June 17, 1941. R. E. B. SHARP 2,246,472

HYDRAULIC POWER-ACCUMULATION SYSTEM

Filed Jan. 28, 1939 2 Sheets-Sheet 1

Fig. 1

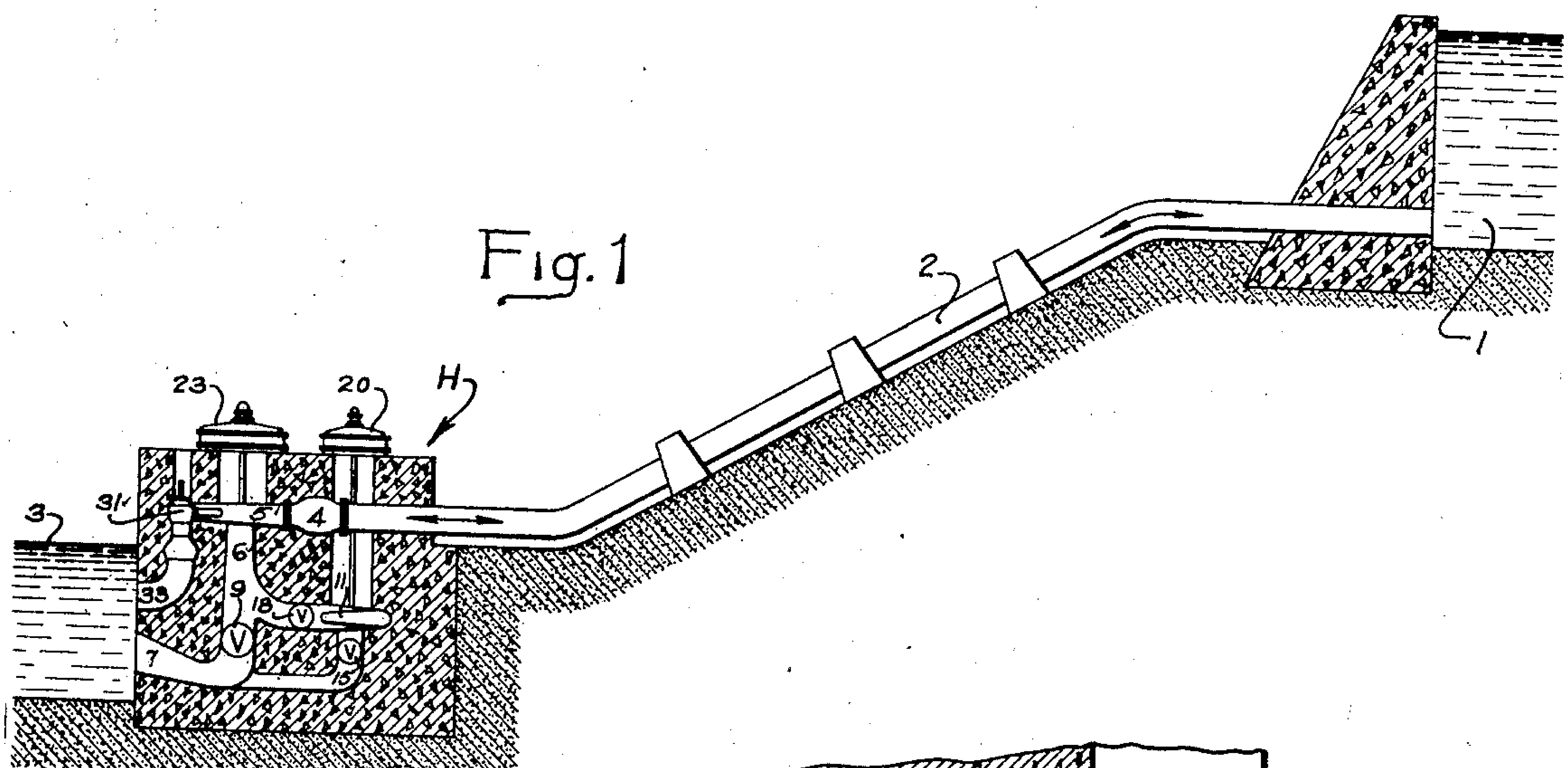


Fig. 3

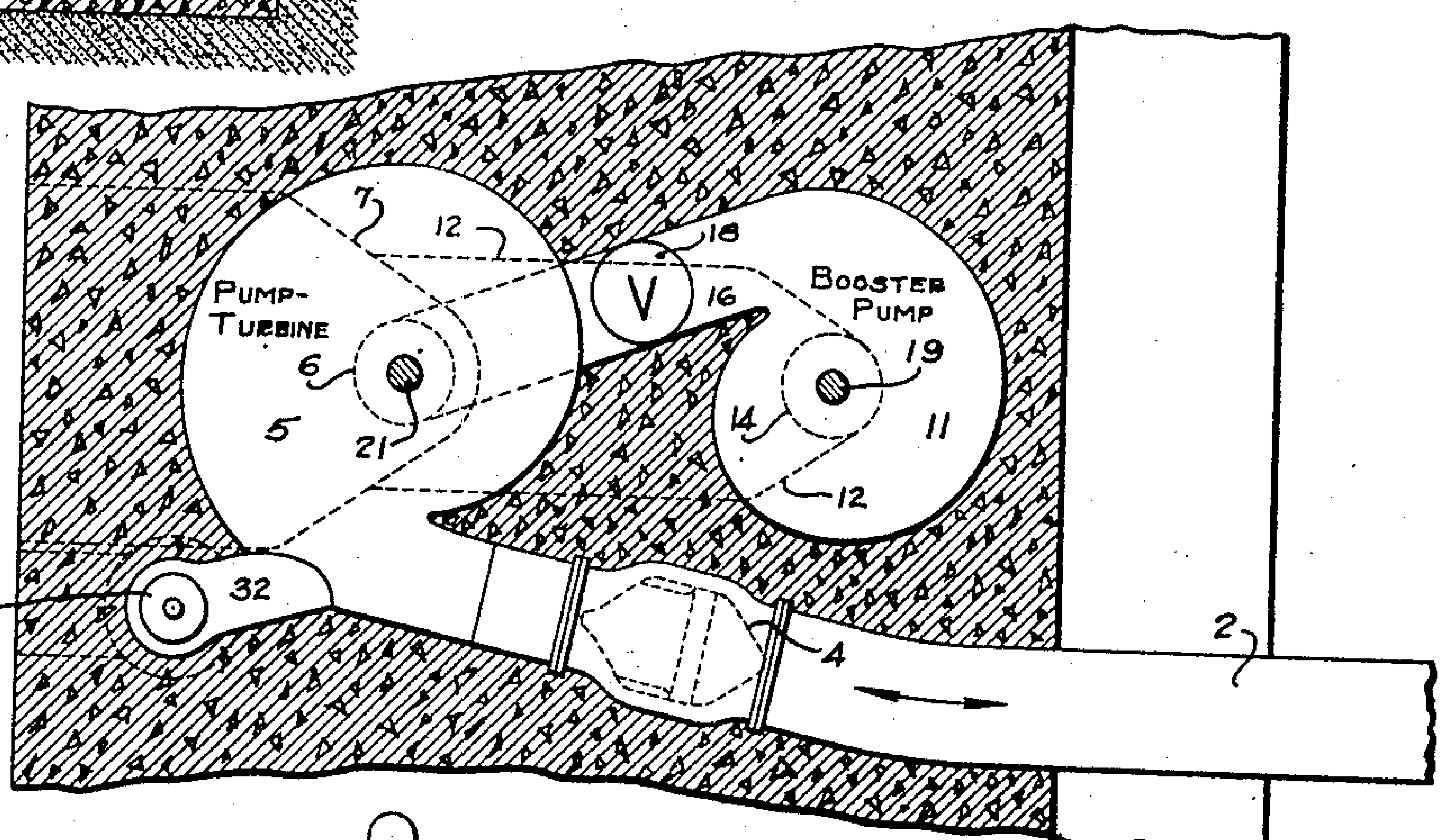
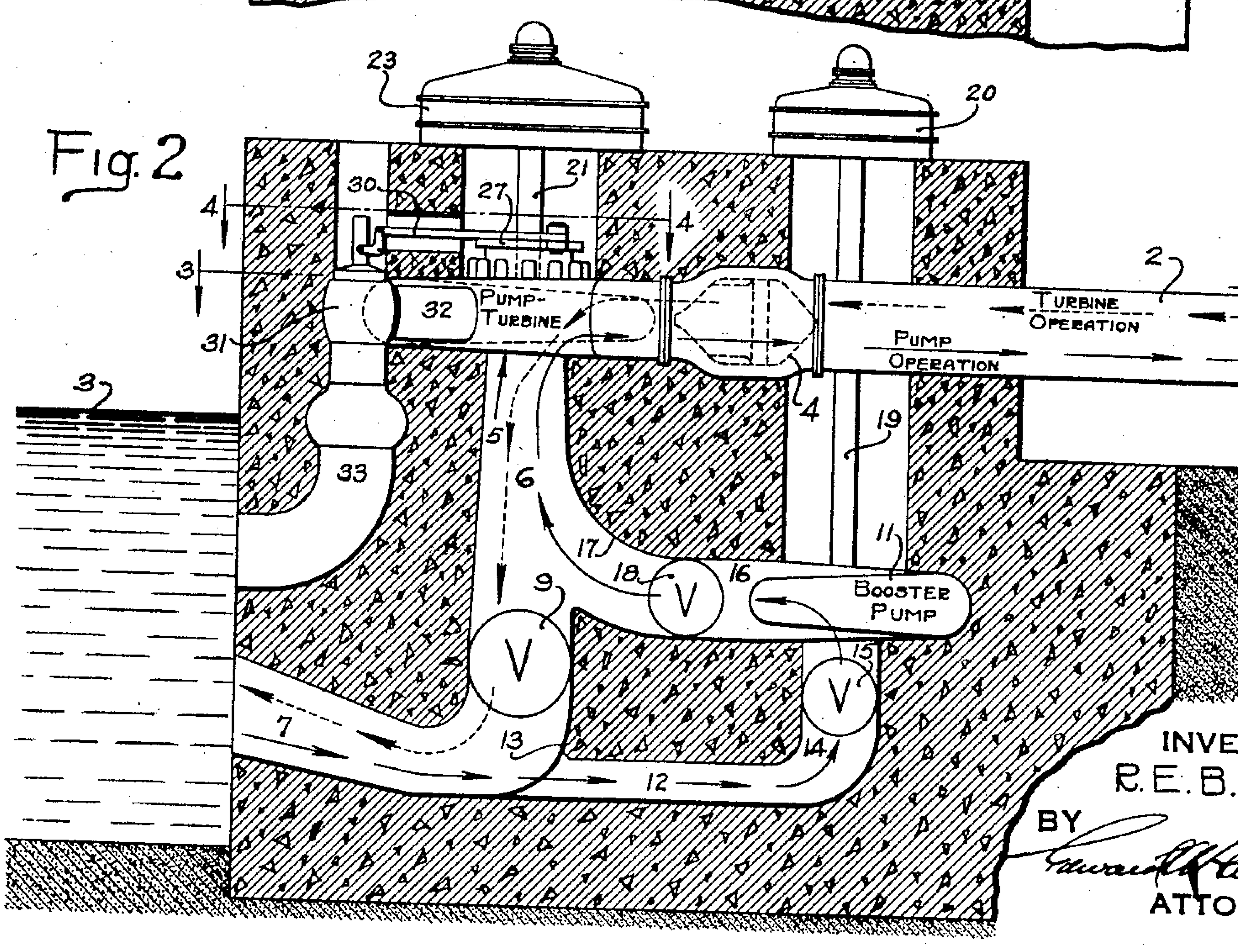


Fig. 2



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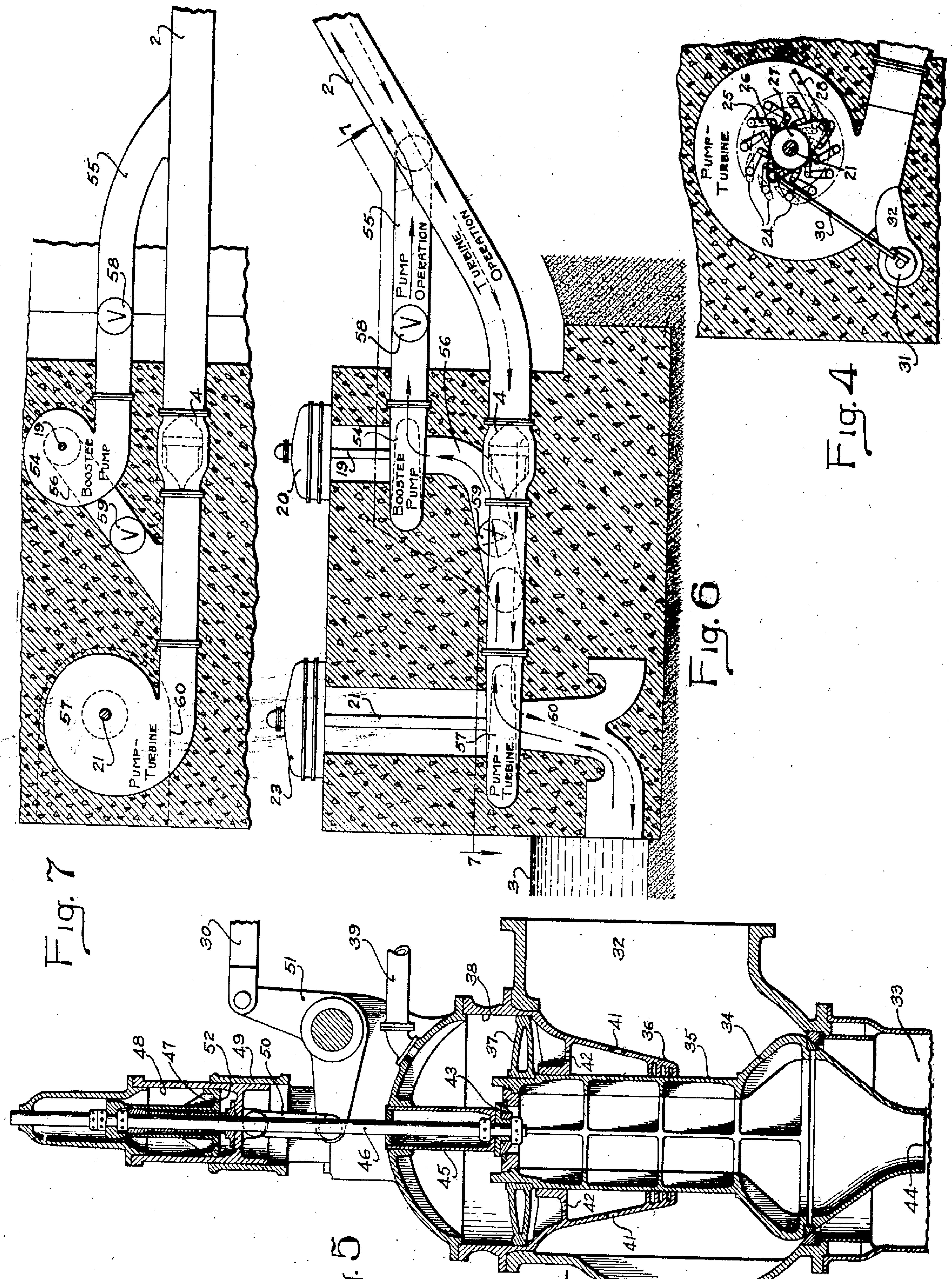

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HYDRAULIC POWER-ACCUMULATION SYSTEM

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7 Claims. (Cl. 290—52)

This invention relates generally to hydraulic power-accumulation systems of the type employing a pump-turbine unit and relates more particularly to an improved system whereby the pump-turbine unit may operate efficiently at the same speed for either pump or turbine operation.

During off peak periods of load demand in an electrical generating system, the available excess capacity of the system is utilized to pump water into a storage pond or reservoir, whereas during peak load periods on the generating system the water previously stored up is used to generate current and supply the same to the system. Various arrangements have heretofore been proposed for permitting a single machine to function either as a pump during the storing-up operation or as a turbine during the generating operation, but the principal difficulty with these prior arrangements is the necessity of operating the machine at different speeds for pump and for turbine operation if best efficiency is to be obtained for each operation. When a machine operates at different speeds for pump and turbine operations, the motor-generator unit connected to the pump-turbine is of costly construction to permit operation at two different speeds.

It is an object of my invention to provide an improved hydraulic power-accumulation system and apparatus that will permit the pump-turbine unit to operate efficiently at the same speed for either pump or turbine operation and thereby allow the motor-generator electrical equipment to be adapted for a single operating speed. This will insure the lowest possible initial cost for such equipment.

A further object is to provide an improved system and apparatus whereby the pump-turbine unit operates under a substantially similar head when pumping and when operating as a turbine regardless of the fact that for a given installation the total head for the pumping operation is generally greater than the total head for turbine operation. This difference in head is partly accounted for by the head created by penstock friction being added to the static head during pumping operation, whereas during turbine operation the penstock friction tends to retard the flow of water to the turbine and thereby reduce the effective head on the unit.

In the specific aspects of my improved system I employ what I herein term a booster pump arranged in such a manner as to be connected in series with the pump-turbine unit during pumping operation and to be rendered inoperative when the pump-turbine unit operates as a turbine. The booster pump is so functionally arranged as to carry a portion of the total pumping head and thereby permit the pump-turbine unit to operate under only so much pumping head as to permit the same operating speed as when generating, or in other words, when acting as a turbine. The novel arrangement and relation of the booster pump to the pump-turbine unit insures the foregoing advantages and many others as will be seen more fully by those skilled in the art from the following description of the accompanying drawings in which:

Fig. 1 is a diagrammatic sectional elevation of a hydraulic power-accumulating system embodying the features of my invention;

Fig. 2 is an enlarged sectional view of the pump and pump-turbine equipment and arrangement thereof;

Fig. 3 is a sectional plan view taken substantially on the line **3—3** of Fig. 2 with parts of the pump-turbine removed in order to show clearly the flow passage arrangement;

Fig. 4 is a plan view of the pump-turbine taken substantially on the line **4—4** of Fig. 2 showing the operating relation between the relief valve and the guide vane control of the pump-turbine unit;

Fig. 5 is an enlarged sectional view of a relief valve suitable for use in my improved system;

Fig. 6 is a sectional view similar to Fig. 2 but showing a modified arrangement of the booster pump, pump-turbine and passage arrangement therefor; and

Fig. 7 is a sectional plan view taken substantially on the line **7—7** of Fig. 6, parts being omitted to show clearly the passage arrangement.

In the particular embodiments of the invention, such as are disclosed herein merely for the purpose of illustrating certain specific forms among possible others that the invention might take in practice, I have diagrammatically shown in Fig. 1 a reservoir or pond for storage of head water **1** which is connected, by a conduit including a penstock **2**, to the pumping and generating equipment generally indicated at H. The tail water level is indicated at **3**.

As shown in Fig. 2 the penstock **2** has a stop valve **4**, preferably of the so-called Larner-Johnson type shown in Larner Patent 1,629,957, which is adjacent to a spiral casing of a suitable rotatable pump-turbine generally indicated at **5**.

The pump-turbine can be of any suitable type, capacity or specific speed. While the structure thereof per se does not constitute a part of my present invention, yet for purposes of defining the component elements of the broad combination, it will be considered that the pump-turbine embodies the structure of any suitable unit certain examples of which are shown in Moody Patents 1,919,376 and 2,010,555 both of which relate to pump-turbines. The pump-turbine 5 has axial communication with a draft tube comprising a vertical passage 6 and a horizontal outlet passage 7, each preferably gradually enlarging in downward and outward directions. This draft tube is broadly of the elbow type and completes the lower end of the conduit which broadly connects the head water with the tail water. A stop valve 9 of any suitable form or construction is disposed in the lower portion of the draft tube for purposes to be described.

A booster pump 11 is disposed to one side of the pump-turbine and preferably below the tail water level 3 thereby insuring that the pump will be primed at all times. The inlet passage to the pump has a horizontal portion 12 connected to the draft tube at the lower outermost portion 13 of the elbow, this passage being relatively wide and shallow so as to insure minimum disturbance to the downward fluid flow in the draft tube during turbine operation. The vertical portion 14 of the pump inlet passage enters the central portion of the pump casing 11 in a manner that is usual and well-known for pumps of various forms whether of the centrifugal or axial flow type. Certain forms of said pumps which might be considered as incorporated herein are shown in Moody Patents 1,321,538 or 1,322,810. A suitable stop valve diagrammatically indicated at 15 is disposed in the vertical portion of the passage.

The booster pump has a spiral casing whose outlet connects with a discharge pipe 16 which preferably curves upwardly as at 17 to join the draft tube 6 in such a manner as to insure relatively smooth flow lines. A stop valve diagrammatically indicated at 18 is disposed within the pump discharge passage 16.

The booster pump has a rotor shaft 19 extending upwardly through a suitable pit to an electric motor 20. The pump-turbine unit also has a rotor shaft 21 extending upwardly through a pit for connection to a motor-generator unit 23, this unit being adapted either for uni-directional rotation or reversible rotation, depending upon whether the pump turbine is of the type requiring uni-directional rotation for both pump and turbine operations or has reversible rotation for these operations.

To control flow of water to or from the pump-turbine, usual pivotal guide vanes diagrammatically indicated at 24, Fig. 4, may be employed. As is well-known the guide vanes normally vary the volume of water flowing to or from the pump-turbine or the vanes may be completely closed against each other to shut off flow through the unit. The guide vanes are adjusted through suitable guide vane arms 25 and links 26 connected to a suitable shifting ring diagrammatically indicated at 27. This ring is arranged concentrically to rotor shaft 21 and is oscillated by a suitable servo-motor (not shown) whose piston rod 28 is pivotally connected to a suitable arm or lug on the shifting ring. The foregoing guide vane and operating mechanism therefor is well known in the art and hence further detailed disclosure thereof is not necessary. This mechanism however broadly constitutes one element of a more specific aspect of my improved system.

The shifting ring 27 is connected by a rod 30 to a relief valve generally indicated at 31 which communicates with the pump-turbine casing or with the penstock by a pipe 32 and discharges into a free discharge outlet 33 whose lower end turns into the tail water 3. To control discharge through the relief valve it is provided with a needle valve 34 which has an elongated stem 35 guided in a suitable bearing structure 36. A piston 37, secured to the upper end of stem 35, is disposed in a cylinder 38 whose upper end is continuously supplied with fluid through a pipe 39 from any suitable source such as from penstock 2 at a point thereof above penstock valve 4 or from pump-turbine casing. The under side of piston 37 is continuously supplied with fluid from pipe 32 through ports 41 and 42. The fluid supplied to the upper side of piston 37 can be relieved by a pilot valve 43 so as to discharge the fluid successively through hollow stem 35 and an orifice 44 formed in needle valve 34. Pilot valve 43, having a stem 45 extending through and guided by the upper cylinder head, is connected by a rod 46 to a dash pot piston 47. This piston is disposed within a floating cylinder 48 guided by a stationary bracket 49. The floating cylinder is also connected by a link 50 to a bell crank 51 to which the shifting ring rod 30 is connected. The foregoing relief valve is of a well-known form and does not per se constitute part of my present invention, except that it comprises broadly one element of my improved combination. When guide vanes 24, Fig. 4, are closed relatively rapidly by movement of distributing ring 27 in a clockwise direction the rod 30 moves to the right thereby moving floating cylinder 48 upwardly through bell crank 51 and link 50, Fig. 5, so as to cause trapped liquid beneath piston 47 to move the latter upwardly together with valve rod 46 and pilot valve 43. Upon opening of pilot valve 43 fluid in the upper end of cylinder 38 discharges through free orifice 44 thereby reducing the pressure on the upper side of piston 37. The constant pressure supplied through ports 41 and 42 to the under side of said piston will accordingly move needle valve 34 upwardly and allow free discharge of fluid from the pump-turbine casing to the relief valve discharge passage 33. Due to the weight of the needle valves and associated parts acting downwardly on piston 47, the fluid trapped beneath the same will gradually escape through suitable by-pass ports 52 thereby allowing gradual reclosure of the needle valve 34 without causing excessive pressure rises in the penstock.

In the modification shown in Figs. 6 and 7 a booster pump unit 54 is located at a higher elevation than the pump-turbine unit, both units being disposed above the tail water level 3. The discharge pipe 55 of the pump is connected to penstock 2 at a point above the main penstock valve 4 while pump inlet passage 56 connects into the penstock at a point between the penstock valve 4 and a pump-turbine unit 57. The booster pump 54 and the pump-turbine unit 57 are to be considered as the same as the pump and pump-turbine units of the preferred form. Stop valves 58 and 59 are also disposed in the passages 55 and 56 of the booster pump. Inasmuch as the booster pump 54 of this modification is placed in series with the pump-turbine unit at a point above the same, it is seen that the draft tube 60 for the pump-turbine unit may be of the symmetrical type such as shown in Moody Patent 1,713,775. It will, of course, be understood that the pump motor and the motor-generator are the same as in the preferred arrangement and that the pump-turbine unit may be equipped with adjustable pivotal guide vanes together with a connection to a relief valve in the same manner as shown in the preferred form. However, for purposes of simplicity and clarity these elements are not repeated in this modification.

Operation.—The pumping operation of the preferred form shown in Figs. 1 to 5 requires closure of valve **9** and opening of valves **15** and **18** thereby placing booster pump **11** in series with the pump-turbine unit **5**. The guide vanes **24** are opened and the relief needle valve **34** is closed while the penstock valve **4** is also open. The booster pump and pump-turbine unit are now in series so that upon operations of motors **20** and **23**, fluid is drawn from passages **7** and **12** to booster pump **11** and thence discharged through passages **16** and **6** to the pump-turbine unit from which the fluid is further pumped through penstock **2** to the head water **1**. Conversely, during a power generating operation, the valves **4** and **9** are opened and valves **18** and **15** are closed thereby eliminating booster pump **11**. Water then flows from ahe head water **1** through penstock **2** to the pump-turbine unit which discharges through draft tube **6** and **7** to tail water **3**.

The foregoing arrangement has many distinctive and unique functional advantages and cooperative effects from a hydraulic standpoint. One very important advantage is that the booster pump may be arranged to reduce the head on the pump-turbine unit when operating as a pump so that the pump-turbine is permitted to run at the same speed for both pump and for turbine operation with good efficiency for both conditions. This arrangement, therefore, obviates loss in efficiency during either pumping or turbine operation, one of which cannot be avoided if the pump-turbine unit is used alone without my improved series booster pump arrangement. Heretofore it has been necessary, (*a*) to suffer reduced efficiency under either turbine or pumping operation, or (*b*) to provide a two speed motor-generator unit involving special design and large cost due to the two speed requirement. Even with the two speed motor-generator, it may not be possible to obtain the best possible efficiency under both turbine and pump operation, as it is necessary to design the two speed motor-generator not for any desired difference in speeds that may be required to give best efficiency under both turbine and pump operation, but at certain fixed differences in speed which correspond with the proper number of pole pieces at the two speeds to result in the proper number of alterations per second (usually 60 or 25 cycles) to suit the system frequency into which the energy when operating as a turbine is supplied and from which the energy is obtained when operating as a pump. On the other hand, with my arrangement, by proper selection of the head to be taken by the booster pump it is possible to have the ratio of the head to be pumped against by the pump-turbine to that utilized when acting as a turbine such that the best efficiency possible can be secured under both conditions of operation.

It is, of couse, well known that cavitation may be a very serious matter in pump and turbine operations. In my improved arrangement the booster pump is below tail water level, thus insuring self-priming of the pump at all times and also making it possible to have ample margin against cavitation (this margin varying with the depth of the pump below tail water), and at the same time, it is possible to place the pump-turbine above tail water without danger of cavitation. This is due to the fact that the booster provides pressure to the suction of the pump turbine, thus in effect, increasing the pressure in this passage and thereby increasing correspondingly the margin against cavitation.

The relief valve, Fig. 5, has an important function both when the pump-turbine is acting as a turbine and when it is pumping. When the pump-turbine is acting as a turbine, or in other words, when power is being generated, the relief valve prevents excessive pressure rise in the pump casing and in the penstock upon the rejection of load following which the turbine governor closes the turbine gates and at the same time opens the plunger **34** of the relief valve. This prevents the sudden stoppoge of flow in the penstock. The construction of the relief valve previously described results in the plunger gradually closing at a permissible and controlled rate after its initial opening.

When pumping, the relief valve functions as a surge suppressor. Under these circumstances, the adjustable gates of the pump-turbine close upon failure of current supplied to the motors, by any usual or well-known governor equipment such as shown in Kerr Patent 1,901,831. The stoppage of the pumping operation results in the mass of water in the penstock continuing for a limited length of time, dependent on the inertia of this mass, in the original or upward direction in the penstock, following which this water tends to return by gravity to the pump turbine. Unless a temporary relief is provided, the returning column of water causes an excessive pressure surge due to water hammer. However, the relief valve is opened by the closing of the adjustable gates of the pump-turbine as above described and a portion or all of this returning water is permitted to flow through the relief valve, thus preventing or minimizing the effects of the pressure surge. The relief valve after opening is permitted to close slowly by the action of the dash pot hereinbefore described in connection with the relief valve shown in Fig. 5. Hence the relief valve is peculiarly adapted to perform the dual functions of a relief valve and of a surge suppressor which functions in turn are especially alternatively related to the pump and turbine operations of my system.

The adjustable gates of the turbine in closing upon the failure of current during the pumping operation prevent the returning mass of water from going through the pump-turbine runner or impeller and also through the impeller of the booster pump, thus avoiding injurious results due to excessive reverse rotation.

In the modification shown in Figs. 6 and 7 the booster pump **54** is located above the pump-turbine thereby necessitating closure of the penstock valve **4** and opening of valves **58** and **59** in order to place the pump-turbine and booster pump in series during the pumping operation. During turbine operation penstock valve **4** is opened and valves **58** and **59** closed thereby removing the pump from operation. This arrangement has the same cooperative functional advantages from a hydraulic standpoint as the preferred form in that the head is reduced on the pump-turbine during pumping operation thereby allowing the pump-turbine to operate at the same speed as when acting as a turbine.

It will of course be understood that various changes in details of construction and arrangement of parts may be made by those skilled in the art without departing from the spirit of the invention as set forth in the appended claims.

I claim:

1. A hydraulic power-accumulation system comprising, in combination, means providing sources of head water and tail water connected together by a conduit, a pump-turbine unit communicating with said conduit and which when functioning as a turbine operates at best turbine efficiency at a predetermined speed under a given head and which when functioning as a pump operates at its best pumping efficiency at said predetermined speed but against a lower head such as is necessary to give best pumping efficiency, an electric machine permanently connected to said pump-turbine unit to function as a motor to drive the same or to function as a generator to be driven thereby in accordance with pump or turbine operation respectively, and a separate booster pump having a motor permanently connected thereto for driving the same independently of the speed of the pump-turbine unit but the booster pump being adapted during a pumping operation to operate in series with said pump-turbine unit for overcoming the remaining portion of the total head pumped against.

2. The combination set forth in claim 1 further characterized in that the conduit includes a draft tube leading from the pump-turbine to the tail water, and the booster pump is provided with a discharge passage which communicates laterally with said draft tube and an inlet communicating with the tail water, and means for preventing direct communication of said draft tube with the tail water when said booster pump is operating in series with said pump-turbine unit.

3. The combination set forth in claim 1 further characterized in that said conduit includes a draft tube leading from the pump-turbine to the tail water, and the booster pump is provided with an inlet passage communicating laterally with said draft tube and a discharge passage also communicating with said draft tube, and means for preventing direct communication of said draft tube with the tail water when said booster pump is operating in series with said pump-turbine unit.

4. The combination set forth in claim 1 further characterized in that said conduit includes a draft tube leading from said pump-turbine to the tail water and having vertical and horizontal portions, an inlet passage for the booster pump communicating with the draft tube adjacent the horizontal portion thereof and a discharge passage for the booster pump communicating with the vertical portion of said draft tube, and means for preventing direct communication of said draft tube with the tail water when said booster pump is operating in series with said pump-turbine unit.

5. A hydraulic power-accumulation system comprising, in combination, means providing sources of head water and tail water connected together by a conduit, a pump-turbine unit communicating with said conduit, an electric machine permanently connected to said pump-turbine unit to function as a motor to drive the same or to function as a generator to be driven thereby in accordance with pump or turbine operation respectively, a separate booster pump having a motor permanently connected thereto for driving the same independently of the speed of the pump-turbine unit but the booster pump being adapted during a pumping operation to operate in series with said pump-turbine unit for overcoming the remaining portion of the total head pumped against, gate means for controlling flow of fluid through the pump-turbine unit so as to shut down the same during either pump or turbine operation, a valve adapted when opened to discharge fluid from said conduit at a point substantially at the elevation of said pump-turbine unit on the head water side thereof, and means operative during either pump or turbine operation for automatically opening said valve in response to shutting down of said pump-turbine unit whereby in turbine operation said valve is initially opened during an increase of conduit pressure above normal accompanying initial closure of the gate means whereas in pump operation said valve is initially opened during an initial decrease in conduit pressure below normal accompanying initial closure of the gate means thereby to provide a discharge outlet that is freely open prior to the return pressure surge that follows said initial pressure drop.

6. A hydraulic power-accumulation system comprising, in combination, means providing sources of head water and tail water connected together by a conduit, a pump-turbine unit communicating with said conduit, an electric machine permanently connected to said pump-turbine unit to function as a motor to drive the same or to function as a generator to be driven thereby in accordance with pump or turbine operation respectively, a separate booster pump having a motor permanently connected thereto for driving the same independently of the speed of the pump-turbine unit but the booster pump being adapted during a pumping operation to operate in series with said pump-turbine unit for overcoming the remaining portion of the total head pumped against, adjustable gate mechanism for the pump-turbine unit, a valve communicating with said conduit for discharging fluid therefrom when open, and means controlled by the operation of said adjustable gate mechanism upon closing movement thereof to open said valve during either pump or turbine operation of said pump-turbine unit, whereby said valve mechanism is operative upon closure of said gate mechanism to prevent pressure rises during turbine operation and is operative upon closure of said gate mechanism to allow free discharge of a return pressure surge in the conduit during pumping operation.

7. A hydraulic power-accumulation system comprising, in combination, means providing sources of head water and tail water connected together by a conduit, a pump-turbine communicating with said conduit at an elevation above the tail water level, and a booster pump disposed at an elevation below the tail water level and having series communication with the pump-turbine so as to reduce the head thereon during a pumping operation below the net head between said head water and tail water but to allow said net head to be fully effective on the pump-turbine during a turbine operation.

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