May 9, 1933. R. V. TERRY 1,907,466

HYDRAULIC MACHINE

Filed April 1, 1932 4 Sheets-Sheet 1

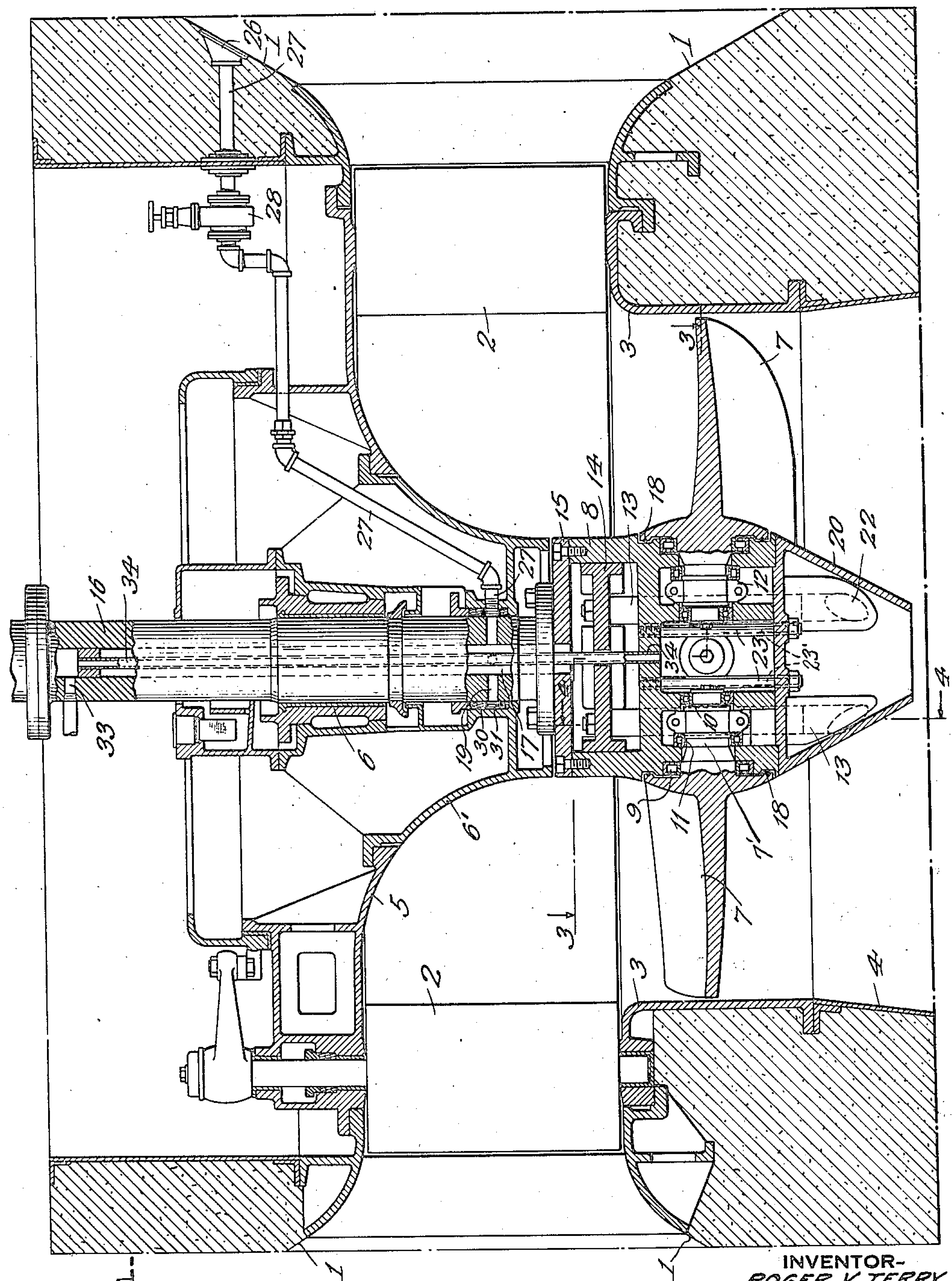

Fig-1

INVENTOR-
ROGER V. TERRY.

BY Sheffield & Betts
HIS ATTORNEYS

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FIG. 2

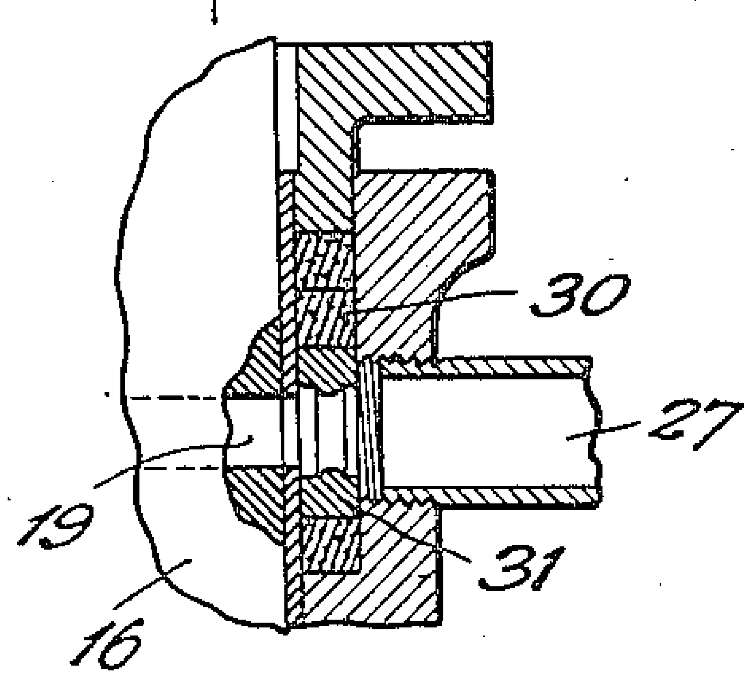


FIG. 3.

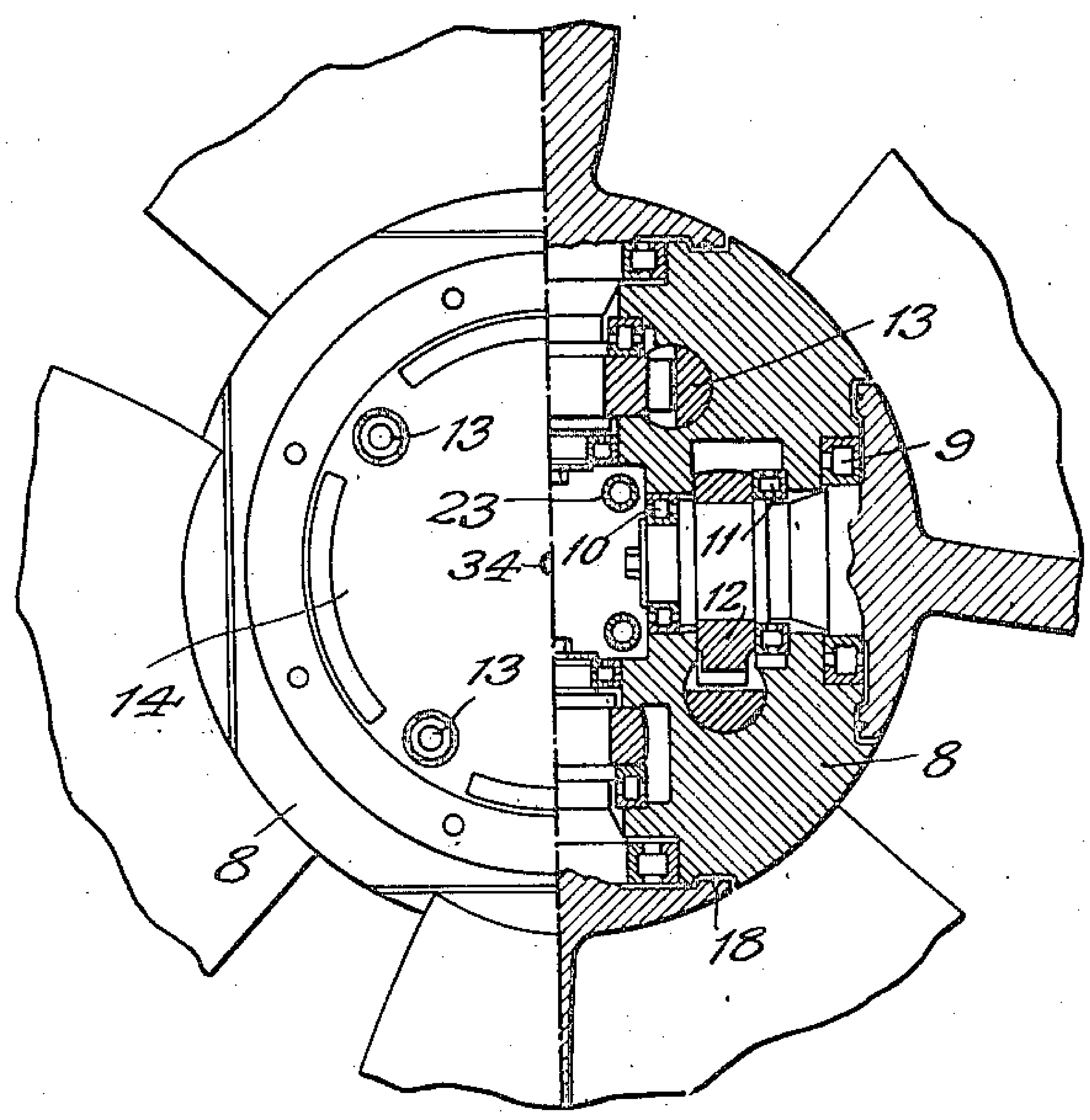


FIG. 5.

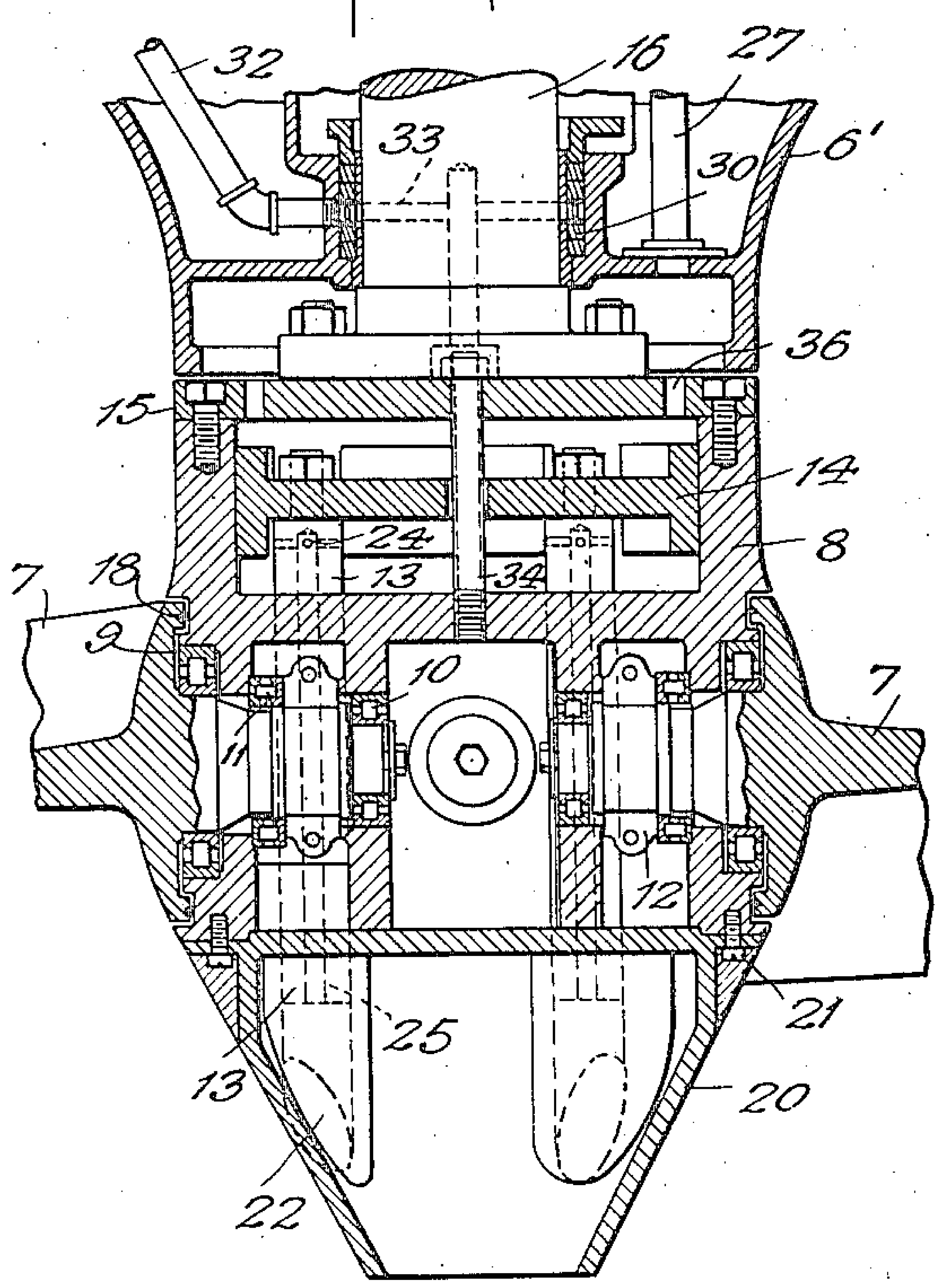
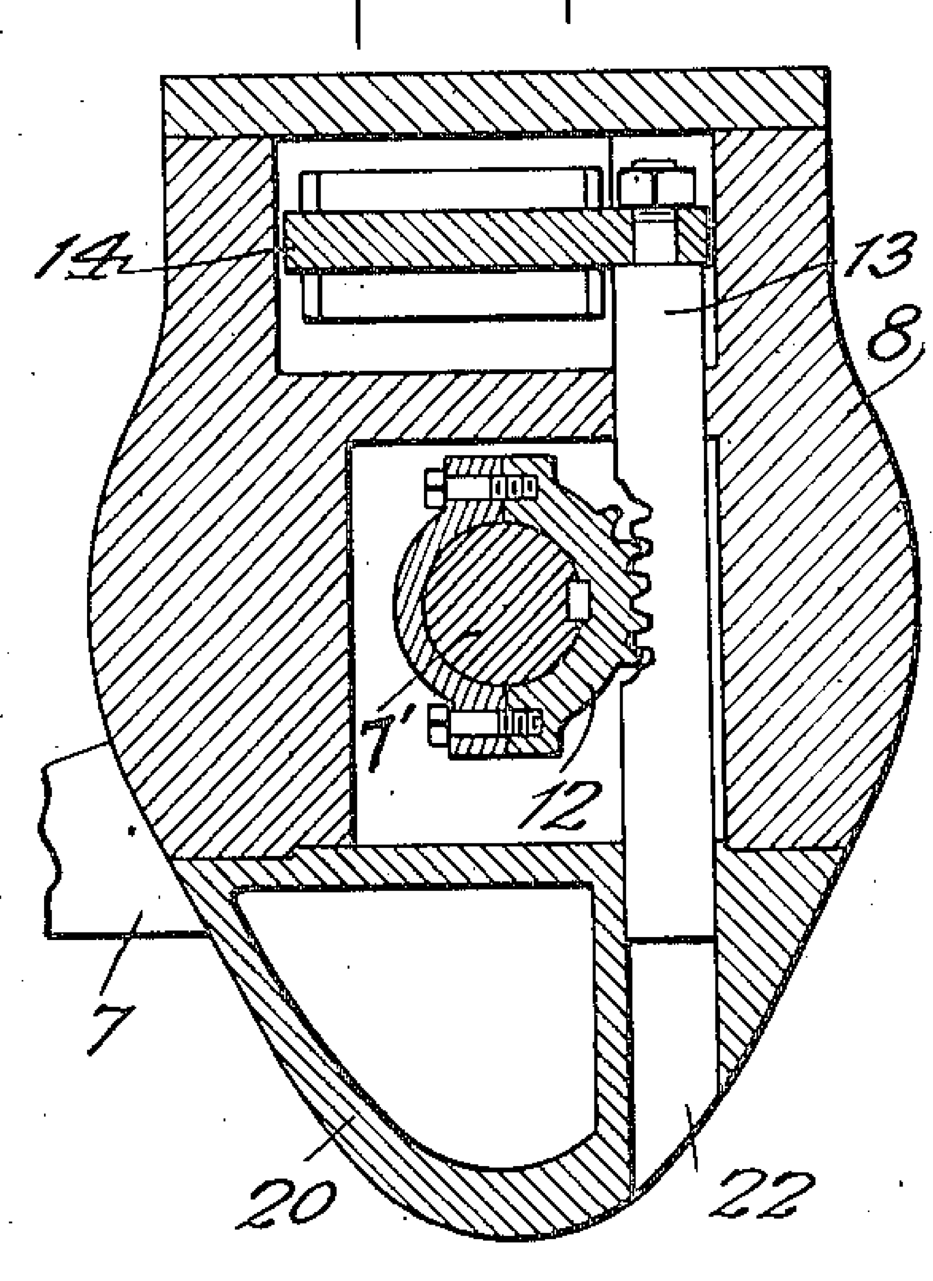


FIG. 4.



INVENTOR-
ROGER V. TERRY

BY Sheffield & Betts
HIS ATTORNEYS

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HYDRAULIC MACHINE

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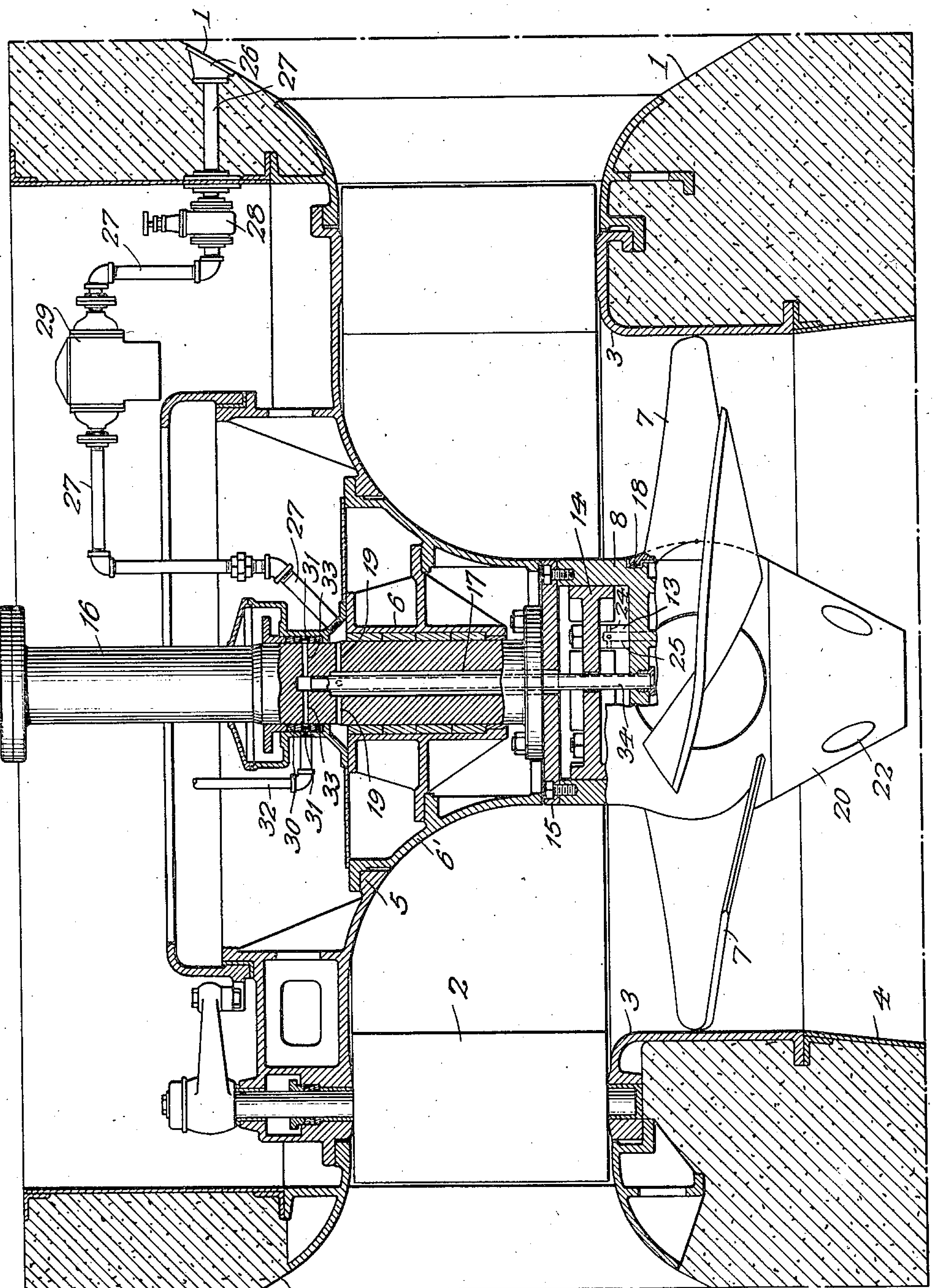


FIG. 6.

INVENTOR-
ROGER V. TERRY.
BY Sheffield & Betts
HIS ATTORNEYS

FIG. 7.

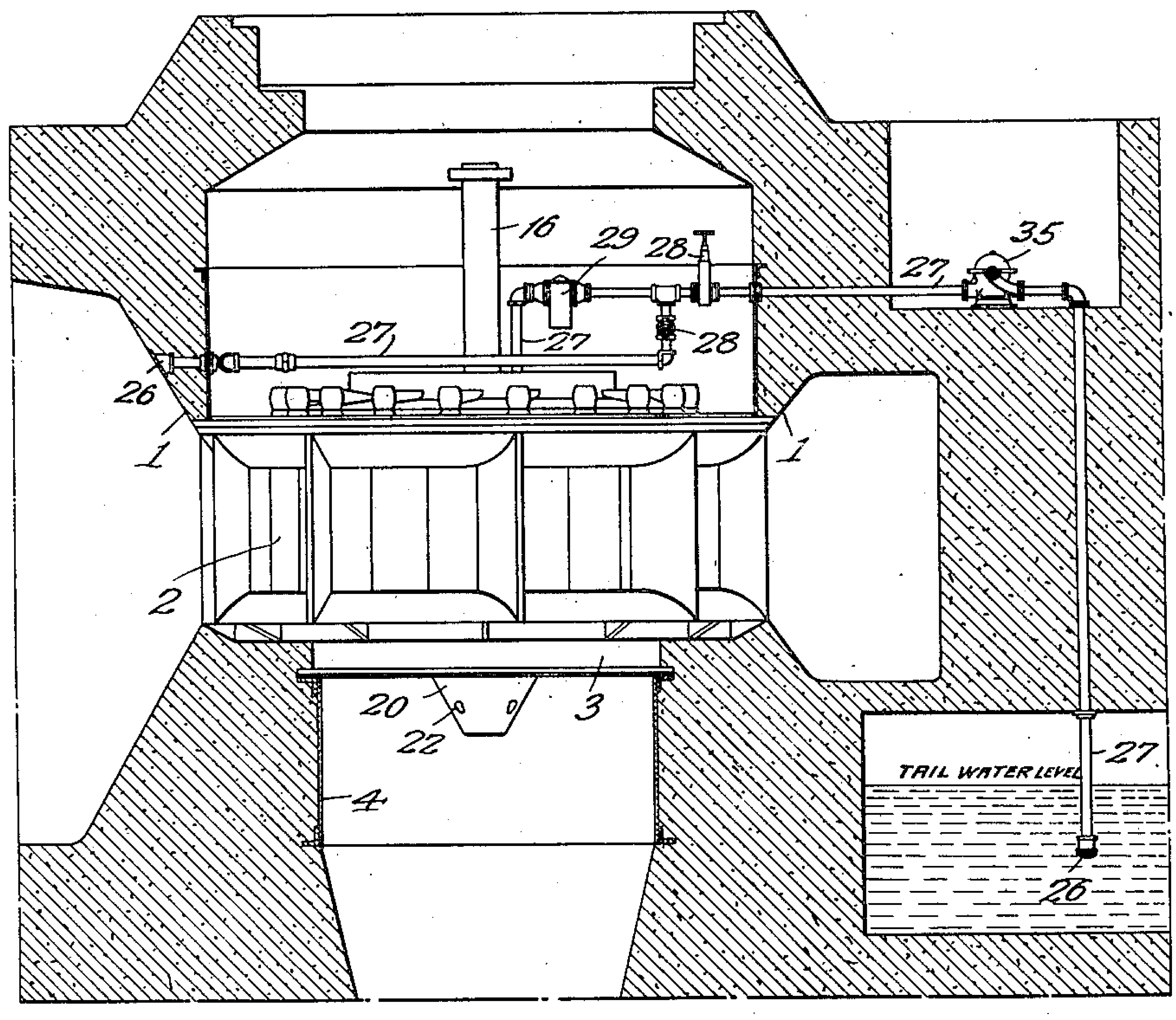
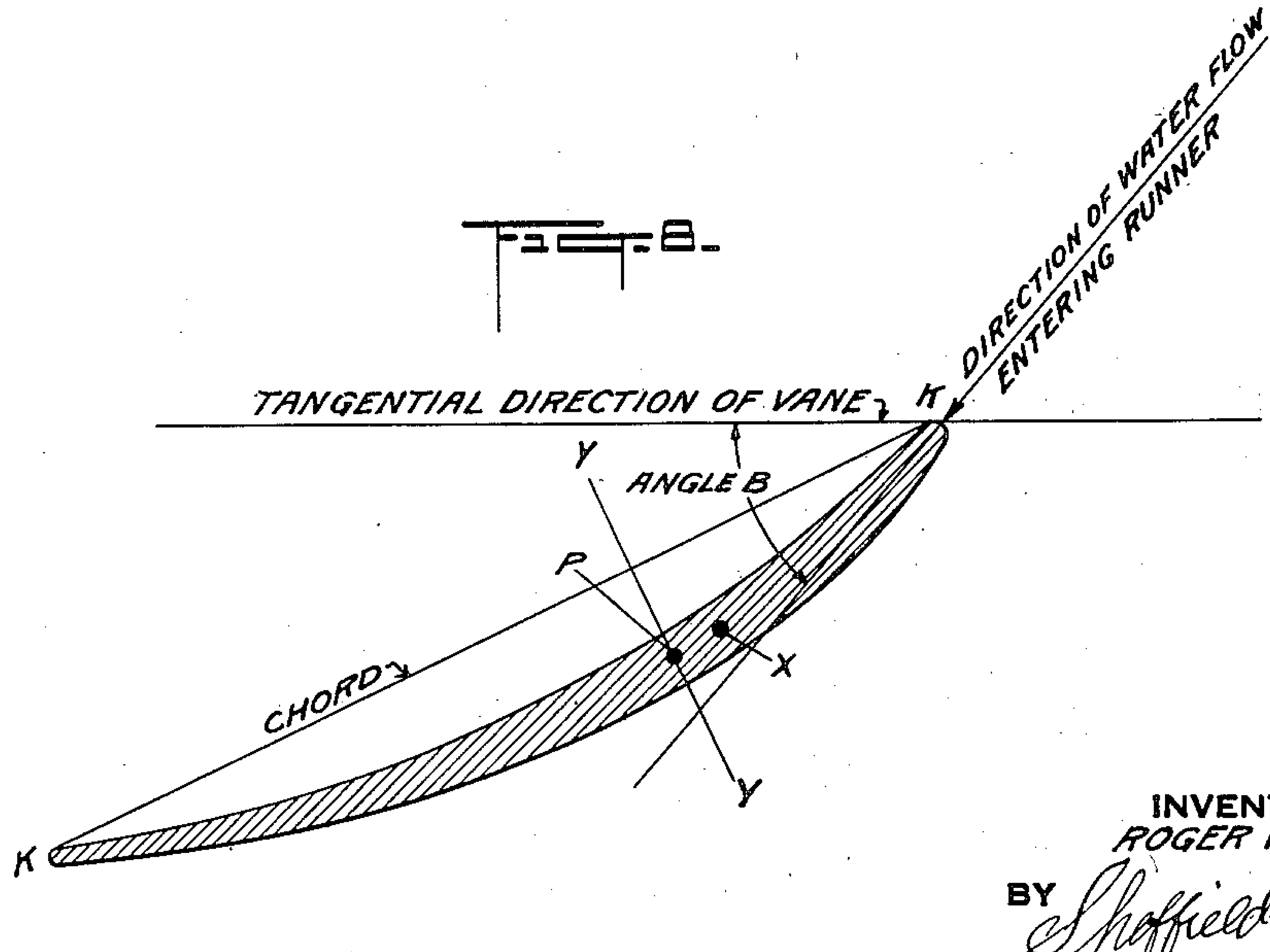


FIG. 8.



INVENTOR-
ROGER V. TERRY.
BY Sheffield & Betts
HIS ATTORNEYS

Patented May 9, 1933 **1,907,466**

UNITED STATES PATENT OFFICE

ROGER V. TERRY, OF HILTON VILLAGE, VIRGINIA, ASSIGNOR TO NEWPORT NEWS SHIPBUILDING AND DRY DOCK COMPANY, A CORPORATION OF VIRGINIA

HYDRAULIC MACHINE

Application filed April 1, 1932. Serial No. 602,534.

This invention relates to hydraulic machines and particularly those of the type that may be used for the generation of power hydraulically or, by applying power thereto, may be used to cause a flow of water therefrom in the desired direction.

My invention relates more particularly to hydraulic power producing machines known as hydraulic turbines either of low or of high specific speed.

The principal object of my invention is to provide a hydraulic turbine in which the blades or vanes of the rotor or runner are pivoted and of variable angle with reference to a plane of rotation that is at right angles to the axis of the runner, the changes in the angles of the vanes being accomplished automatically by the flow of the water past or through the runner.

The accomplishment of the above mentioned object not only enables a turbine to operate at its maximum efficiency for varying loads but also allows the blades of the runner to accommodate themselves to changes in the hydraulic head or pressure of the source of supply of water and also to changes due to the angles of the wicket gates and the changes due to variations in the speed of rotation of the runner itself.

Automatically variable vanes, when used as in my improved runner, obviously eliminate complicated and expensive parts that have heretofore been required when changes in the angles of the vanes of a runner have been produced by adjustment of certain mechanism at or near the upper portion of the turbine shaft. Among the parts that are thus eliminated are governor pressure systems that can take care of the total capacity of the turbine, elaborate oil supply apparatus having rotating parts requiring stuffing boxes that require renewal from time to time and that are often the source of oil leaks, as well as necessary pipes, parts and apparatus required to keep former adjustable vane runners in the best condition for efficient operation.

The rotor or runner hereafter to be described has many advantages not incident with former runners. In addition to automatic operation at maximum efficiency, the runner vanes automatically open or are more inclined when starting a turbine, thereby giving a maximum starting torque with the use of a minimum flow of water.

The vanes also remain closed or at a minimum angle with the plane of rotation when the unit is being used as a synchronous condenser, resulting in a minimum loss of power when the runner is operating in either water or air.

Due to the cushioning action of a dashpot (to be described) foreign objects carried through the runner give much less trouble and greatly lessen the possibility of damage to the runner.

My improved runner, furthermore, can be readily installed in a turbine designed for use with a fixed blade runner. The substitution of my improved runner for a fixed blade runner does not require changes in the electric generator or the usual turbine governor.

It is well known in the turbine art that the angle at which water enters a runner varies with the angular position of the wicket gates, and with the tangential speed of the runner. The angle of flow of the water entering the runner with reference to the circular rotation of the runner, increases relative to a tangent to the circle of rotation, as the wicket gates are opened, and decreases as the peripheral speed of the runner is increased.

It has been found from experiment that the centers of pressure on the various flow line sections of vanes of the shape and angles of flow normally used for turbine runners are located at points varying from 25 to 40 per cent. of the corresponding chord distances from the leading edge to the trailing edge of the vanes.

It will be appreciated that there is a maximum efficiency position of the vane for each combination of flow conditions, consisting of the direction of water flow entering the runner, the velocity of this flow, and the tangential speed of the runner. With the vane at its proper angle to result in maximum efficiency under these particular conditions, all forces acting on each vane are equivalent to a single force acting through a center of pressure. This force times its distance from the vane axis creates a moment tending to rotate the vane about its axis. This moment is balanced by building into the runner hub a reactive device acting on the vanes through the proper mechanism. The reactive device includes a piston on the two sides of which there is a difference in pressure, the preponderance acting always in the same direction and tending to oppose or balance the moment created by the water flowing through the runner. The preponderance in pressure is secured by the application of the pressure of the head water taken from the penstock, to the space at one side or the other of the piston, as the case may be, the other side of the piston being connected to the draft tube or to some other point in the main conduit down stream from the runner. If desired, the pressure may be supplied to one side of the piston by means of a pump, as indicated in Fig. 7, instead of from the penstock alone, as in Figs. 1 and 6.

The moment of force required to hold the vanes in their proper positions for the various conditions of flow, may be ultimately determined experimentally by calibrated springs properly connected to the vanes of a model. In the light of experimental data I am, of course, quite familiar with the action which takes place when the inlet flow angle is changed. This might perhaps be best illustrated by an example. Assume the runner to be in steady operation under certain flow conditions, the hydraulic moment on the vanes being balanced by the reactive moment. Now assume that the angle of flow relative to the runner is increased by increasing the wicket gate angle or by decreasing the speed of the turbine. This is equivalent to increasing the "angle of attack" as generally known in aeronautics. The center of pressure moves down-stream an appreciable amount and the total force on the vane also increases, thus increasing the moment about the vane axis. The hydraulic turning moment is now greater than the reactive moment and a certain angular movement of the vane in the opening direction will consequently take place. As the vane moves in the opening direction the angle of attack decreases, the center of pressure moves up-stream on the vanes, the hydraulic moment tending to open the vanes thus decreases until again balanced by the reactive moment. The angular movement of the vanes then stops at this balanced position, and the turbine operates with the vanes in the new position until the flow conditions are again changed. The above action takes place automatically.

From the above explanation, it will be clear that the center of pressure is not fixed, but varies somewhat with the flow conditions. It is really the change in the center of pressure which, together with the change in force on the vanes, causes the vane movement. Under normal conditions of operation at or near the best efficiency for the various flow conditions, the center of pressure moves an appreciable amount, but not a very large amount, when compared with the chord distance. When starting up a runner from rest the water impinges directly on the vane at a comparatively large angle of attack. Under this condition the center of pressure moves a relatively large distance down-stream on the vanes, approaching 50 per cent. of their chord distances as a limit. I find from experiments that this is a desirable feature, as the vanes will open wide, giving the required starting torque with a minimum quantity of water. As the runner picks up speed the angle of attack decreases, the center of pressure moves up-stream, thereby reducing the hydraulic turning moment in the vanes, and the vanes therefore close until the hydraulic and reactive moments are balanced.

Similarly, when the hydro-electric unit is used as a synchronous condenser, the runner being driven by the generator with the turbine gates closed, the angle of attack reaches a large negative value; the center of pressure moves down-stream a large amount; the vane force acts on the back side of the vanes causing them to close, thus resulting in a minimum amount of power required to drive the runner in either water or air.

It is deemed preferable to arrange the pivots of the vanes so that their axes will be slightly upstream from their normal centers of pressure, so that they will tend to assume a position somewhat in line with the water flow entering the runner, in a manner similar to the action of a weather-vane. With the vanes thus pivoted, they will automatically tend to follow any changes in the angle of water entering the runner resulting from a change in gate opening or from a change in head.

Figure 8 illustrates how the vanes are preferably pivoted with respect to the center of pressure on the vanes, as found by experiment. The cross hatched portion represents the development of a section through a vane along a flow line through the runner. P represents the center of pressure whose location varies somewhat with different flow conditions in the runner but which has been found from experiment to be down-stream from a point 25 to 40 per cent. of chord K—K. X represents the axis or pivot point of the vane. Y—Y represents a line through the center of pressure normal to chord K—K. With the vanes freely pivoted as above described, they will follow any changes of the water flow passing through the runner.

For a detailed description of several embodiments of my invention, which I at present deem preferable, reference may be had to the following description and to the accompanying drawings forming a part thereof, in which

Fig. 1 is a vertical sectional view of one form of a turbine embodying my invention.

Fig. 2 is an enlarged cross-section, substantially similar to a portion of Fig. 1, showing connection for water supply.

Fig. 3 is a horizontal sectional view on the line 3—3 of Fig. 1.

Fig. 4 is a vertical sectional view on the line 4—4 of Fig. 1.

Fig. 5 is a vertical sectional view of a modified form of the turbine.

Fig. 6 is partly a vertical sectional view of a modified form of the turbine.

Fig. 7 is a part vertical sectional view of a turbine installation of modified form.

Fig. 8 is a cross sectional view of one of the runner vanes, indicating the relation of the center of water pressure to the longitudinal axis of its pivot.

In these figures, the same numerals refer to similar parts. Referring particularly to Figs. 1–4, inclusive, 1 is the scroll casing, 2 the wicket gates which are adjusted by the turbine governor in the customary manner, 3 the throat ring, 4 the draft tube, 5 the crown plate, 6 the main bearing, and 6′ the main bearing housing. The above parts are of standard design well known to the turbine art.

The numeral 7 represents the runner vanes which are pivoted as at 7′ in runner hub 8. 9 and 10 are roller bearings carrying the pivots 7′ of vane 7. Roller bearings 11 eliminate friction due to the centrifugal forces of the vanes set up by the rotation of the runner. Gear sector 12 is keyed to the vane stem within suitable recesses forming grease containers, and engages teeth on racks 13 bolted to piston 14 (Fig. 4). Any desired number of runner vanes may be used. The piston 14 serves as a common connecting means for all of the vanes. Since all of the vanes are connected together, they will move together. The upper part of runner hub 8 is bored out to receive piston 14. The depth of the bore may be made just sufficient to give the vanes the proper angular travel. The bottom of the bore and the runner cover 15 will then serve as stops to limit the angular travel of the vanes in either direction. It will be evident that adjustable means to limit the stroke of the dashpot plunger 14 may be used if desired. Obviously the shaft 16 is a continuation of the shaft from an electric generator or other power transmitting device. The runner shaft is provided with a central bore or passage 17 and radial passages 19. These passages supply water under pressure to the space above the piston 14. The shaft is also provided with radial openings 33 for supplying oil or grease to the runner hub.

Packings 18, or rubber or other suitable material, are provided for the purpose of preventing water from entering the hub, and to prevent the loss of oil or grease around the vane stems.

The bottom of the runner hub is provided with a cap 20 that may be held in place by screws or by hollow stay bolts 23. These bolts 23 may constitute tubes as indicated in Figs. 1 and 3 at 23′ and also serve as one means for connecting the space below the dashpot piston 14 with the draft tube 4 through the cap 20. The cap 20 is provided with cylindrical openings 22 which serve as bearings for racks 13 and permit the latter to work up and down when the vanes move angularly on their axes. As shown in Fig. 5, the racks may be provided with radial passages 24 and vertical passages 25 which form additional means for draining the bottom side of the dashpot piston to the draft tube. Referring now to Fig. 6:

Water under pressure is supplied to the space above the top of piston 14 from the water within the scroll casing 1 through coarse strainer 26, piping 27, valve 28, fine strainer 29, lantern ring 31 in stuffing box 30, then through holes 17 and 19 in the shaft previously mentioned.

If desired, a centrifugal pump 35, Fig. 7, may be used as an auxiliary means of water supply interchangeable with or in addition to the supply from the scroll casing. The pump preferably takes its suction from the tail water or draft tube, so that when the runner is rotating at constant speed the difference in pressure on the two sides of the piston 14 will be substantially constant although the hydraulic head acting on the turbine may vary by a substantial amount.

In Fig. 5, water under pressure is admitted to the space above the top of piston 14 through holes 36 in runner cover 15.

The runner hub is packed with grease when the runner is assembled and thereafter oil or grease is supplied to the central chamber in the runner hub through the radial holes 33 in shaft 16 and pipe 34 as in Fig. 1, or through the pipe 32, holes 33 and pipe 34 as in Figs. 5 and 6, whence it passes through the recesses or openings containing the roller bearings, into the chambers containing the racks 13.

It will be noted that racks 13 pass through the grease containers or spaces as they slide up and down when the vanes turn angularly on their axes. This keeps their sliding contacts lubricated. At the same time the volume of chamber forming the grease space remains substantially constant and there is no tendency to force grease out of or to suck water into the grease chamber.

It will be noted that no connection is provided between the runner vanes and any outside source of power for turning or oscillating them. The angular movement of the vanes is entirely automatic and determined by the action of the water flowing past them, as modified by a reactive device actuated by a portion of the same fluid medium which is rotating the turbine.

While the above description applies particularly to high specific speed runners of the so-called "propeller" type where relatively few vanes are employed, the principle and means of producing angular adjustment of the vanes is applicable, with modification in design and construction, to turbines of lower specific speed with a large number of vanes and to certain forms of centrifugal pump vanes or similarly constructed fluid pressure machines.

What I claim and desire to protect by Letters Patent is:

1. In an hydraulic machine having a runner provided with pivoted vanes, the improvement which comprises, providing within said runner a reactive device consisting of a cylinder, a conduit connecting the same with the head water passage, a piston in said cylinder connected with said vanes, said piston being continuously acted upon by a preponderating difference in pressure in proportion to the hydraulic head acting on the machine, said difference in pressure being always in the same direction and tending to balance the moment caused by the fluid flowing past the vanes to maintain the latter at the desired angle.

2. In an hydraulic machine having a runner provided with vanes which are pivoted so that their axes are upstream from their effective centers of pressure and so that the fluid flowing past the vanes will tend to make them assume a steeper angle relative to their plane of rotation, a reactive device consisting of a cylinder, a conduit connecting the same with the head water passage, a piston in said cylinder connected with said vanes, said piston being continuously acted upon by a preponderating difference in pressure in proportion to the hydraulic head acting on the machine, said difference in pressure being always in the same direction and tending to balance the moment caused by the fluid flowing past the vanes.

3. In an hydraulic machine having a runner provided with pivoted vanes, a reactive device connected therewith including a piston located in a chamber connected with the head water which operates the machine and which is continuously acted upon in the same direction by a preponderating difference in fluid pressure produced by said head water and adapted to balance the moment tending to turn said vanes.

4. In an hydraulic machine of the governor operated wicket gate type having a runner provided with pivoted vanes, the improvement comprising, a reactive device connected with said vanes, said reactive device including a piston located in a chamber connected with the head water which operates the machine and which is continuously acted upon in the same direction by a preponderating difference in fluid pressure for causing the vanes to assume the proper angle for maximum efficiency with relation to the required speeds of rotation and the directions and rates of water flow determined by said wicket gates and water head.

5. In an hydraulic machine having a runner provided with pivoted vanes, the improvement which comprises, providing a chamber connected with the head water acting upon said machine, a piston therein connected with said vanes, said piston being acted upon, in one direction only, by a preponderance of fluid pressure produced by said head water whereby the vanes are caused automatically to assume the proper angles for maximum efficiency in accordance with the required speeds of rotation and the angles and rates of water flow.

6. In an hydraulic machine having a runner provided with pivoted vanes, a piston connected therewith, and a conduit connected with the cylinder within which said piston is located and adjacent one side of said piston and leading from the supply passage and a discharge conduit connected with the discharge passage of said turbine and with said cylinder adjacent the other side of said piston so that said piston is acted upon by a preponderance of fluid pressure determined by the relative pressure in the water supply and discharge passages of the machine, respectively.

7. In an hydraulic machine having a runner provided with pivoted vanes, a piston located in a chamber therein and connected with said vanes to produce thereon a turning moment, said chamber being connected with the turbine supply passage whereby said piston is acted upon always and in the same direction by a preponderance of fluid pressure, and a conduit extending from said supply passage to the runner casing for supplying said pressure on said piston.

8. In an hydraulic machine having a runner provided with pivoted vanes, connections between the pivots of said vanes to cause them to move simultaneously about the axes of their respective pivots, a reactive device including a piston having one side adapted to be acted upon by hydraulic pressure applied continuously and in the same direction, a conduit connecting the supply passage of said turbine with the cylinder containing said piston whereby said vanes are caused automatically to assume the proper angles for maximum efficiency of operation relative to the required speeds of rotation and the angles and rates of water flow and de-

pendent upon the pressure supplied by said external source thereof.

9. In an hydraulic turbine having wicket gates for the regulation of water flow and a runner having pivoted vanes thereon, the improvement which comprises, providing within said runner, a reactive device actuated by a preponderance of hydraulic pressure applied continuously and in the same direction, said reactive device including a piston, a chamber enclosing said piston, fluid material in said chamber and supply and discharge conduits connected with said chamber and with the main supply and discharge passages for said turbine, said piston also constituting a dashpot plunger, whereby said vanes are caused progressively and automatically to assume the proper angles and be maintained uniformly at such angles, for maximum efficiency in accordance with the angles of water flow produced by said gates and the rates of water flow produced by the differences in hydraulic head acting through said conduits.

Signed this 18th day of March, 1932.

ROGER V. TERRY.