper portion 136 and the lower portion 138 a downwardly facing annular shoulder 140. The lower end portion 138 makes coupling engagement within the intermediate bore section 123 of the pump inlet head 42 with the downwardly facing annular shoulder 140 thereof seated upon the before mentioned upperwardly facing annular shoulder 124. An O-ring seal and groove, as shown at 125, is provided between contiguous surface of the outside of the upper portion 136 of the retainer body 134 and the inside surface of the housing 18. A set screw 142 threaded through the wall of the pump inlet head 42 extends into engagement at its inner end with a drilled recess 144 in the lower retainer body and serves to lock said retainer body firmly seated and free of axial and rotational movement within the pump inlet head 42.

The annular lower retainer body 134 is provided with an axial bore extending therethrough, said bore having an upper, upwardly converging, frusto-conical portion 146 and a lower cylindrical portion 148. Supported within the lower cylindrical bore portion 148 of the lower re-

tainer body 134, by means of a spider structure comprising a plurality of radially extending integrally formed web members as shown at 150, is a central, coaxially located, cylindrical shaped bearing housing 152. Press fitted within the bearing housing 152 is a sleeve bushing 154 which constitutes a bearing for the lower end of the turbine and pump drive shaft 122.

Rotatably and longitudinally slidably contained within the hereinbefore described sleeve shaped bearing liner 112 contained within the upper retainer body 104 is an annular shaped, combined shaft bearing and plunger or piston member 154 having integrally formed at its upper end a coaxial, radially outwardly extending flange member or balancing disk 156, the outside diameter of which is greater than that of the annular plunger or piston member 154, but less than the inside diameter of the adjacent walls of the cavity 76. The peripheral, marginal portion of the balancing disk 156 is formed with a downwardly depending annular rim 158 which normally, under non-operating conditions rests upon and is supported by the upper surface of the radially outwardly extending flange portion 114 of the bearing liner 112 and under which is formed an annular cavity 159. The upper side of the balancing disk 156 is formed with an upwardly extending, annular rim 157 which makes a relatively loose rotatable and axially slidable fit within the lower cylindrical base portion 74 of the cup shaped cavity 68.

The annular plunger member 154 is provided with a coaxial bore therethrough, the major section 160 of which has an inside diameter substantially greater than that of the upper most end portion 162 thereof located centrally of the balancing disk 156, thereby forming at the juncture of such upper and lower bore sections a downwardly facing annular shoulder 164 located coaxially of the before mentioned balancing disk 156. The upper end of the shaft 122 is formed with an upwardly extending attachment portion 166 of reduced outside diameter and carrying external threads 168 adjacent its upper end. The upper end portion of the shaft 122 extends into and is fixed within the bore 160 in abutment with the before mentioned downwardly facing annular shoulder 164 and with the upwardly extending attachment portion 166 extending through the bore 162 of the balancing disk 156. An annular nut 170 threaded on the shaft threads 168 serve to retain the intergal plunger member and balancing disk 154, 156 firmly attached to the upper end of the shaft 122. The plunger member 154 is keyed to the shaft 122 as shown at 172.

Contained coaxially with the housing 18 between the upper annular retainer body 104 and the lower annular retainer body 134 is a plurality of coaxially, superimpared turbine drive stages and centrifugal pump stages, which generally occupy the upper and lower portions of the turbo-pump unit housing indicated at 34 and 30 respectively in FIGURE 1. For convenience of illustration, three turbine stages, located and indicated generally at T_1, T_2, and T_3, and three centrifugal pump stages located and indicated generally at P_1, P_2, and P_3, have been shown and described herein. However, a greater or lesser number of such stages in either or both turbine section and pump section may be employed, the choice being dependent upon various factors and requirements of a particular installation, such as for example the available differential pressure, quality and kind of driving fluid, and the pumping head, volume and kind of fluid required to be handled by the pumping unit.

Each of the turbine drive stages comprises in brief, with reference mainly to turbine stage T_2 as being typical, a turbine stater or cover body comprising an upper, annular cover plate 174, a lower annular base plate 176 and an intermediate annular separator member 178, all preferably although not necessarily, integrally formed in a single casting. The upper cover plate, intermediate annular separator member, and base plate are held together by intervening, radially extending vanes which direct the fluid flow therearound and therethrough as is well known in the art. Between the outer marginal portion of the intermediate annular separator member 178 and the annular base plate 176 is a vaned diffuser section 180 which, in operation, directs the flow of power fluid inwardly at the proper angle into the turbine runner, as indicated by the arrows therein. An O-ring seal and groove, as shown at 183 is provided around the periphery of each cover plate of each turbine cover body, making sealing engagement with the inside surface of the housing 18.

Between the annular cover plate 174 and the intermediate separator member 178 is formed a radially vaned, annular passage 182 for directing the flow of power fluid discharged from the preceding stage, to the diffuser section 180, as indicated by the arrows therein. Rotatably contained within a generally cylindrical cavity formed within the diffuser section of the turbine cover body is an internally vaned turbine runner 186 of the mixed flow type, adapted to receive power fluid radially from the diffuser section 180 and discharge the same axially through the central opening of the next succeeding cover plate 174 of the next succeeding turbine cover body. The runner 186 is secured to the shaft 122 by means of a tapered locking sleeve 187, which is press fitted between the bore of the hub 188 of the runner 186 and the exterior cylindrical surface of the shaft 122. The runner hub 188 extends outwardly into and makes a relatively free rotatable fit within the circular opening in the center of the before mentioned intermediate annular separator member 178 of the cover body.

The turbine runner 186 is formed with a coaxial, downwardly extending, axial discharge sleeve 190 which, like the hub, makes a relatively free, rotatable fit within the central, circular opening in the annular cover plate 174 of the next adjacent lower turbine cover body. Each of the runners is formed with an exterior, radially extending, downwardly facing, annular bearing surface as shown at 192, adapted under certain operating conditions, as hereinafter described, to make supporting engagement with the adjacent upper surface of the before mentioned cover plate 174*a* of the next adjacent lower turbine cover body.

Each of the turbine stages has a construction similar or identical to that of the hereinbefore described turbine stage T_2 except the first turbine T_1, which, for convenience of manufacture, has a separate diffuser section shown at 194 which is not formed as a part of a cover body of the kind hereinbefore described, but makes coupling engagement at its upper end as shown at 196 with an annular groove formed in the lower end of the annular retainer body 104.

Each of the centrifugal pump stages has a construction which is similar to that of the hereinbefore described turbine drive stages except that the vanes of the impeller and the diffuser sections may be shaped slightly differently, as is well known in the art, to provide for the proper direction of flow of pumped fluid therethrough which is in general in a relative direction having a tangential component opposite to that of the flow of fluid in the turbine drive stages, such flow in the pump stages and turbine drive stages being indicated by the several arrows in FIGURE 2. As hereinbefore mentioned, the fluid discharged from the final stage of the turbine drive, which is that leaving the discharge of the runner of turbine stage T_3, and the fluid discharge from the final pump section, which is that discharged from the impeller through the diffuser section of pump stage P_3, commingle within the adjacent portion of the housing 18 and are discharged directly therefrom through the ports 32 into the annular space intermediate the housing 18 and the casing 10, and thence flow up through said annular space to the casing head 12 and out through the outlet pipe 22, as hereinbefore mentioned.

The several turbine drive and centrifugal pump stator cage or cover body units are coaxially nested together, one upon another, and secured by indexing pins as shown at **198** against relative rotation thereof, and such cover body units are clamped together axially by means and between the upper annular retainer body **104** and the lower annular retainer body **134**, which are in turn clamped together by adjustment of the coupling of the threaded connection at **128, 130** between the lower end of the housing **18** and the pump inlet head **134**. The hereinbefore described lock ring **130** serves to maintain such clamping coupling adjustment.

In operation of the hereinbefore described apparatus of the invention shown in FIGURES 1 and 2, power fluid is forced under suitable pressure down the tubing or pipe **14** to the upper end of the turbine pump unit **16** where it passes through the upper enlarged bore portion **60** of the upper turbine inlet head **40** and thence thru the downwardly divergingly directed inlet passages **70** into the annular space **72** within the housing **18**. From the annular space **72**, the power fluid flows under pressure through the first diffuser section **194** radially inwardly into the passages in the runner of the first turbine drive state T_1 from which it is discharged axially downwardly into passage **182** of the cover body of the second turbine drive stage T_2. From the passage **182**, fluid under pressure flows around the outer edge of the separator member **178** and radially inwardly through the next diffuser section **180** into the main passages of the runner of the second stage turbine drive T_2. From the runner of the second stage turbine the pressure fluid is discharged axially downwardly through the discharge sleeve **190** and thence flows radially outwardly through the adjacent passage around the next intermediate annular separator member and inwardly through the next diffuser section into the runner of the third turbine drive stage T_3 in the same manner as herebefore described. The power fluid finally discharged from the runner of the third turbine drive stage T_3 flows outwardly through the discharge ports **32**, as hereinbefore mentioned.

Production fluid which has entered the bottom of the casing **10**, flows in through the openings in the strainer pipe **28**, up through the pump inlet head **42**, through the bore of the lower retainer body **134** and fills the passages within the centrifugal pump section of the housing **18**. Rotation of the pump impellers by the turbine drive then causes the production fluid to be drawn in through the strainer pipe **28** and up into the central inlet of the impeller of a first pump stage P_1 from which it is discharged into the passages of the vaned cover body thereof, and thence flows around into the central inlet of the impeller of the second pump stage P_2 and so on until it is discharged from the third centrifugal pump stage P_3 and out through the before mentioned discharge ports **32**.

The power fluid discharged from the last stage T_3 of the turbine drive and the production fluid from the last stage P_3 of the pump section commingle as they are discharged, as indicated by arrow **36**, from the openings **32** in the housing **18** into the annular space in the casing and from there the commingled power fluid and pump production fluid flows upwardly, as indicated by arrow **37**, through the annular space in the casing to the casing head **12** and thence is discharged through the outlet pipe to the storage and separating means, as hereinbefore mentioned.

Because of the axial forces acting upon the several runners of the turbine drive stages and the impellers of the centrifugal pump stages resulting from the pressure differentials and dynamic forces of the fluids flowing therethrough which are seldom if ever in exact balance with each other, the whole rotating system including the shaft **122** is usually subjected to a resultant axial force, which tends to displace it and the rotors and impellers carried thereby axially relative to the turbine and pump cover bodies and housing. This axial force must be resisted by some means which is relatively free from friction and wear and which will automatically compensate for changes in such axial forces which must be resisted resulting from changes in variations in pumping conditions. Such means must also automatically maintain the proper axial positioning of the shaft **122** and the impellers and runners relative to the structural members of their surrounding cover bodies, otherwise inefficient running conditions and excessive wear will occur and even in extreme cases possible damage or destruction of the runners and impellers may eventually result.

Usually under normal operating conditions, the resultant axial force in the shaft **122** is downward relative to the stationary portions of the apparatus, and relatively friction free automatic compensation for this downward force is accomplished as follows.

Sufficient clearance is provided at the outer edge and along the upper portion of the runner of the first stage turbine drive T_1 to permit pressure fluid from the first diffuser **194** to flow under pressure between the top of the runner and the bottom of the annular retainer body **104** and thence into the space surrounding the drive shaft **122** at the lower end of the annular plunger member **154**. The clearance between the outside diameter of the plunger member **154** and the inside diameter of the bearing sleeve **112**, which may be approximately 0.006", is sufficient to permit flow of a relatively small quantity of pressure fluid therethrough into the annular space **159** formed under the balancing disk **156** within the rim **158**. The differential pressure thus established across the annular plunger **154** and the balancing disk **156** with respect to the fluid pressure in the frusto-conical shaped cavity **76** and the cup shaped recess **68** tends to lift the drive shaft **122** axially upwardly sufficient to balance the otherwise unbalanced downwardly directed axial forces therein. As the balancing disk **156** is thus lifted, the lower edge of the rim **158** is raised out of sealing contact with the upper surface of the bearing flange **114**, thereby permitting escape of a small quantity of pressure fluid from the space **159** into the cavity **76** from which it is exhausted at reduced pressure through the outlet ducts **80**, thereby causing a small drop in pressure under the balancing disk **156**. This action continues either until equilibrium is reached between the fluid pressure differential acting upwardly on the plunger **154** and balancing disk **156** and the downward force transmitted thereto through the shaft **122** under which conditions the lower edge of the rim **158** would float a short distance above and out of contact with the upper surface of the bearing flange **114**, or until the plunger **154** balancing disk **156** together with the shaft **122** continues to move upwardly until the upper end of the threaded portion **168** of the shaft **122** is brought into contact with the lower end of the valve plunger shank **98**. Such contact of the upper end of the shaft **122** with the lower end of the valve plunger shank **98** results in slight upward movement of the shank **98** and plunger head **100**, which in turn lifts the ball valve **86** off of its annular seat **88** sufficient to permit pressure fluid entering the upper bore portion **60** of the turbine inlet head **40** to flow under pressure therefrom past the control valve **84** into the cup shaped recess **68**. Since the pressure of the fluid thus entering recess **68** from the pressure fluid inlet is higher than the fluid pressure acting under the plunger **154** and balancing disk **156**, the upward pressure differential thereacross is thereby reduced, whereby in effect a resultant downward force is applied to the upper, central piston area of the balancing disk **156** as defined by the bore **74**. This downward force compensates for any excess upward force acting through shaft **122**, plunger **154** and flange **156** and is automatically regulated by the distance to which the ball valve is raised off of its annular seat **88** and the rate of leak-

age of such fluid passed the flange 157 into the cavity 76, thereby establishing equilibrium between the opposing forces and resulting in axial positioning of the rotating system of the turbo-pump assembly in a predetermined equilibrium position.

As hereinbefore described, the presseure fluid which escapes into the cavity 76 either from below the plunger 154 or from the recess 68 passed the flange 157 is exhausted through the passages 80 into the annular space between the casing 10 and the pipe 14 at the upper bevel surface 82 of the turbine inlet head 40. It has been discovered that the provision for the discharge of pressure fluid from the cavity 68 to this particular low pressure location at the upper end of the turbine inlet head is an important factor not only in the proper functioning of the hereinbefore described balancing action, but also results in an important practical simplification of the structure of the upper end portion of the turbine pump unit. A particular advantageous feature of this arrangement is that it requires only a simple single seal on the upper end of the housing 18 and the turbine inlet head 40, as shown at 54. Structural simplification and reduction in undesirable bypass leakage is thus eliminated.

Referring next primarily to FIGURE 5, in which a modified form of the axial thrust balancing features of this invention are illustrated, the turbine inlet head 40 into which the supporting pipe or tubing 14 makes screwed connection at 64, and the control valve assembly shown generally at 84, have a construction which is identical to that of FIGURE 2. However, the annular retainer body and balancing plunger and disk assembly have a modified form of construction as follows.

Seated coaxially upwardly within the lower skirted portion 52 of the turbine inlet head 40 is an annular upper retainer body 104*a* having a coaxial bore, the upper end portion 200 and the lower end portion 202 of which have the same inside diameter and an intermediate section 204 of which is of reduced inside diameter relative to the end portions. The upper bore portion 200 of the retainer body 104*a* has fitted therein a sleeve shaped bearing liner 206, said liner having integrally formed at its upper end a radially outwardly extending flange 208 which seats on the annular upper end surface of the retainer body 104*a*. The lower bore portion 202 of the retainer body 104*a* has fitted therein a sleeve shaped bearing liner 210. The inner cylindrical surfaces of the bearing liners 206 and 210 are formed with a plurality of axially spaced apart semi-circular sectioned inwardly facing annular grooves as shown at 212 and 214.

Rotatably and longitudinally slidably contained within the hereinbefore described upper annular retainer body 104*a* is a combined shaft bearing and plunger member shown generally at 154*a*, said plunger member having integrally formed at its upper end a coaxial, radially outwardly extending flange member or balancing disk 156*a*, the outside diameter of which is greater than that of the annular plunger member, but less than the inside diameter of the adjacent walls of the cavity 76. The peripheral, marginal portion of the balancing disk 156*a* like that of the hereinbefore described balancing disk 156 in FIGURE 1 is formed with a downwardly depending annular rim 158*a* which normally under non-operating conditions rests upon and is supported by the upper surface of the radially outwardly extending flange portion 208 of the bearing liner 206. The portion of the plunger member 154*a* extending below the balancing disk 156*a* is formed with an upper cylindrical portion 216 rotatable and axially slidable within the bearing liner 206 and a lower cylindrical portion 218 rotatable and axially slidable within the bearing sleve 210 said cylindrical portions being of substantially the same outside diameter and separated axially by an intermediate section 220 of reduced outside diameter. A downwardly facing annular piston shoulder 222 and an opposite upwardly facing annular piston shoulder 224 is thereby formed on the plunger. Slight clearances of approximately 0.006" are provided between the inside diameters of the bearing liners 206 and 210 and the outside diameters of the upper cylindrical portion 216 and the lower cylindrical portion 218, respectively, of the plunger 154*a*. A similar clearance is provided between the intermediate bore portion 204 of the retainer body 104*a* and the intermediate portion 220 of the plunger 154*a*.

An upper annular chamber 226 of variable volume is formed between the downwardly facing annular piston shoulder 222 and the upwardly facing annular shoulder 228 in the surrounding retainer body 104*a* and a lower annular chamber 230 of variable volume is likewise formed between the upwardly facing annular piston shoulder 224 and the downwardly facing annular shoulder 232 of the retainer body 104*a*. The upper annular chamber 226 is vented to the annular space 72*a* by one or more ducts as shown at 234 and the lower annular chamber 230 is vented by one or more ducts as shown at 236 to an annular passage groove 238 formed in an intermediate, increased outside diameter portion 240 of the retainer body 104*a*. A pair of O-ring seals and grooves 242 and 244 are provided in the increased diameter portion 240 adjacent upper and lower sides of the groove 238 and which make sealing engagement with the adjacent inside surface of the housing 18. One or more ducts as shown at 246 are formed through the housing 18 in such position as to communicate with the annular groove 238. One or more longitudinal passages as shown at 239 are provided for placing the annular space 72*a* in communication with inlet to the first stage turbine drive T_1.

As hereinbefore described in connection with FIGURE 1, sufficient clearance is provided at the outer edge and along the upper portion of the runner of the first stage turbine drive T_1 to permit pressure fluid from the diffuser 194 to flow under pressure between the top of the runner and the bottom of the annular retainer body 104*a*, and thence into the space surrounding the drive shaft 122 at the lower end of the annular plunger member 154*a*. As hereinbefore described, the clearance between the outside diameter of the lower cylindrical portion 218 of the plunger 154*a* and the inside diameter of the adjacent lower bearing sleeve 210 is sufficient to permit flow of a relatively small quantity of pressure fluid therethrough into the lower annular chamber 230 and thence out through the ducts 236 and 246 to the annular space between the housing 18 and the inside of the casing 10. The differential pressure thus established across the lower increased diameter portion 218 of the plunger 154*a* tends to lift the plunger and drive shaft 122 axially upwardly. Power fluid which enters the annular space 72*a* through the passage 70 flows inwardly through the ducts 234 into the upper annular chamber 226 and thence flows through the clearance space between the upper increased diameter portion 216 of the plunger 154*a* and the upper bearing sleeve 206 into the annular space 159 formed under the balancing disk 156*a* within the surrounding rim 158*a*. The differential pressure thus established across the upper increased diameter portion 216 of the plunger member 154*a* and under the balancing disk 156*a* within the surrounding rim 158*a*. The differential pressure thus established across the upper increased diameter portion 216 of the plunger member 154*a* and under the balancing disk 156*a* also tends to lift the drive shaft 122 axially outwardly. The sum of the before mentioned lifting forces are ordinarily sufficient to balance the otherwise unbalance downward axial forces imposed upon the plunger 154*a* and the balancing disk 156*a* through the shaft 122.

As the balancing disk 126*a* is lifted off of contact with the upper surface of the flange portion 208 of the

upper bearing sleeve **206**, escape of a small quantity of pressure fluid from the space **159** under the balancing disk **156***a* into the cavity **76** is permitted which is in turn exhausted through the passages **80** thereby causing a small drop of pressure under the balancing disk **156***a*. This action ordinarily continues until equilibrium is reached between the fluid pressures acting upwardly on the lower and upper portions of the plunger **154***a* and that of the balancing disk **156***a* and the downward unbalanced forces transmitted thereto by the shaft **122**, and under such conditions of equilibrium, the lower edge of the rim **158***a* will float on a relatively thin film of pressure fluid a short distance above and out of contact with the upper surface of the before mentioned bearing flange **208**.

In the event, the upward forces acting on the plunger **154***a* and balancing disk **156***a* as contributed to by the fluid pressures in the annular chambers **226** and **230** is in excess of that necessary to resist all of the downward forces acting through the shaft **122**, upward movement of the shaft **122** would then result until the upper end of the threaded portion **168** of the shaft **122** is brought into contact with the lower end of the valve plunger shank **98** resulting in the lifting of the ball valve **86** off its annular seat **88** permitting pressure fluid to enter from the upper bore portion **60** of the turbine inlet head **40** to flow downward past the control valve **84** into the cup shaped recess **68** as hereinbefore described in connection with the operation of the apparatus of FIGURE 2. As before described since the pressure of the fluid thus entering the recess **68** will be higher than the fluid pressure acting under the plunger **154***a* and balancing disk **156***a*, a resulting downward force will be applied to the upper central piston area defined by the upwardly extending annular flange **157** of the balancing disk **156***a*. This downward force will compensate for the excess upward force acting through the shaft **122** and which will be automatically regulated by the distance to which the ball valve is raised off its annular seat **88** thereby establishing equilibrium between the opposing axial forces, resulting in axial positioning of the rotating system of the turbine pump assembly at a satisfactory predetermined point of equilibrium.

Under some operating conditions, the resultant downward forces imposed through the shaft **122** are greater than that which can be supported by the balancing system of FIGURE 2 and under such conditions, the so-called two stage balancing system shown in FIGURE 4 has the advantage of being capable of exerting a greater upward balancing force. However, with the balancing system of FIGURE 4, which is capable of exerting such greater upward balancing forces, variations in pumping conditions are apt to cause greater variations in these forces. To guard against and take care of such greater variations in the axial forces, the control valve system **84** as employed in connection with the apparatus of FIGURE 4 is of considerable important.

Referring next primarily to the apparatus of FIGURE 4, the axial thrust balancing apparatus therein illustrated is identical to that illustrated in and hereinbefore described in connection with FIGURE 5 except the control valve assembly **84** is omitted. The turbine inlet head **40***b* is shaped slightly differently than that of the inlet head **40** of FIGURE 5 in that it is formed with a coaxial, downwardly facing, generaly frusto-conical shape cavity **250**, the lowermost internal cylindrical portion of which is bounded by an inner wall of an annular skirted section **252**. A plurality of downwardly, divergingly directed inlet passages, as shown at **70***b* serve to connect the bore **60***b* of the metal head **40***b* with the annular space **72***b*, and serve to connect the pipe **14** with the first stage T_1, of the turbine drive apparatus and with the balancing plunger apparatus. A plurality of obliquely directed outlet ducts as shown at **80***b* circumferentially interspaced between the before mentioned passages **70***b* extend through the turbine inlet head **40***b* and serve to connect the cavity **250** with the exterior of the turbine inlet head **40***b* at the upper exterior bevel end portion **82***b* in the same manner as that hereinbefore described and shown in connection with FIGURE 4.

The uppermost inner, downwardly facing end portion of the frusto-conical recess **250** is formed with a downwardly facing, flat bottomed circular recess **254** in which seated a metal thrust disk **256** held in place by suitable means such as screws **258**.

In operation under some conditions, where driving fluid pressure and the character and head of the fluid being pumped are subject to rapid and abrupt changes causing surges, the result and axial forces in the drive shaft **122** may be intermittently reversed, or the downwardly directed forces therein intermittently reduced such as to result in upwardly directed forces in the shaft **122** sufficient to bring the upper end portion **168** of the shaft into rotating abutment with the lower surface of the thrust disk **256**. Under such conditions, the thrust disk **256** acts temporarily as a thrust bearing.

The turbine runners and pump impellers, as heretofore conventionally designed, have had no provision for limiting the axial displacment thereof relative to their respective surrounding structure and therefore at a certain stage in the life and wear of the unit, sudden destruction of the runners and impellers occasionally resulted. Therefore, another important feature of this invention resides in forming each of the runners and impellers with an exterior, radially extending, downwardly facing annular bearing surface as shown at **192** in FIGURES 2, 3 and 4. Such bearing surface **192** acts as a seat or thrust bearing means under certain operating conditions occasionally encountered, particularly in the event excessive wear has occurred at the lower edge of rim **158**, **158***a* or **158***b* as illustrated in FIGURES 2, 3 or 4 respectively, or in event other clearance conditions in the balancing system change in time by reason of wear of the several parts which would permit such runners and impellers to lower into rotating contact with the upper surfaces and edges of the central passages through the several cover plates of the several stator cages or cover bodies. Such wear apparently occurs mainly at the times when the pump is just starting or being shut down when the initial or final rotation of the runners, impellers, and shaft occur with the full weight thereof being supported by the balancing disk rim **158**, **158***a* or **158***b* in metal-to-metal rotational contact with the bearing flange **114** or **208**.

Since the power fluid as it enters the top of the turbo pump unit, is subjected to a cleaning process as hereinbefore mentioned, will be substantially free of foreign material, such as would have an abrasive effect on the various parts of the mechanism, abrasion of the turbine drive runners, bearings and particularly the hereinbefore described axial thrust balancing mechanism can be maintained at a minimum.

It is to be understood that the foregoing is illustrative only and that the invention is not limited thereby, but may include various modifications and changes made by those skilled in the art within the scope of the invention as defined in the appended claims.

We claim:

1. In a turbo-drive for installation in wells, apparatus comprising:
   - a housing adapted to be lowered into a well;
   - a turbine in said housing having runners adapted to be driven by power fluid supplied thereto;
   - inlet means for introducing such power fluid into said housing and drivingly to said runners;
   - shaft means upon which said runners are fixed for support and rotation therewith about a common axis;
   - and means for balancing axial thrust in said shaft including:
   - a cylinder fixed in said housing,

plunger means fixed to said shaft and rotatable and axially slidable in said cylinder, there being clearance space between said cylinder and plunger means such as to permit a relatively low volume of fluid flow therethrough from one end to the other end of said cylinder when a differential fluid pressure is applied across said plunger in said cylinder,

inlet duct means in said housing interconnecting said inlet means and said one end of said cylinder,

discharge duct means in said housing interconnecting said other end of said cylinder and a discharge zone which may be of lower pressure than said inlet means, whereby said differential fluid pressure may be applied across said plunger in said cylinder and a resultant axial balancing force thereby applied to said shaft,

and control means, actuatable by axial displacement of said shaft from a predetermined position to vary the resistance to flow of power fluid through said inlet duct means, thereby to vary said differential fluid pressure and said resultant axial force such as to tend to restore said shaft to said predetermined axial position.

2. In a turbo-pump apparatus for installation in wells, apparatus comprising:

a housing adapted to be lowered into a well;

rotatable fluid reaction means in said housing for flow of fluid therethrough;

inlet passage means for admitting fluid into said housing and to said rotatable reaction means;

discharge passage means for discharging such fluid from said rotatable reaction means and from said housing;

shaft means upon which said reaction means is fixed for support and rotation about a common axis, whereby there may be an axial thrust imparted to said shaft by said fluid upon rotation of said rotatable reaction means and said shaft;

and means for balancing said axial thrust including:

a cylinder fixed in said housing,

plunger means fixed to said shaft, and rotatable and axially slidable in said cylinder,

duct means in said housing interconnecting one of said passage means and one end portion of said cylinder, and duct means in said housing interconnecting the other of said passage means and the other end portion of said cylinder, whereby a differential fluid pressure may be applied across said plunger in said cylinder, such as to apply an axial balancing force to said shaft,

and means, actuatable by axial displacement of said shaft in excess of a predetermined amount from a predetermined axial position relative to said cylinder means to vary the resistance of flow of fluid in one of said duct means to vary said differential pressure and the said axial balancing force resulting therefrom such as to tend to restore said shaft to said predetermined position.

3. In a turbo-pump apparatus for installation in wells, apparatus comprising:

a housing adapted to be lowered into a well;

fluid reacton means in said housing for flow of fluid therethrough;

inlet passage means for admitting fluid into said housing and to said reaction means;

discharge passage means for discharging such fluid from said reaction means and from said housing;

shaft means upon which said reaction means is fixed for support and rotation about a common axis, whereby there may be an axial thrust imparted to said shaft by said fluid upon rotation of said reaction means and said shaft;

and means for balancing said axial thrust including:

a cylinder force means in said housing,

plunger force means rotatable and axially slidable in said cylinder force means;

means fixing one of said force means to said housing and the other of said force means to said shaft means,

duct means in said housing interconnecting one of said passage means and one end portion of said cylinder force means, and duct means in said housing interconnecting the other of said passage means and the other end portion of said cylinder force means, whereby a differential fluid pressure may be applied across said plunger force means in said cylinder, such as to apply an axial balancing force to said shaft,

and means, actuatable by axial displacement of said shaft in excess of a predetermined amount from a predetermined axial position relative to said cylinder means to vary the resistance of flow of fluid in one of said duct means to vary said differential pressure and the resultant balancing axial force such as to tend to restore said shaft to said predetermined position.

4. In a turbo-pump apparatus for installation in wells, apparatus comprising:

a housing adapted to be lowered into a well;

fluid reaction means in said housing for flow of fluid therethrough;

inlet passage means for admitting fluid into said housing and to said reaction means;

discharge passage means for discharging such fluid from said reaction means and from said housing;

shaft means upon which said reaction means is fixed for support and rotation about a common axis, whereby there may be an axial thrust imparted to said shaft by said fluid upon rotation of said reaction means and said shaft;

and means for balancing said axial thrust including:

a cylinder force means in said housing,

plunger force means rotatable and axially slidable in said cylinder force means,

means fixing one of said force means to said housing and the other of said force means to shaft means,

duct means in said housing interconnecting one of said passage means and one end portion of said cylinder force means, and duct means in said housing interconnecting the other of said passage means and the other end portion of said cylinder force means, whereby a differential fluid pressure may be applied across said plunger force means in said cylinder, such as to apply an axial balancing force to said shaft, and means, actuatable by axial displacement of said shaft from a predetermined axial position relative to said cylinder means to vary the resistance of flow of fluid in the one of said duct means which is connected to said inlet passage means to vary said differential pressure and the resultant axial balancing force such as to tend to restore said shaft to said predetermined position.

5. In a turbo-drive for installation in wells, apparatus comprising:

a housing adapted to be lowered into a well;

a turbine in said housing having runners adapted to be driven by power fluid supplied thereto;

inlet means for introducing such power fluid into said housing and drivingly to said runners;

shaft means upon which said runners are fixed for support and rotation therewith about a common generally vertical axis;

and means for balancing axial thrust in said shaft including:

a pair of separate cylinder means fixed in said housing coaxial with said shaft,

a pair of separate plunger means fixed to said shaft, one of each thereof being rotatable and axially slidable in each of said cylinder means, the clear-

ance space between each of said cylinder means and each of said plunger means being such as to permit a relatively low volume of fluid flow therethrough from one end to the other end of each of said cylinder means when a differential pressure is applied across each said plunger means in said cylinder means,

inlet passage means in said housing interconnecting said inlet means and the lower ends of each of said cylinder means,

separate discharge passage means in said housing separately interconnecting the upper ends of each of said cylinder means and the exterior of said housing, whereby a differential fluid pressure may be applied across each of said plungers in said cylinder means and a resultant axial balancing force thereby applied to said shaft, and control means, actuatable by axial displacement of said shaft from a predetermined position to vary the resistance to flow of fluid through at least one of said discharge passage means, thereby to vary said differential fluid pressure in at least one of said cylinder means and thereby vary said resultant axial force such as to tend to restore said shaft to said predetermined axial position.

6. Apparatus according to claim 5 and control means, actuable by axial displacement of said shaft from a predetermined position to vary the resistance to flow of fluid through at least one of said inlet passage means.

7. In a turbo-drive for installation in wells, apparatus comprising:

a housing adapted to be lowered into a well;

a turbine in said housing having runners adapted to be driven by power fluid supplied thereto;

inlet means for introducing such power fluid into said housing and drivingly to said runners;

shaft means upon which said runners are fixed for support and rotation therewith about a common generally vertical axis;

and means for balancing axial thrust in said shaft including:

means fixed in said housing having a bore of axially stepwise varying inside diameter,

plunger means fixed to said shaft and rotatable and axially movable therewith,

a pair of axially spaced apart annular piston means carried on said plunger means and having outside cylindrical surfaces which are coaxial with and axially and rotatably slidable in said bore, said bore having an intermediate section of reduced inside diameter making a sliding fit with the outside of said plunger means intermediate said piston means, thereby dividing said bore into upper and lower cylinder chambers in which said piston means are rotatable and axially slidable as aforesaid,

separate inlet passage means in said housing separately interconnecting said inlet means and the lower ends of each of said cylinder chambers;

separate discharge passage means in said housing separately interconnecting the upper ends of each of said cylinder chambers and the exterior of said housing, whereby a differential fluid pressure may be applied across each of said piston means in said cylinder chambers and a resultant axial balancing force thereby applied to said plunger and thence to said shaft,

and control means, responsive to axial displacement of said shaft from a predetermined position to vary the resistance to flow of power fluid through at least one of said inlet passage means, thereby to vary said differential fluid pressure and said resultant axial force such as to tend to restore said shaft to said predetermined axial position.

8. In a turbo-drive for installation in wells, apparatus comprising:

a housing adapted to be lowered into a well;

a turbine in said housing having runners adapted to be driven by power fluid supplied thereto;

inlet means for introducing such power fluid into said housing and drivingly to said runners;

shaft means upon which said runners are fixed for support and rotation therewith about a common, generally vertical axis;

and means for balancing axial thrust in said shaft including:

a cylinder fixed in said housing,

plunger means fixed to said shaft and rotatable and axially slidable in said cylinder,

three axially spaced apart annular piston means carried on said plunger means, and having outside cylindrical surfaces which are coaxial with and axially and rotatably slidable in said cylinder, said cylinder having an intermediate section of reduced inside diameter making a sliding fit with the outside of said plunger means intermediate a pair of said piston means, thereby dividing said cylinder into upper and lower cylinder chambers in the lower one of which one of said piston means is rotatably and axially slidable, and in the upper one of which two of said piston means is rotatably and axially slidable as aforesaid, the clearance space between each of said piston means and the bores of each of said cylinder chambers in which it slides being such as to permit a relatively low volume of fluid flow therethrough from one end to the other end thereof when differential pressures are applied thereacross,

inlet passage means in said housing interconnecting said inlet means and the lower ends of each of said cylinder chambers,

a passage means in said housing interconnecting said inlet means and the upper end of said upper cylinder chamber,

a discharge passage means in said housing interconnecting the upper end of said lower cylinder chamber and the exterior of said housing, and a discharge passage means in said housing interconnecting the intermediate portion of said upper cylinder chamber, intermediate said two of said piston means therein and the exterior of said housing, whereby such differential fluid pressures may be applied across each of said piston means in said cylinder chambers and a resultant axial force thereby applied to said shaft,

and control means, responsive to axial displacement of said shaft from a predetermined axial position relative to said housing to vary the rate of flow of power fluid through at least one of said inlet passage means, thereby to vary the differential fluid pressures across said piston means and the resultant axial force such as to tend to restore said shaft to said predetermined axial positions.

9. In a turbo-drive for installation in wells, apparatus comprising:

a housing adapted to be lowered into a well;

a turbine in said housing having runners adapted to be driven by power fluid supplied thereto;

inlet means for introducing such power fluid into said housing and drivingly to said runners;

shaft means upon which said runners are fixed for support and rotation therewith about a common, generally vertical axis;

and means for balancing axial thrust in said shaft including:

a cylinder fixed in said housing,

plunger means fixed to said shaft and rotatable and axially slidable in said cylinder,

three axially spaced apart annular piston means carried on said plunger means, and having outside cylindrical surfaces which are coaxial with and axially and rotatably slidable in said bore, said bore having an intermediate section of reduced inside diameters making a sliding fit with the outside

of said plunger means intermediate a pair of said piston means, thereby dividing said bore into upper and lower cylinder chambers in the lower one of which one of said piston means is rotatable and axially slidable and in the upper one of which two of said piston means is rotatably and axially slidable as aforesaid, the clearance space between each of said piston means and the bores of each of said cylinder chambers being such as to permit a relatively low volume of fluid flow therethrough from one end to the other end thereof, inlet passage means in said housing interconnecting said inlet means and the lower ends of each of said cylinder chambers,

a passage means in said housing interconnecting said inlet means and the upper end of the said upper cylinder chamber,

a discharge passage means in said housing interconnecting the upper end of said lower cylinder chamber and the exterior of said housing, and a discharge passage means in said housing interconnecting the intermediate portion of said upper cylinder chamber, intermediate said two of said piston means therein and the exterior of said housing, whereby differential fluid pressures may be applied across each of said piston means in said cylinder chambers and a resultant axial force thereby applied through said plunger means to said shaft,

control means, responsive to axial displacement of said shaft from a first predetermined axial position to vary the rate of flow of power fluid through one of said inlet passage means,

and separate control means responsive to axial displacement of said shaft from a second predetermined axial position to vary the resistance to flow of fluid through one of said discharge passage means, thereby to vary the said differential fluid pressures across said piston means and said resultant axial force such as to tend to restore said shaft to said predetermined axial positions.

10. In a turbo-drive for installation in wells, apparatus comprising:

a housing adapted to be lowered into a well;

a turbine in said housing having runners adapted to be driven by power fluid supplied thereto;

inlet means for introducing such power fluid into said housing and drivingly to said runners;

shaft means upon which said runners are fixed for support and rotation therewith about a common, generally vertical axis;

and means for balancing axial thrust in said shaft including:

a cylinder fixed in said housing,

plunger means fixed to said shaft and rotatable and axially slidable in said cylinder,

three axially spaced apart annular piston means carried on said plunger means, and having outside cylindrical surfaces which are coaxial with and axially and rotatably slidable in said bore, said bore having an intermediate section of reduced inside diameter making a sliding fit with the outside of said plunger means intermediate a pair of said piston means, thereby dividing said bore into upper and lower cylinder chambers in the lower one of which one of said piston means is rotatably and axially slidable and in the upper one of which two of said piston means is rotatably and axially slidable as aforesaid, the clearance space between each of said piston means and the bores of each of said cylinder chambers being such as to permit a relatively low volume of fluid flow therethrough from one end to the other end thereof,

inlet passage means in said housing interconnecting said inlet means and the lower ends of each of said cylinder chambers,

a passage means in said housing interconnecting said

inlet means and the upper end of said upper cylinder chamber,

a discharge passage means in said housing interconnecting the upper end of said lower cylinder chamber and the exterior of said housing, and a discharge passage means in said housing interconnecting the intermediate portion of said upper cylinder chamber, intermediate said two of said piston means therein and the exterior of said housing, whereby differential fluid pressures may be applied across each of said piston means in said cylinder chambers and a resultant axial force thereby applied through said plunger means to said shaft,

control means, responsive to axial displacement of said shaft from a first predetermined axial position to vary the rate of flow of power fluid through one of said inlet passage means,

and separate control means responsive to axial displacement of said shaft from a second predetermined axial position to vary the resistance to flow of fluid through one of said discharge passage means, thereby to vary the said differential fluid pressures across said piston means and said resultant axial force such as to tend to restore said shaft to said predetermined axial position.

11. In a turbo-drive for installation in wells, apparatus comprising:

a housing adapted to be lowered into a well;

a turbine in said housing having runners adapted to be driven by power fluid supplied thereto;

inlet means for introducing such power fluid into said housing and drivingly to said runners;

shaft means upon which said runners are fixed for support and rotation therewith about a common, generally vertical axis;

and means for balancing axial thrust in said shaft including:

a cylinder bore fixed in said housing,

three axially spaced-apart, annular piston means fixedly carried on said shaft means, coaxial with and axially and rotatably slidable in said bore,

means fixed relative to said housing dividing said bore into upper and lower bore chambers, one of said piston means being contained in the lower bore chamber and the other pair of piston means being contained in the upper bore chamber,

an annular supporting flange fixedly carried by said shaft in said upper bore chamber intermediate said pair of piston means,

an upwardly facing, inwardly extending annular supporting shoulder formed around an intermediate portion of the bore of said upper bore chamber normally closely adjacent the lower surface of said flange, thereby forming a relatively narrow annular clearance space therebetween and upon which said flange is adpted to seat when said shaft is in its lowermost axial position relative to said housing,

a first inlet passage means in said housing interconnecting said inlet means and the lower ends of each of said bore chambers,

a second inlet passage means in said housing interconnecting said inlet means and the upper end of said upper bore chamber above the uppermost piston therein,

a first discharge pasage means in said housing interconnecting the upper end of said lower bore chamber and the exterior of said housing,

a second discharge passage means in said housing interconnecting the exterior of said housing and an intermediate portion of said upper bore chamber intermediate said pair of piston means, above said annular supporting shoulder,

and control means responsive to axial displacement of said shaft upwardly from a given axial position relative to said housing to vary the resistance to

flow of fluid through said second inlet passage means, the resistance to flow of fluid from the lower end of said upper cylinder bore through the clearance space between said flange and said supporting shoulder and thence out through said second discharge passage means variable in acocrdance with variations of said annular clearance space between said flange and said shoulder attendant upon axial upward displacement of said shaft from its lowermost position, thereby, in operation, to vary the differential fluid pressure across said piston means and the resultant axial forces thereon such as to tend to restore said shaft to a predetermined axial position.

12. In a turbo-drive for installation in wells, apparatus comprising:

housing adapted to be lowered into a well;

a turbine in said housing having runners adapted to be driven by power fluid supplied thereto;

inlet means for introducing such power fluid into said housing and drivingly to said runners;

shaft means upon which said runners are fixed for support and rotation therewith about a common axis;

and means for balancing axial thrust in said shaft including:

a cylinder fixed in said housing,

plunger means fixed to said shaft and rotatable and axially slidable in said cylinder, there being clearance space between said cylinder and plunger means such as to permit a relatively low volume of fluid flow therethrough from one end to the other end of said cylinder when a differential fluid pressure is applied across said plunger means in said cylinder,

inlet duct means in said housing interconnecting said inlet means and said one end of said cylinder,

discharge duct means in said housing interconnecting said other end of said cylinder and a discharge zone which may be of lower pressure than said inlet means, whereby said differential fluid pressure may be applied across said plunger means in said cylinder and a resultant axial balancing force thereby applied to said shaft,

and valve means in said housing, actuatable by axial displacement of said shaft from a predetermined axial position to vary the resistance in said inlet duct to flow of power fluid therethrough to said one end of said cylinder, thereby to vary said differential pressure and thereby vary said force such as to tend to restore said shaft to said predetermined axial position.

13. In a turbo-drive for installation in wells, apparatus comprising:

a housing adapted to be lowered into a well;

a turbine in said housing having runners adapted to be driven by power fluid supplied thereto;

Inlet means for introducing such power fluid into said housing and drivingly to said runners;

shaft means upon which said runners are fixed for support and rotation therewith about a common axis;

and means for balancing axial thrust in said shaft including:

a cylinder fixed in said housing,

plunger means fixed to said shaft and rotatable and axially slidable in said cylinder, there being clearance space between said cylinder and plunger means such as to permit a relatively low volume of fluid flow therethrough from one end to the other end of said cylinder when a differential fluid pressure is applied across said plunger means in said cylinder,

inlet duct means in said housing interconnecting said inlet means and said one end of said cylinder,

discharge duct means in said housing interconnecting said other end of said cylinder and a discharge zone which may be of lower pressure than said inlet means, whereby said differential fluid pressure may be applied across said plunger means in said cylinder and a resultant axial balancing force thereby applied, to said shaft,

valve means in said housing, actuatable for varying the resistance to flow of fluid from said inlet means through said inlet duct means to said other end portion of said cylinder,

and push rod means for so actuating said valve means, said push rod means being axially slidably positioned in said housing with one end thereof adjacent one end of said shaft for contact with and axial movement by said shaft upon axial displacement of said shaft in a gvien direction from a predetermined position, such as to actuate said valve to vary said resistance to flow and thereby vary the axial force applied to said plunger means in opposition to said displacement of said shaft.

14. In a turbo-drive for installation in wells, apparatus comprising:

a housing adapted to be lowered into a well;

rotatable fluid reaction means in said housing for flow of fluid therethrough;

inlet passage means for admitting such fluid into said housing and to said reaction means;

shaft means upon which said reaction means is fixed for support and rotation therewith about a common axis;

and means for balancing resultant axial thrust in said shaft including:

a cylinder fixed in said housing,

plunger means fixed to said shaft and rotatable and axially slidable in said cylinder, there being flow passage means from one end to the other end of said cylinder such as to permit a relatively low volume of fluid flow therethrough from one end to the other end of said cylinder when a differential fluid pressure is applied across said plunger means in said cylinder,

inlet duct means in said housing interconnecting said inlet means and said one end of said cylinder,

discharge duct means in said housing interconnecting said other end of said cylinder and a discharge zone which may be of a different pressure than said inlet means whereby said differential fluid pressure may be applied across said plunger in said cylinder and a resultant axial balancing force thereby applied to said shaft,

and control means, actuatable by axial displacement of said shaft from a predetermined position to vary the said resistance in said inlet duct to flow of fluid therethrough such as to vary said differential fluid pressure and thereby vary said resultant axial balancing force in such manner as to oppose such axial displacement of said shaft.

15. In a turbo-drive for installation in wells apparatus comprising:

a housing adapted to be lowered into a well;

rotatable reaction means in said housing for flow of fluid therethrough;

inlet means for admitting such fluid into said housing and to said reaction means;

shaft means upon which said reaction means is fixed for support and rotation therewith about a common generally vertical axis;

and means for balancing resultant axial thrust in said shaft including:

a pair of separate cylinder means fixed in said housing coaxial with said shaft,

a pair of separate plunger means fixed to said shaft, one of each thereof being rotatable and axially slidable in each of said cylinder means, the clearance space between each of said cylinder means and each of said plunger means being such as to permit a relatively low volume of fluid flow therethrough from one end to the other end of each of said cylinder

means when a differential fluid pressure is applied across each said plunger means in said cylinder means,

inlet passage means in said housing interconnecting said inlet means and the lower end of one of said cylinder means, and the upper end of the other of said cylinder means,

discharge passage means in said housing connecting the upper end of said cylinder means and the lower end of said other of said cylinder means with a discharge zone which may be of a different fluid pressure than said inlet means, whereby differential fluid pressures may be applied across each of said plungers in said cylinder means in opposite axial directions and a resultant axial balancing force be thereby applied to said shaft,

and control means responsive to axial displacement of said shaft in either axial direction from a predetermined axial position for varying the said differential

pressures thus applied across said plungers relative to one another, thereby to vary said resultant axial force such as to tend to restore said shaft to said predetermined position.

16. Apparatus according to claim 15 in which said control means includes valve means in a portion of said inlet passage means to vary the flow of fluid from said inlet pasage means to at least one of the ends of said cylinder means.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,171,630

March 2, 1965

Doran B. Harney et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 17, line 4, for "rotatable" read -- rotatably --; column 18, line 56, for "adpted" read -- adapted --; column 19, line 6, for "means variable in acocrdance" read -- means being variable in accordance --.

Signed and sealed this 10th day of August 1965.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents