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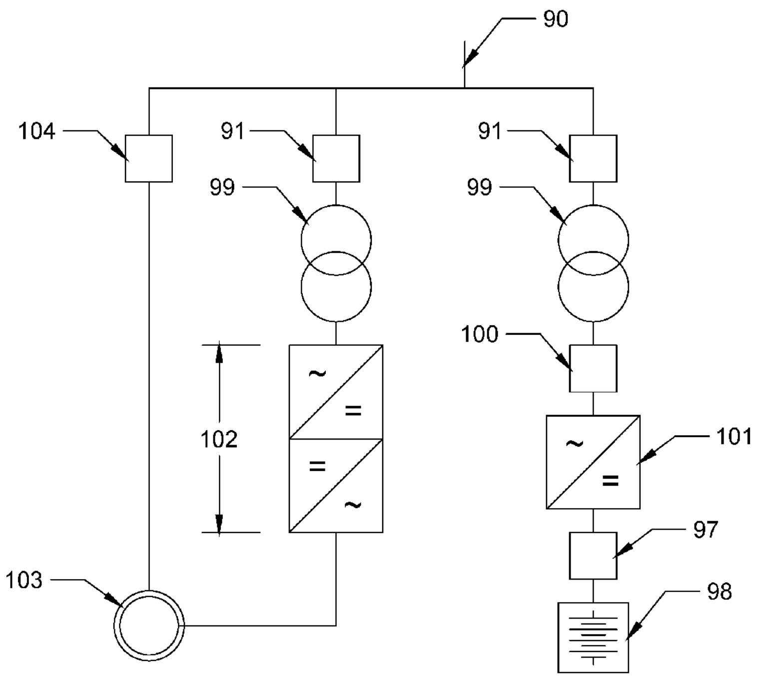

Fig. 36

(57) Abstract: The present invention is a reversible pump-turbine installation position in a vertical shaft instead of in a conventional underground powerhouse or deep concrete powerhouse. The required plant cavitation coefficient may be achieved by simply boring a vertical shaft to the required depth rather than routing the water flow to and from a deeply buried powerhouse. A pneumatically controlled pressure relief valve may be incorporated into this invention.

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IMPROVED REVERSIBLE PUMP-TURBINE INSTALLATION

PCT Patent Application of Henry K Obermeyer

FIELD OF THE INVENTION

The present invention relates to reversible pump-turbines used for storage of electrical energy. Conventional pumped storage facilities as shown in Figure 1 b generally use an underground powerhouse to provide sufficient absolute pressure at the runner to prevent destructive cavitation. The elevation of the runner may be 100 meters below tailwater, for example. Constructing and maintaining such an underground facility is expensive and the expense does not decrease in proportion to size in the case of smaller facilities. There are therefore very few pumped storage facilities of less than 100 MW in North America. A typical conventional pump-turbine sectional elevation is shown in Figure 1 b. The prior art pump-turbine flow path with a 90 degree turn in the meridional plane is illustrated in Figure 1c, this being similar to the flow path in the meridional plane of a conventional Francis turbine. The present invention relates to single purpose turbines and pumps as well as to reversible pump-turbines. With respect to prior art multi-stage pumps, the relationship between the impeller and diffuser in the meridional plane is shown in Figure 2, where the acceleration imparted by the runner (impeller) to the fluid is outward and downward, this results in an unnecessarily small runner tip diameter compared to the maximum water passageway diameter that in this case occurs in the diffuser. This unnecessarily small diameter results in limited head differential across each stage and in turn results in more stages and lower overall efficiency.

SUMMARY OF THE INVENTION

The present invention establishes the required plant cavitation coefficient by positioning reversible pump-turbines with motor-generators, generally well below tailwater level in a generally vertical bore hole. Reversible pump-turbines with motor-generators will be referred to herein simply as "pump-turbines" or as "machines" The term "bore hole",ather than "shaft", is used herein to avoid confusion with the rotating shaft of the pump-turbine located therein.

Conventional pumped storage facilities position the runner well below tailwater elevation to suppress cavitation while keeping unit power and specific speed high. The critical cavitation coefficient for reversible pump-turbines is higher than it is for either turbines or pumps because the hydraulic profiles are a compromise between pumping and generating and are optimized for neither. Positioning of the runner below tailwater has heretofore required a deep and expensive excavation regardless of machine size and rating. The expense of excavation and underground construction has been cost prohibitive for small installations, of less than 100 MW, for example. Sites suitable for large installations are limited by geology, geography, competing land uses, and adequate transmission lines. Many suitable smaller scale sites exist, but existing reversible pump-turbines, even if scaled down in size and rating, still require excavation and construction costs that are prohibitive.

The proposed configuration utilizes a simple and inexpensive bore hole of perhaps 1 to 3 meters in diameter to position a high specific output reversible pump-turbine sufficiently below tailwater elevation to suppress cavitation. Such bore holes are routinely drilled as a commodity construction service for reasonable prices. A steel liner and conduits for hoisting water, electrical and control cables, for example, may be grouted in place within the bore hole. Pump-turbines adapted to this type of installation may be configured as single stage machines or may be configured as multi-stage machines utilizing specially configured "diffuser bowls" similar in function to those used on multi-stage submersible pumps. These pump-turbines would not normally use conventional scroll cases. As such, stages of these pump-turbines may be stackable to allow standard hydraulic designs to be used over a wide range of head conditions. The use of standard pump-turbine stages is further facilitated by the fact that the required plant cavitation coefficient can be achieved by simply establishing the required vertical bore hole depth. Compared to conventional underground powerhouse pump-turbine installations, there is a less frequent need to design and manufacture site specific machinery and there is no need carry the penstock nor tailrace conduit to extraordinary depths, which would be cost prohibitive in conjunction with small pumped hydro installations at most locations. The use of standard components results in increased quantities of like parts at reduced cost. Reduced costs in turn enable a greater number of projects to be built with increased part quantities.

Water flow to and from the reversible pump-turbine may be through coaxial penstocks positioned in the shaft above the pump-turbine assembly. The associated motor-generator may be submersible and in certain preferred embodiments located below the pump-turbine(s). Locating the motor-generator below the pump turbines allows for a larger diameter, and therefore more economical, motor-generator for a given bore hole size. Allocating substantially all of the bore hole cross sectional area to water conveyance (up and down), rather than to space for the motor-generator, allows for the maximum power rating for a given diameter of bore hole.

The generator may alternatively be located outside of the water passageways and connected to the runner with a shaft. Such an arrangement may be cheaper than providing an underground powerhouse large enough to incorporate a scroll case, while allowing the use of a readily available air-cooled generator.

In a preferred embodiment, a removable manifold may be used to connect the inner pipe to tailwater and connect the outer pipe to the penstock leading to headwater. It is generally more efficient to connect the smaller diameter pump inlet/turbine outlet with the smaller of the coaxial pipes while connecting the larger pump outlet/turbine inlet with the larger of the two coaxial pipes. Alternative embodiments of this invention may utilize another arrangement as may be the case when multiple pump turbines might be installed, on a bulkhead, for example, in a common bore hole. The removable manifold may include an integral pneumatically controlled pressure relief valve. This integral pressure relief valve will itself reduce civil works costs by eliminating the need for a surge shaft and by reducing penstock surge pressure and penstock cost. Additionally, or alternatively, an air cushion may be left under the cover of the bore hole. Removal of the manifold allows removal of the machinery from the borehole. Dedicated hoisting equipment will facilitate installation, service, and maintenance without the need for confined space work. A water pressure actuated piston attached to the bottom of the eversible pump turbine may be used for raising and lowering. A spacer between the piston and the machine may be used to allow the machine to be raised entirely clear of the borehole.

Variable speed operation is facilitated by the ready availability of power control electronics developed for the wind industry. As in the case of wind turbine power converters, full power converters may be used in conjunction with permanent magnet motor generators and partial power converters may be used in conjunction with (generally larger) doubly fed induction generators.

The bore hole in which the reversible pump-turbine is installed may include provision for delivery of pressurized water to the bottom of the shaft, through a conduit separate from the main bore hole to hydraulically hoist the equipment for maintenance and repair and to controllably lower the equipment into operating position. The electrical power connection is preferably configured to automatically engage when the machine is lowered and to automatically disengage when the machine is raised. Such a connector may use conventional "wet mate" marine electrical connector technology or may be use a combination of compressed gas, insulating oil and inflatable seals, for example, to establish robust electrical connections isolated from ground potential.

The bore hole in which the equipment is located may terminate at the upper portal, the lower portal or at any convenient intermediate location. In the case of installation in conjunction with an existing pipeline, the vertical shaft may be located according to desired pressure profiles resulting from operation, load rejection, and other considerations. The shaft cover may incorporate a pressure relief valve and may be used to cap off a surge shaft containing air.

Multiple machines may be installed in a single shaft, on a common bulkhead, for example. The reversible pump turbines in accordance with the present invention may be used in conjunction with Pelton turbines, for example to facilitate generation at low power levels if required. The reversible pump turbines may be used in conjunction with off-stream seasonal storage reservoirs, where their primary purpose may be to raise water to the storage reservoir during high flow periods and to return water while recovering energy when stored water is required downstream.

In accordance with certain embodiments of this invention, gas pressure balanced pressure relief valves may be used to limit overpressure from water hammer.

An elbow with actuatable seals may be used in order to connect the draft tube to the tail race during operation. Inflatable seals may be used to seal the elbow in its operating position while allowing it to move freely during hoisting and lowering operations. Inflatable seals or supports may also be used to fix the machine into position during operation and to release it to allow it to be raised for maintenance.

In accordance with a further aspect of the invention a reversible pump turbine runner or pump impeller is provided that imparts to the flow an upward velocity component. This upward velocity component allows the flow to proceed directly up through the diffuser or a guide vane - diffuser combination in the case of a reversible pump-turbine, or directly to a diffuser (stator) stage in the case of a multi-stage pump, while maximizing the ratio of impeller tip diameter to maximum water passageway diameter. In the case of the present invention this ratio may be 1.00. This maximizes the head per stage and allows a greater head to be achieved with a single stage machine. Figures 19a, 19b, and 19c illustrate the flow in the meridional plane as well as the X - shaped appearance of the impeller blades when viewed toward the trailing edge.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic of a conventional (prior art) pumped storage facility.
Figure 1 b and 1 c are sectional elevation drawings of a conventional pump-turbine.

Figure 2 is a schematic of a pumped storage facility in accordance with the present invention.

Figure 3 is a section through the meridional plane of a multistage pump of prior art.
Figure 3a is an elevation view of the pumped storage facility of Figure 3a shown with the pump-turbine assembly partially removed.

Figures 4a and 4b are sectional elevations of a pressure relief valve configured for use with the present invention.

Figure 5a-c are sectional elevation drawings of a reversible pump-turbine in accordance with the present invention.

Figure 6 is a cutaway rendering of a reversible pump-turbine and associated pumped storage facility in accordance with the present invention.

Figure 7 is a cutaway view of an elbow connection to the tailrace tunnel with an inflatable seal to secure and seal it in accordance with the present invention.

Figure 8 is a sectional elevation drawing of a pump-turbine installation with the vertical borehole collocated with the headworks in accordance with the present invention.

Figure 9 is a sectional elevation drawing of a pump-turbine installation with the vertical borehole collocated with the tailrace portal in accordance with the present invention.

Figure 10 is a sectional elevation drawing of a pump-turbine installation with the vertical borehole located between the headworks and the tailrace portal in accordance with the present invention.

Figure 11 is a sectional elevation drawing of a pump-turbine installation with the vertical borehole located in association with an underground pressured water storage cavity that serves as the "upper" reservoir.

Figure 12 is a schematic of a pump in accordance with the present invention in association with an air/water accumulator, most likely underground, and a gas turbine.

Figure 13 is a schematic of a pump in accordance with the present invention in association with an air/water accumulator, most likely underground, and a gas turbine, wherein the air may be nearly isothermally compressed with the aid of water spray cooling.

Figure 14 illustrates a tailrace connection elbow in accordance with the present invention that incorporates an inflatable seal that also serves as an adjustable pressure relief element. The inflatable seal (63) features a flow separation control fin 51 to reduce vibration during operation.

Figure 15 illustrates a pumped storage installation in accordance with the present invention including a a tailrace connection elbow.

Figure 16 illustrates a pumped storage installation in accordance with the present invention including a tailrace connection elbow and a penstock entering the borehole at an elevation higher than the tailrace tunnel.

Figure 17 illustrates a pumped storage installation in accordance with the present invention including a tailrace connection elbow.

Figure 18 illustrates a pumped storage installation in accordance with the present invention including a tailrace connection elbow.

Figures 19a and 19b are meridional plane sections of a multistage pump impeller in accordance with the present invention.

Figure 19c is and end on view looking into the discharge edge of the impeller of Figure 19b.

Figure 20 is a plan view schematic of 3 pump turbines installed in association with a single penstock and a single tailrace tunnel.

Figure 22a is a pump turbine installation including a pressure relief valve.

Figure 22b is a schematic of a torque key positioned at the bottom of a bore hole for the purpose of preventing unintended rotation of the pump-turbine.

Figure 23 is a pressure relief valve in accordance with the present invention.

Figure 24a and 24b is a pressure relief valve in accordance with the present invention shown closed and open respectively.

Figure 25a and 25b is a pressure relief valve in accordance with the present invention shown closed and open, respectively.

Figures 26a and 26b show a pressure relief valve in accordance with the present invention shown closed and open respectively.

Figures 27a and 27b show an installation of multiple pump-turbine/motor generators in a single bore hole.

Figure 28 shows schematically one version of the pump turbine of the present invention.

Figure 29 shows another version of the pump turbine of the present invention.

Figure 30 shows another version of the pump turbine of the present invention incorporating a cylinder gate rather than wicket gates.

Figures 31-37 show various installation alternatives.

Figures 38-43 show various embodiments of a reversible pump turbine

Figures 44a-b show a flow inverter section.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to Figure 1a, 1b, and 1c, a conventional pumped storage plant with a reversible pump-turbine is shown. There are several notably expensive features in such a conventional installation. These include;

1) A surge shaft that is typically needed to relieve waterhammer that can result from a load rejection.

2) An underground powerhouse below tailwater level. Such a powerhouse is expensive to construct and is at risk of flooding due to human error or component failure. Flooding of an underground powerhouse is a hazard to the facility itself as well as to its operators.

3) The penstock and tailrace conduit must be routed, at great expense to the same low elevation as the powerhouse itself.

Referring to Figures3a and Figure 3b, a reversible pump-turbine installation in accordance with the present invention is shown. No underground powerhouse is required. Instead, a vertical borehole or shaft 4 allows the pump-turbine and motor-generator assembly 1 to be installed, removed for maintenance as needed, and reinstalled, while providing the desired low height-of-setting of thee unit below tailwater. The height of setting must be sufficiently low that the plant cavitation coefficient (plant sigma) is greater than the critical cavitation coefficient (critical sigma), the cavitation coefficient being defined as the ratio of absolute pressure at the low-pressure side of the runner divided by the vapor pressure of water at the temperature of the water. Shaft 16 connects submersible motor-generator 8 to pump-turbine stages 9, 10, 11, and 12. Vertical tailwater conduit 5 connects to diffuser 14 above the point of entry of penstock 2. Pressure relief valve 7 is preferably mounted to removable manifold 6. Removable manifold 6 bolts down to foundation 13 and connects to tailrace conduit 3 at flange 15a. Tailrace conduit 3 leads to the lower reservoir not shown. It should be noted that the number of stages may be adjusted according to head, height of setting, speed, installation rating and other factors. Penstock 2 connects to upper reservoir 70. Tailrace conduit 3 connects to the lower reservoir 71. Water flows through outer annulus 17 of borehole 4 toward the upper reservoir 70 as a pump and towards the pump turbine 43.

It should be noted that the removable portion may be further divided into conveniently separable subassemblies 6, 7, 14 and 5. For example, the manifold 6 might be lifted off first, the vertical portion of the tailrace conduit 5 might be lifted next, and the pump-turbine stages 9, 10, 11, and 12 might be lifted last along with the motor-generator 8. In the case of a motor generator on top, the stator might be left in place while the rotor, shaft, and balance of the assembly might be lifted out last.

Referring to Figures 4a and 4b, a cross section of a pressure relief valve suitable of use in conjunction with the present invention is shown in its opened and closed positions respectively. Diffuser 14 is connected to ribs 25. Ribs 25, ring 23, and ring 24 together radially support bladder 18 on its inner diameter surface when its inflation pressure is greater than the pressure in shaft 17. Inflatable bladder 18 is supported from below by flange 26 and on its OD by enclosure 7. The air pressure in bladder 18 may be precisely adjusted to just stop leakage from shaft 17 into manifold 6 (at tailwater pressure).

Referring to Figures 5a and 5b a sectional elevation of a pump-turbine in accordance with the present invention is shown. Runner 27 is designed around a toroidal flow path wherein water reverses direction by approximately 180 degrees in the meridional plane. Wicket gates 28 make up an axial flow distributor. Turbine diffuser 29 recovers turbine runner exit energy. Stay vanes 30 provide mechanical support to the distributor hub 31, turbine diffuser 29 as well as wicket gate servo system 32. Generator 33 is preferably located below the turbine. Hoisting piston 34 may be used to raise and lower, using water pressure, the entire pump-turbine assembly with connected draft tube segments, pressure relief valve and elbow. Hoisting piston 34 may incorporate upper seal ring 35 and lower seal ring 36 to maintain a seal while passing across the tailrace connection.

Hollow shaft 72 may be used as a heat pipe evaporator in conjunction with the runner 27 serving as a condenser. Electrical connector 73 engages electrical receptacle assembly 74 when the machine is lowered. Shifting rings 75 and 76 provide torque to actuate wicket gates 28.

Borehole 4 is associated with rock face 77, grout 78 and steel liner 79.

Shaft seal assembly 80 keeps the generator enclosure dry.

Referring to Figure 6, Piston assembly 34 supports generator 33 and pump-turbine 37 during raising and lowering. Valve 38 may be used to shut off water from penstock 39. Tailrace conduit 40 connects to tailwater. Cover assembly 41 is removable.

Referring to Figure 6, valve 42 may be used to fill vertical shaft 4 during hydraulic raising and lowering of pump-turbine-motor-generator assembly 43 with attached pipe, elbow, and pressure relief assemblies 44, Lower portal 45 serves to launch TBM during construction phase and serves as pumping inlet works. Headworks 47 serves as upper portal during construction and as service platform during maintenance. Crane 48 may be used to disassemble draft tube segments, elbow assembly and pressure relief valve from pump-turbine for maintenance.

Referring to Figure 7 an elbow assembly 49 is shown. Inflatable seal 50 seals the upper end. Inflatable seal 51 closes the lower end. Elbow 52 directs flow to the tailrace conduit. Spool 53 travels with the pump-turbine during maintenance moves.

Referring to Figure 8 an installation is shown wherein the machine shaft 54 is located under the headworks 55.

Referring to Figure 9, the machine shaft 54 is located below the tailrace portal 56.

Referring to Figure 10, machine shaft 54 is located at a location between the headworks 55 and tailrace portal 56.

Referring to Figure 11, Machine shaft 54 provides a connection to pressurized reservoir 58 as well as to tailrace tunnel 59.

Referring to Figure 12 a pressurized water reservoir 58 is shown in conjunction with a pressurized air column 59. Pump or pump/turbine 60 may be in accordance with this invention or may be conventional. Air 59 may be fed to a gas turbine generator set 61.

Referring to Figure 13, spray cooling of the air being compressed may be used to provide isothermal air compression.

Figures 6, 7, 16, and 17 depict one of many possible construction sequences.

Referring to Figure 17, another embodiment is shown wherein inflatable seal 63 may also serve as a pressure relief valve.

Referring to Figure 18, a combined seal and PRV 63 positioned in machine shaft 54 is shown in conjunction with elbow 52 and tailrace conduit 40. Machine shaft liner 64 is shown.

Referring to Figure 17, another embodiment is shown wherein inflatable seal 63 may also serve as a pressure relief valve.

Referring to Figure 18 another embodiment is shown with vanes 65 in elbow 52.

Referring to Figures 19a and 19b a runner for a pump or reversible pump turbine is shown wherein flow is directed along a smooth sinusoidal path within the meridional plane. Blades (vanes) impart circumferential acceleration vector and acceleration vectors within meridional plan to guide water through water passageway. Blade sequences may be normal to vector sum. The larger impellar is more efficient and provides higher head per stage. lmpellars may be best made by 3D printing.

Referring to Figures 21-23, various pressure relief valve configurations are shown.

Referring to Figure 24 splitter vanes are used.

Referring to Figure 27, multiple pump turbines are shown sharing a common penstock 2 and tailrace conduit 3.

Referring to Figures 27A and 27b, multiple submersible pump-turbines 62a-62f, installed together in the same machine shaft 54 are shown.

Figures 28 through 30 show pump-turbines configured for installation on a bulkhead in a common machine shaft.

Referring to Figure 31, a medium/high voltage permanent-magnet motor/generator 95 and battery storage array 98 are connected to a utility grid 90 via a single cascade multilevel power converter. The power converter comprises a phase-shifting input transformer 92, power cells incorporating a regenerative-capable front-end 93, isolated DC buses 95, and load-side inverters 94. Each power cell DC bus is connected to a battery bank 98 via a disconnect switch 97.
The individual DC bus 96 voltages are actively managed during operation to charge or discharge the battery banks 98 independently of power consumption or generation by the motor/generator 95.

Referring to Figure 32, a low-voltage permanent-magnet motor/generator 95 and battery storage array 98 are connected to a utility grid 90 via a single two-level power converter. The power converter comprises an active front-end with line-side reactor 93, an intermediate DC bus 96, and a motor-side two-level inverter 94. The power converter is connected to the grid through a disconnect 100 and step-up transformer 99. The power converter DC bus 96 is attached to a battery array 98 through a disconnect switch 97. The DC bus 96 voltage is actively managed during operation to charge or discharge the battery array 98 independently of power consumption or generation by the motor/generator 95.

Referring to Figure 33, a permanent-magnet motor/generator 95 and battery storage array 98 are connected to a utility grid 90 using parallel and independent power converters. The converters may be connected using individual disconnects 91 incorporating protective functions. The motor/generator 95 is connected using a regenerative AC/AC power converter 102. The battery array 98 is connected through DC bus disconnect(s) 97 to a grid-tie inverter 101. A step-up transformer 99 increases inverter 101 output to grid voltage. Optionally, a disconnect 100 is placed between transformer 99 and the battery inverter 101.

Referring to Figure 34, a medium/high voltage doubly-fed induction machine 103 and battery storage array 98 are connected to a utility grid 90. The rotor windings of the electric machine are connected to a cascade multi-level AC/AC drive with connected battery storage as described in FIG 31. The stator windings of the electric machine are connected to the grid through a disconnect 104.

Referring to Figure 35, a medium/high voltage doubly-fed induction machine 103 and battery storage array 98 are connected to a utility grid 90. The rotor windings of the electric machine are connected to a low-voltage two-level AC/AC drive with connected battery storage as described in FIG 32. The stator windings of the electric machine are connected to the grid through a disconnect 104.

Referring to Figure 36, a medium/high voltage doubly-fed induction machine 103 and battery storage array 98 are connected to a utility grid 90. The rotor windings of the electric machine are connected to regenerative AC/AC drive 102. The stator windings of the electric machine are connected to the grid through a disconnect 104. The battery storage array is connected to a separate and independent DC/AC inverter 101 as described in FIG 33.

Referring to Figure 37, multiple medium/high voltage permanent-magnet motor/generators 95 are connected to a utility grid 90 in an arrangement that allows either direct synchronous connection using direct on-line contactors 105 in conjunction with forward/reverse selecting contactors 106/107, which are interlocked to prevent simultaneous closure. Regenerative power converters 102 can be used to bring the electric machines up to synchronous speed in either the pumping or generating mode, or to operate at variable other-than-synchronous speeds. Phase-shift input transformers 92 connect the active front-end of the converters 102 to the grid via disconnects 91. A matrix of disconnects 108 allows any of the electric machines to be operated or started using any of the power converters.

As can be easily understood from the foregoing, the basic concepts of the present invention may be embodied in a variety of ways. It involves both water control and actuator techniques as well as devices to accomplish the appropriate water control or actuation. In this application, the water control techniques are disclosed as part of the results shown to be achieved by the various devices described and as steps which are inherent to utilization. They are simply the natural result of utilizing the devices as intended and described. In addition, while some devices are disclosed, it should be understood that these not only accomplish certain methods but also can be varied in a number of ways. Importantly, as to all of the foregoing, all of these facets should be understood to be encompassed by this disclosure.

The discussion included in this application is intended to serve as a basic description. The reader should be aware that the specific discussion may not explicitly describe all embodiments possible; many alternatives are implicit. It also may not fully explain the generic nature of the invention and may not explicitly show how each feature or element can actually be representative of a broader function or of a great variety of alternative or equivalent elements. Again, these are implicitly included in this disclosure. Where the invention is described in device-oriented terminology, each element of the device implicitly performs a function. Apparatus claims may not only be included for the device described, but also method or process claims may be included to address the functions the invention and each element performs. Neither the description nor the terminology is intended to limit the scope of the claims included in this patent application.

It should also be understood that a variety of changes may be made without departing from the essence of the invention. Such changes are also implicitly included in the description. They still fall within the scope of this invention. A broad disclosure encompassing both the explicit embodiment(s) shown, the great variety of implicit alternative embodiments, and the broad methods or processes and the like are encompassed by this disclosure and may be relied upon for the claims for this patent application. It should be understood that such language changes and broad claiming is accomplished in this filing. This patent application will seek examination of as broad a base of claims as deemed within the applicant's right and will be designed to yield a patent covering numerous aspects of the invention both independently and as an overall system.

Further, each of the various elements of the invention and claims may also be achieved in a variety of manners. This disclosure should be understood to encompass each such variation, be it a variation of an embodiment of any apparatus embodiment, a method or process embodiment, or even merely a variation of any element of these. Particularly, it should be understood that as the disclosure relates to elements of the invention, the words for each element may be expressed by equivalent apparatus terms or method terms--even if only the function or result is the same. Such equivalent, broader, or even more generic terms should be considered to be encompassed in the description of each element or action. Such terms can be substituted where desired to make explicit the implicitly broad coverage to which this invention is entitled. As but one example, it should be understood that all actions may be expressed as a means for taking that action or as an element which causes that action. Similarly, each physical element disclosed should be understood to encompass a disclosure of the action which that physical element facilitates. Regarding this last aspect, as but one example, the disclosure of a "means for actuating" or an "actuator" should be understood to encompass disclosure of the act of "actuating"--whether explicitly discussed or not--and, conversely, were there effectively disclosure of the act of "actuating", such a disclosure should be understood to encompass disclosure of an "actuator" and even a "means for actuating". Such changes and alternative terms are to be understood to be explicitly included in the description.

Any acts of law, statutes, regulations, or rules mentioned in this application for patent; or patents, publications, or other references mentioned in this application for patent are hereby incorporated by reference. In addition, as to each term used it should be understood that unless its utilization in this application is inconsistent with such interpretation, common dictionary definitions should be understood as incorporated for each term and all definitions, alternative terms, and synonyms such as contained in the Random House Webster's Unabridged Dictionary, second edition are hereby incorporated by reference. Finally, all references listed in the list of References To Be Incorporated By Reference In Accordance With The Patent Application or other information statement filed with the application are hereby appended and hereby incorporated by reference, however, as to each of the above, to the extent that such information or statements incorporated by reference might be considered inconsistent with the patenting of this/these invention(s) such statements are expressly not to be considered as made by the applicant(s).

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Claims:

What is claimed is:

1. A pumped storage system having an upper water storage basin, a lower water storage basin, a reversible pump-turbine connected to said upper water storage basin by a penstock conduit and also connected to said lower water storage basin by means of a tail water conduit, wherein said pump turbine is positioned in a vertical shaft at an elevation below the surface of said lower water storage basin, and wherein said pump-turbine is axially removable from said vertical shaft.

2. The system in accordance with claim 1, wherein said pump-turbine comprises multiple stages.

3. The system in accordance with claim 1, wherein said penstock conduit and said tail water conduit are coaxially positioned in said vertical shaft above said pump-turbine.

4. The system in accordance with claim 1, further comprising a motor-generator operably connected to said pump-turbine.

5. The system in accordance with claim 4, wherein said motor-generator is positioned below said pump-turbine.

6. The system in accordance with claim 4, wherein said motor-generator is above said pump-generator and operably connected thereto with a vertical drive shaft.

7. The system in accordance with claim 3, wherein said coaxial conduits comprise an inner conduit and an outer conduit, and further comprising a removable manifold for directing water in said inner conduit to said lower water storage basin and for directing water from said upper water storage basin to said penstock conduit.

8. The system in accordance with claim 7, wherein said manifold further comprises a pneumatically controlled pressure relief valve for reducing surge pressure in said penstock conduit.

9. The system in accordance with claim 1, further comprising a hoisting piston positioned below said pump-turbine for selectively raising and lowering said pump-turbine in said vertical shaft.

10. A pumped storage system having an upper water storage basin, a lower water storage basin, and a reversible pump-turbine connected to said upper water storage basin by a penstock conduit and also connected to said lower water storage basin by means of a tail water conduit, wherein said pump-turbine is positioned in a vertical shaft at an elevation below the surface of said lower water storage basin,; wherein said pump-turbine is axially removable from said vertical shaft; wherein said conduits are coaxially positioned in said vertical shaft.

11. A reversible pump-turbine located in a vertical shaft from which it is removable.

12. The apparatus of claim 11 further comprising a submersible motor-generator

13. The apparatus of claim 12 wherein said motor-generator is located beneath one or more pump-turbine stages.

14. The apparatus of claim 11 further comprising a removable manifold fixed to the top of the shaft during operation.

15. The apparatus of claim 14 wherein the removable manifold includes a pressure relief valve for relieving excess head pressure to the tailwater conduit.

16. The apparatus of claim 15 wherein the pressure relief valve is comprised of an elastomeric diaphragm held by controlled gas pressure against one or more orifices containing headwater pressure.

17. The apparatus of claim 11 wherein the motor-generator is located above the turnout connecting the headwater to the vertical shaft.

18. The apparatus of claim 11 wherein the pump-turbine is comprised of multiple stages.

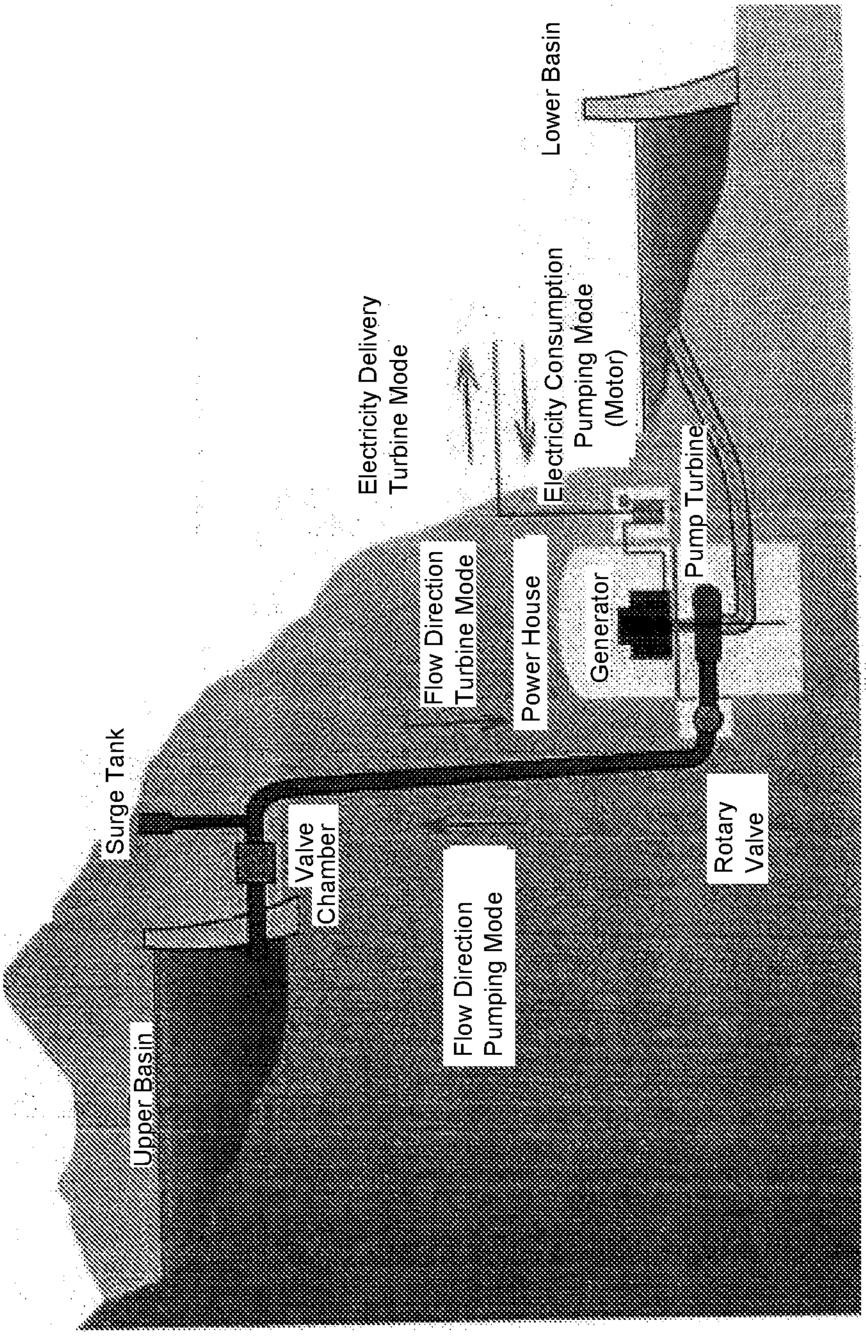


Fig. 1 PRIOR ART

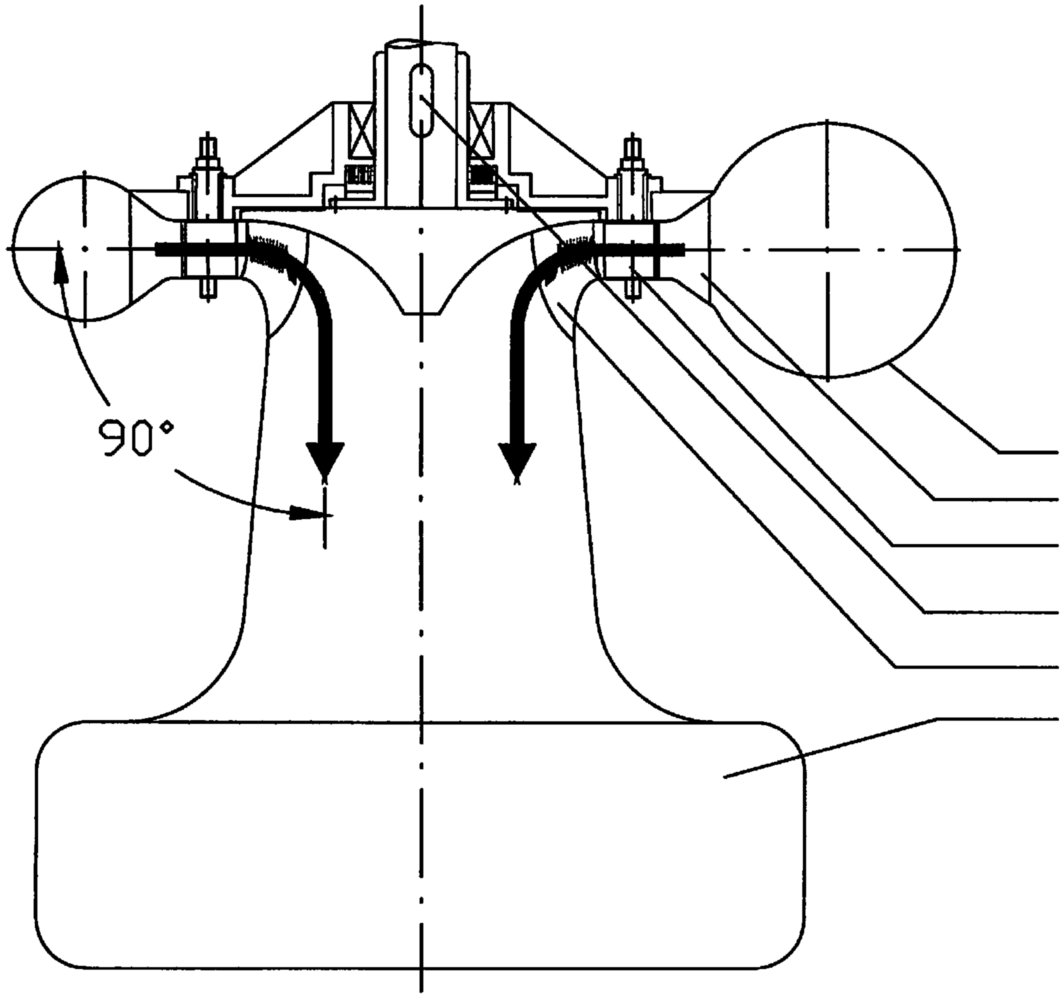


Fig 1b
PRIOR ART

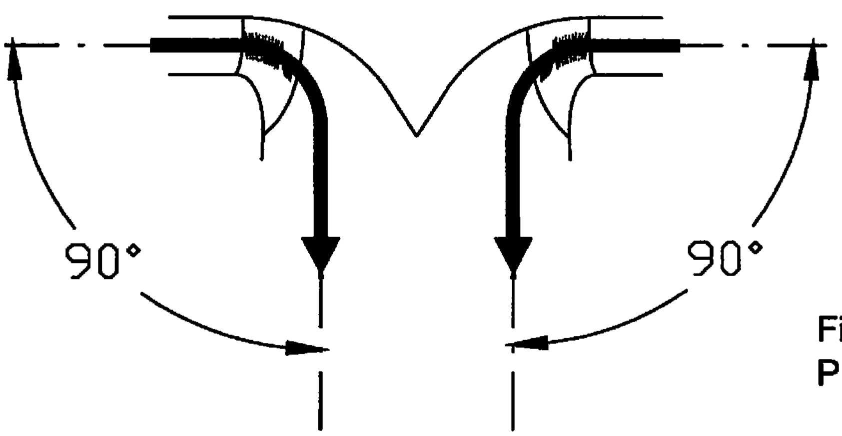
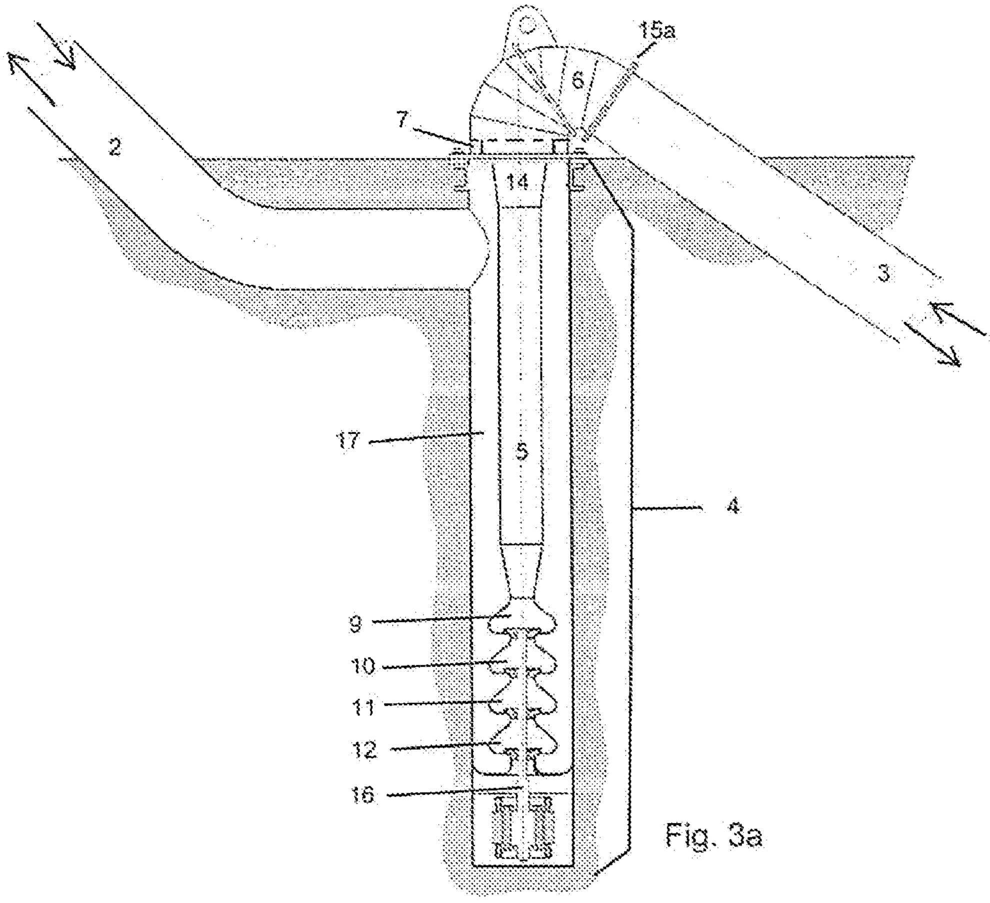


Fig. 1c
PRIOR ART



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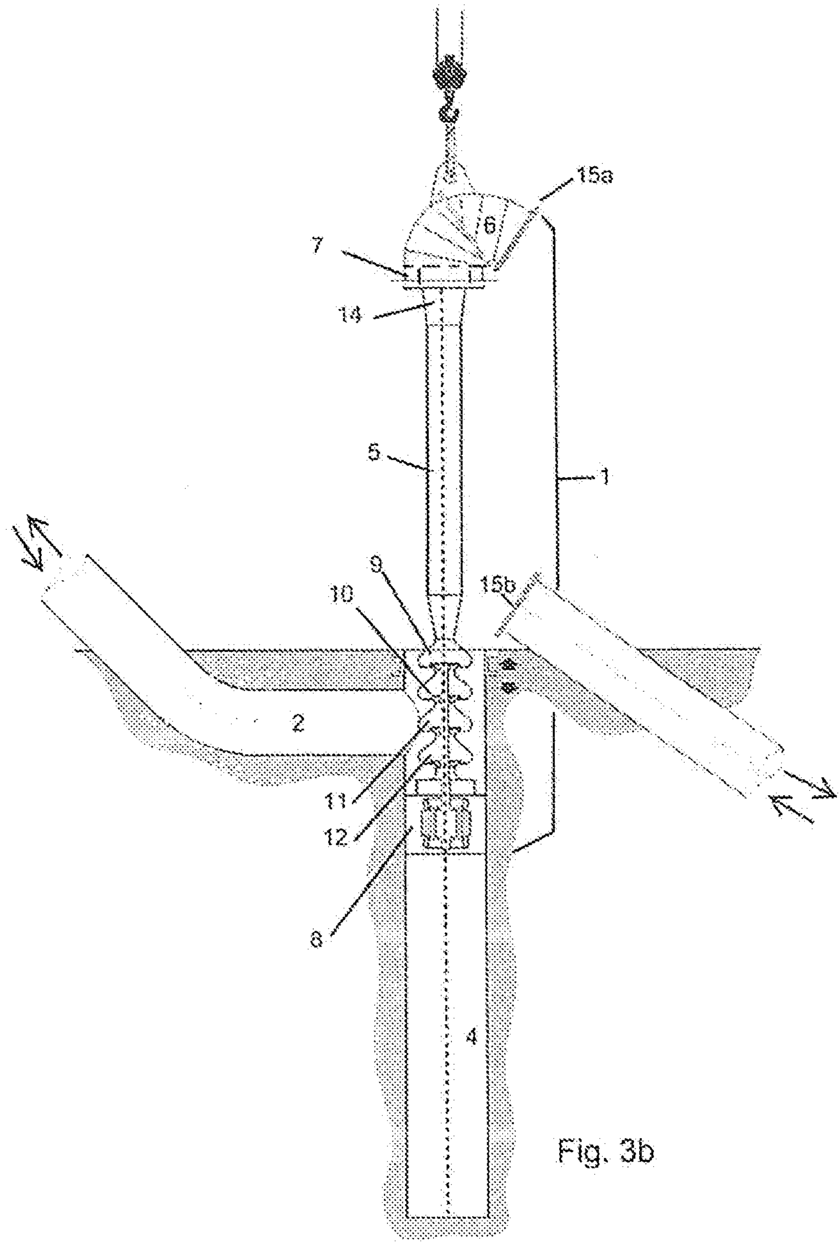


Fig. 3b

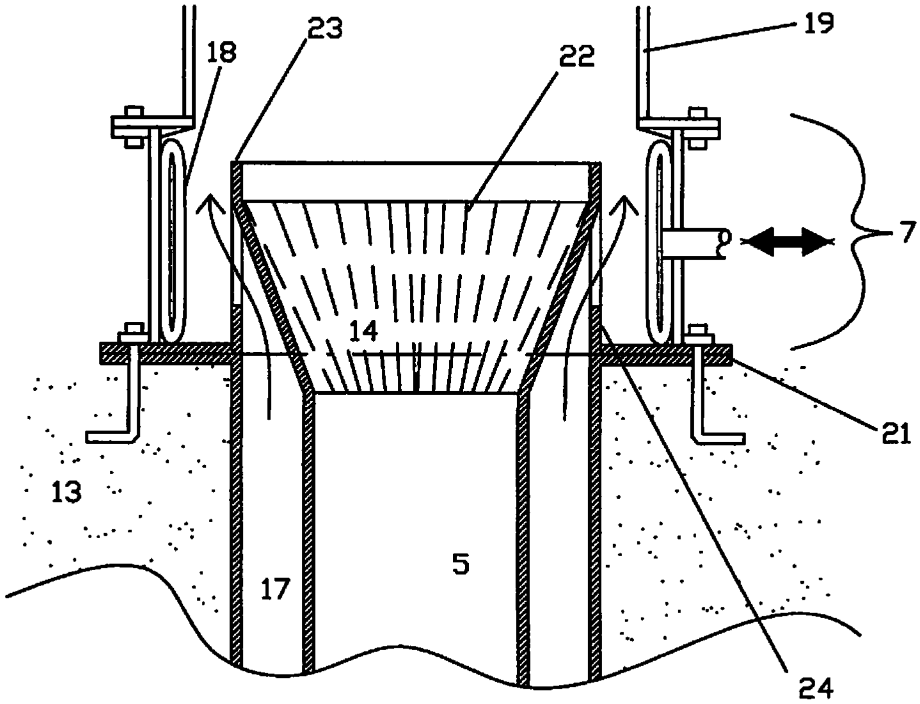


Fig. 4a

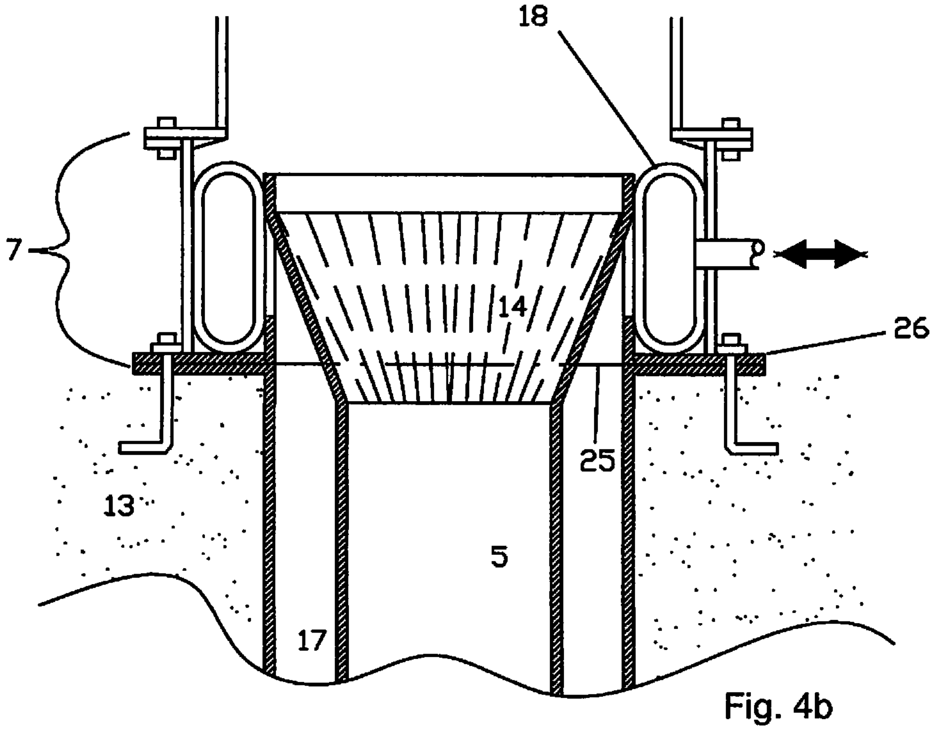


Fig. 4b

Fig 5a

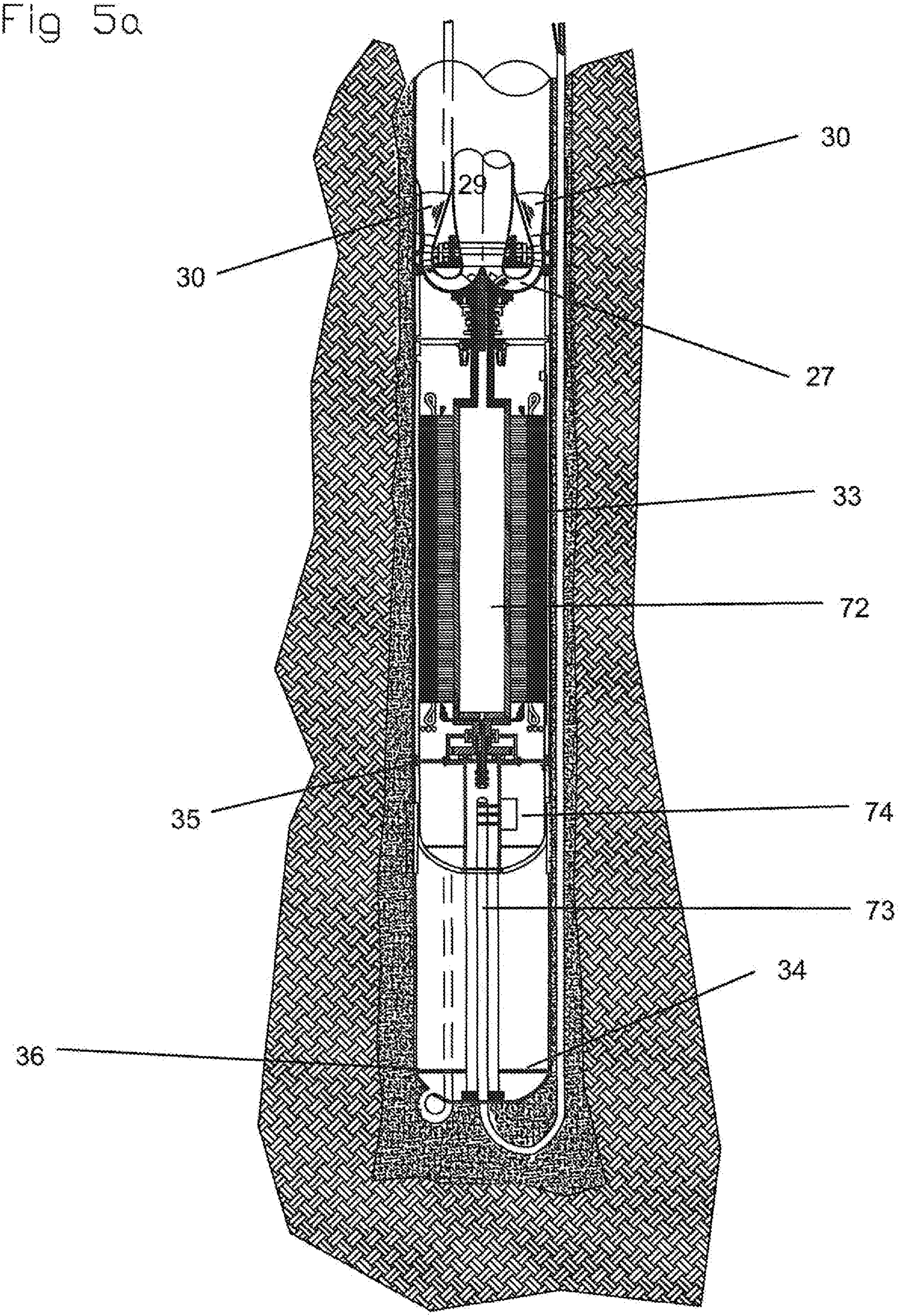
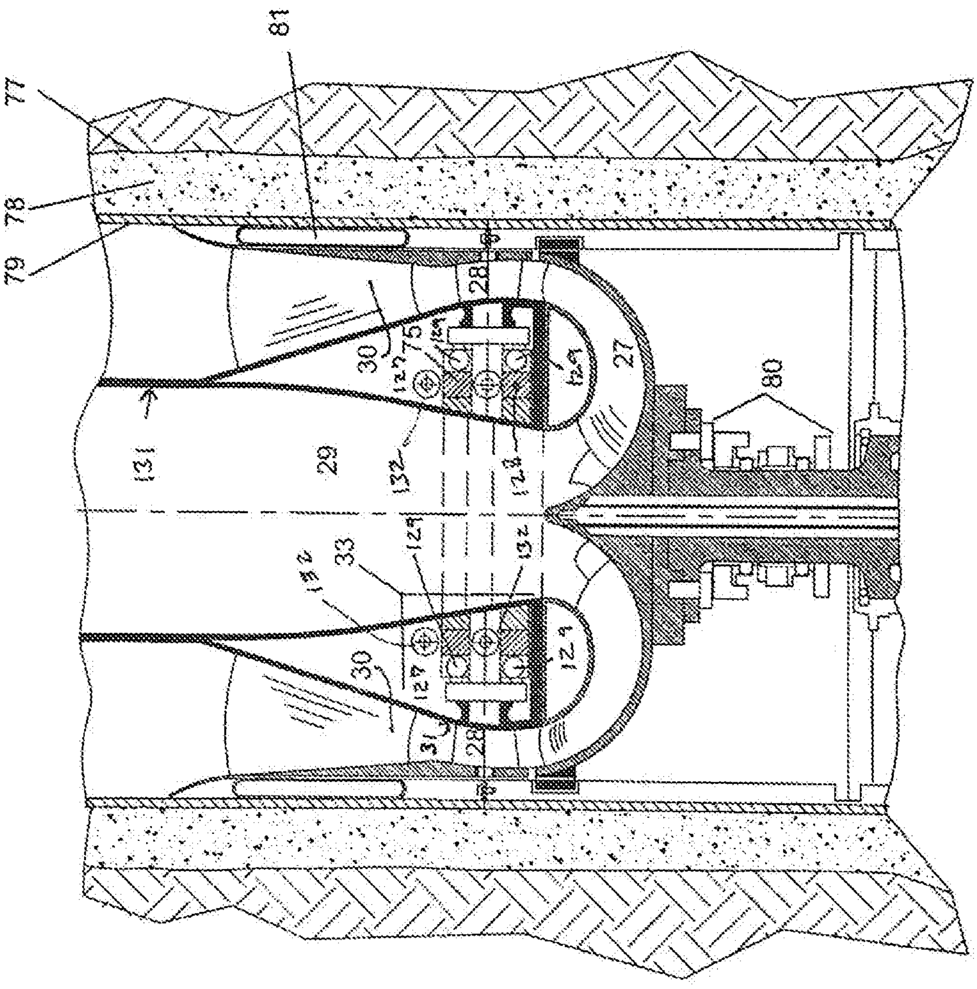


Fig 5b



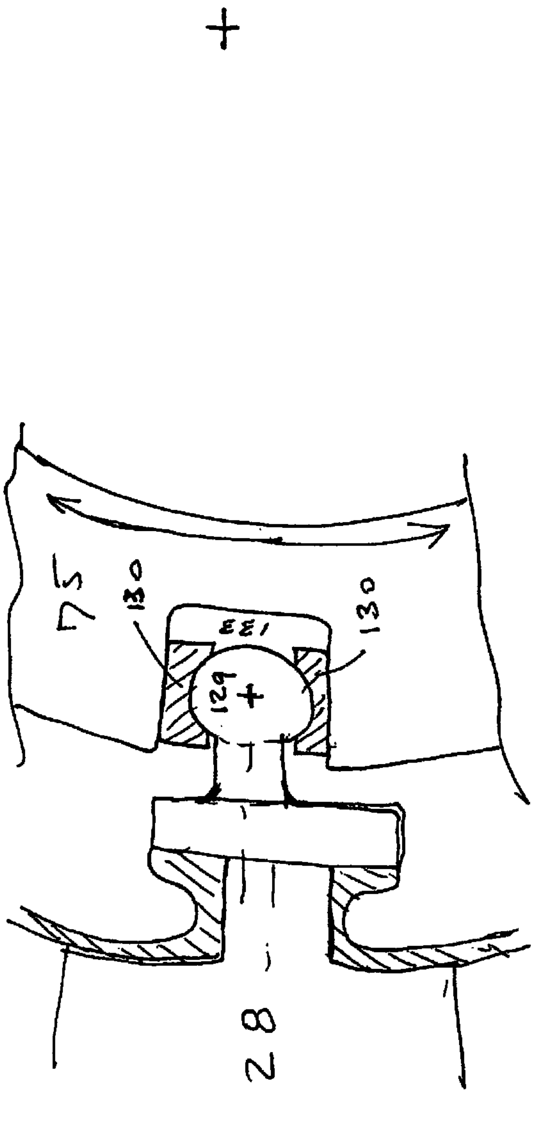
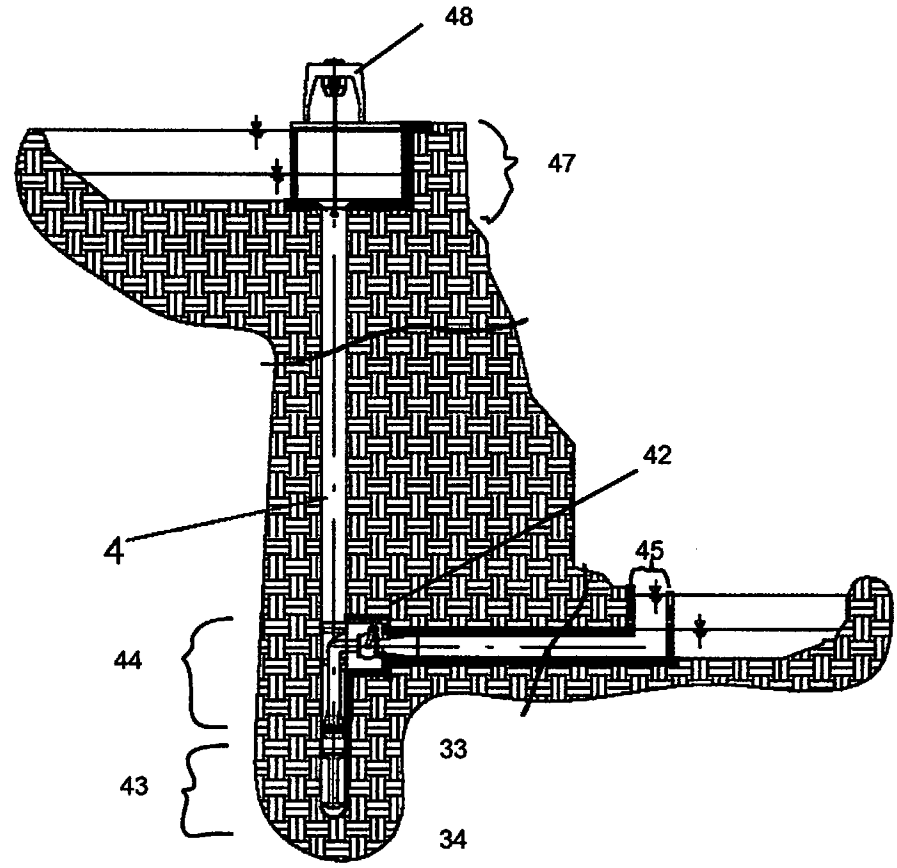


Fig 5c



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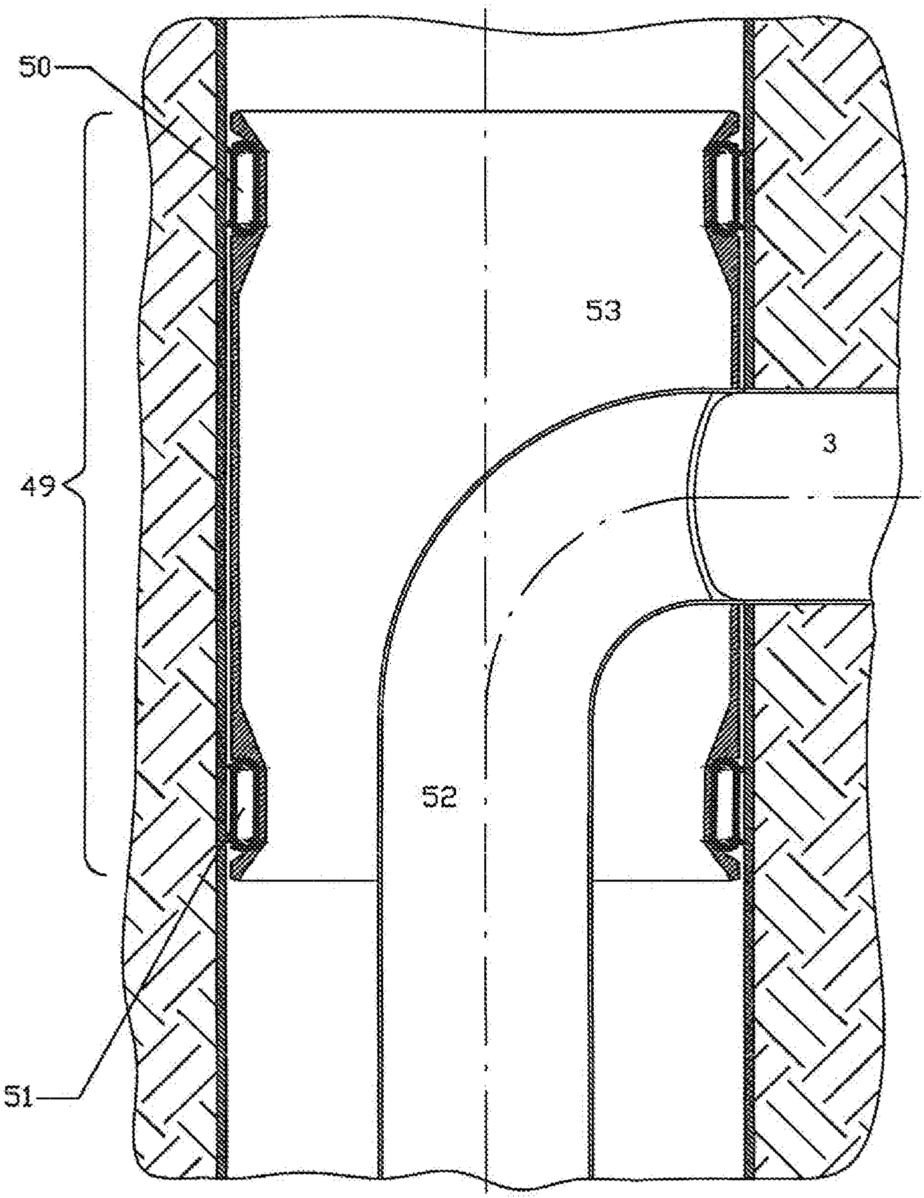
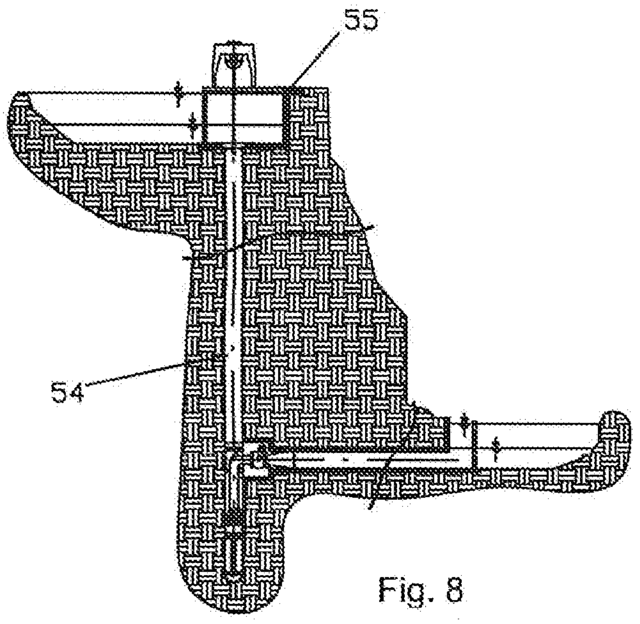


Fig. 7



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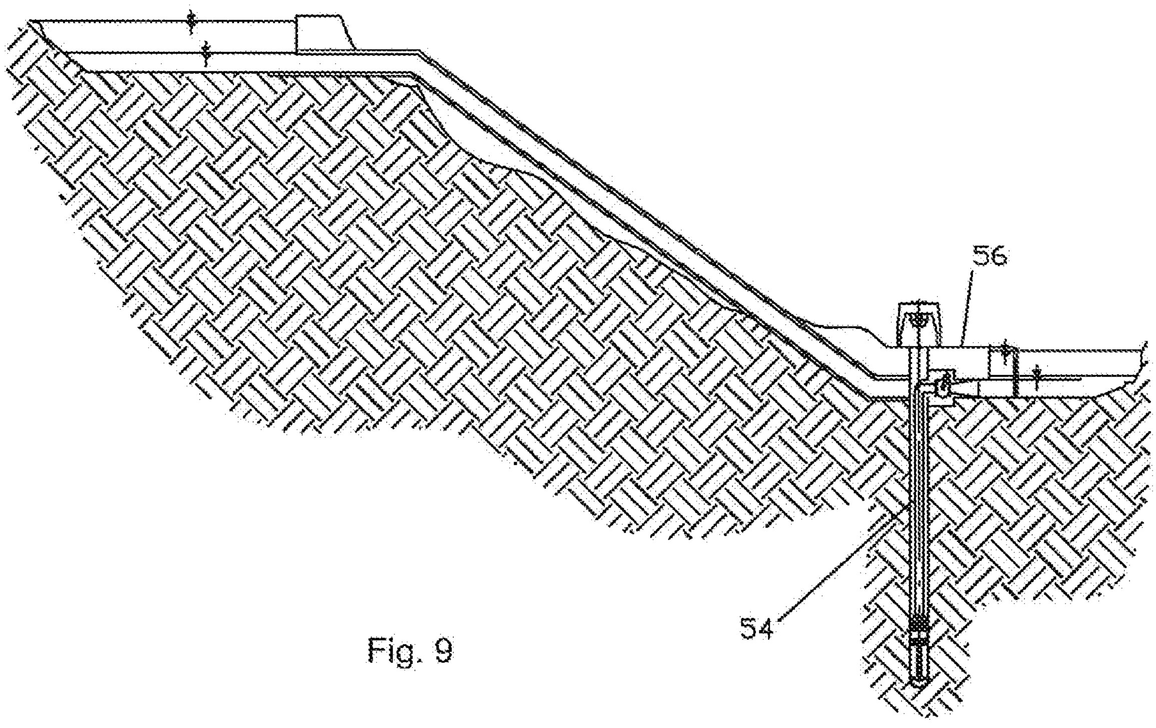

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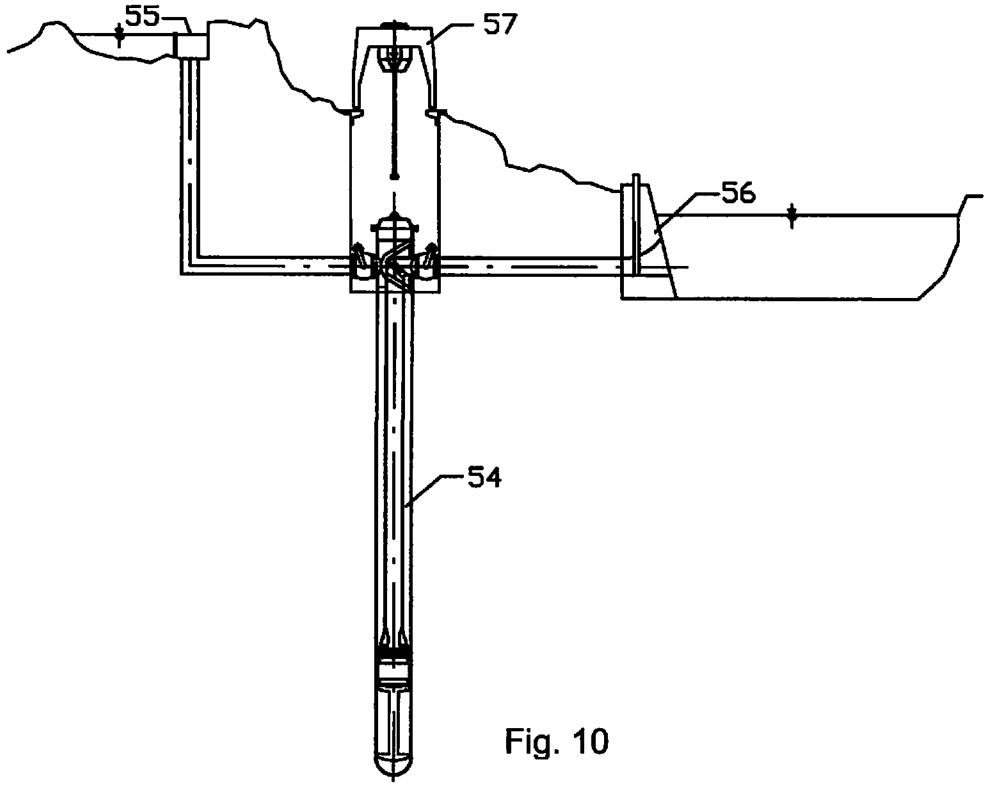

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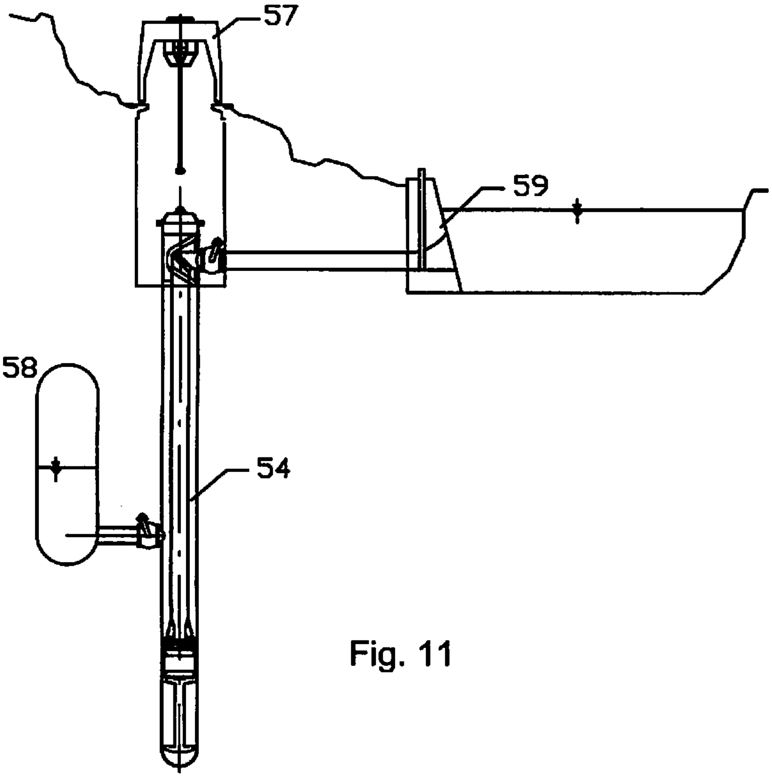

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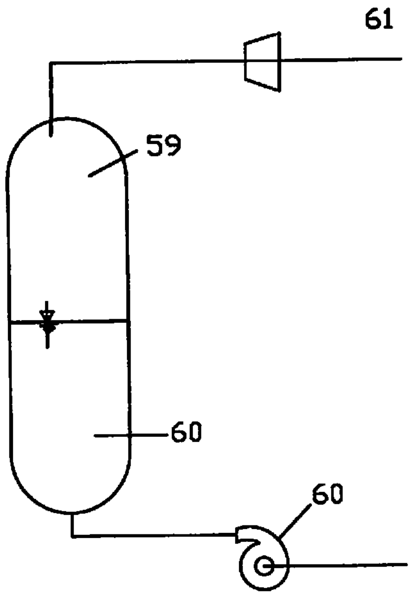

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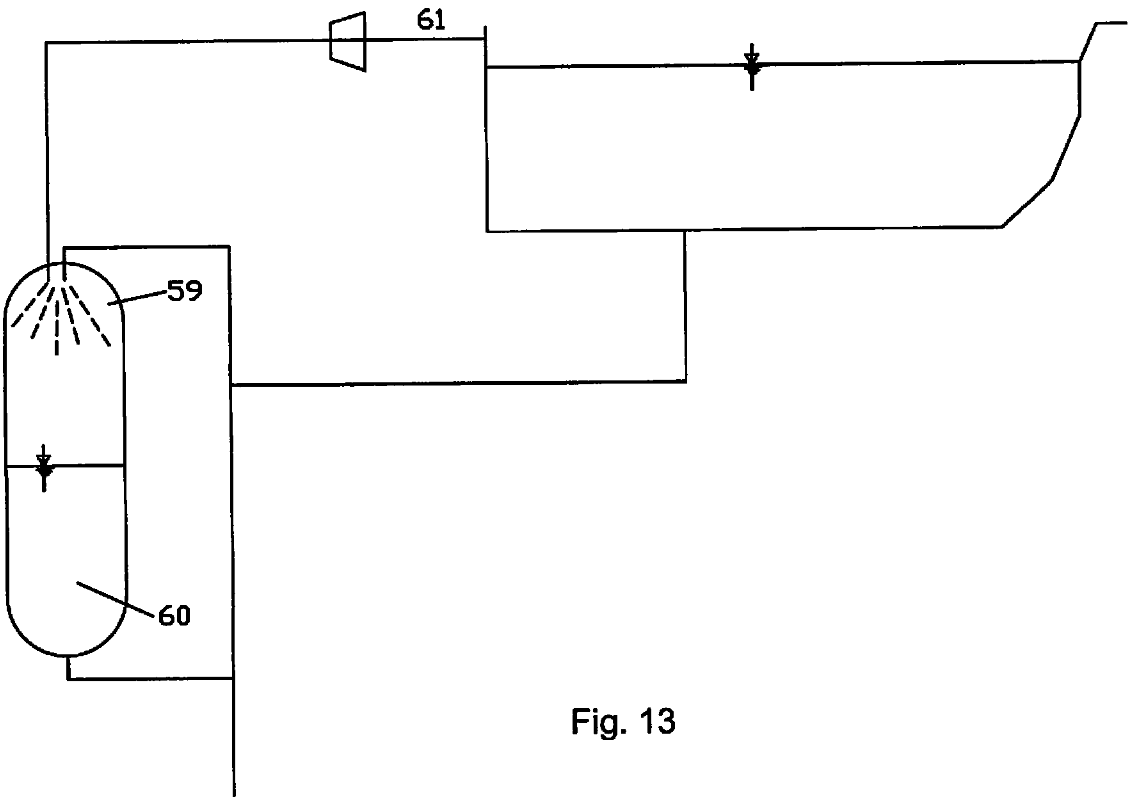

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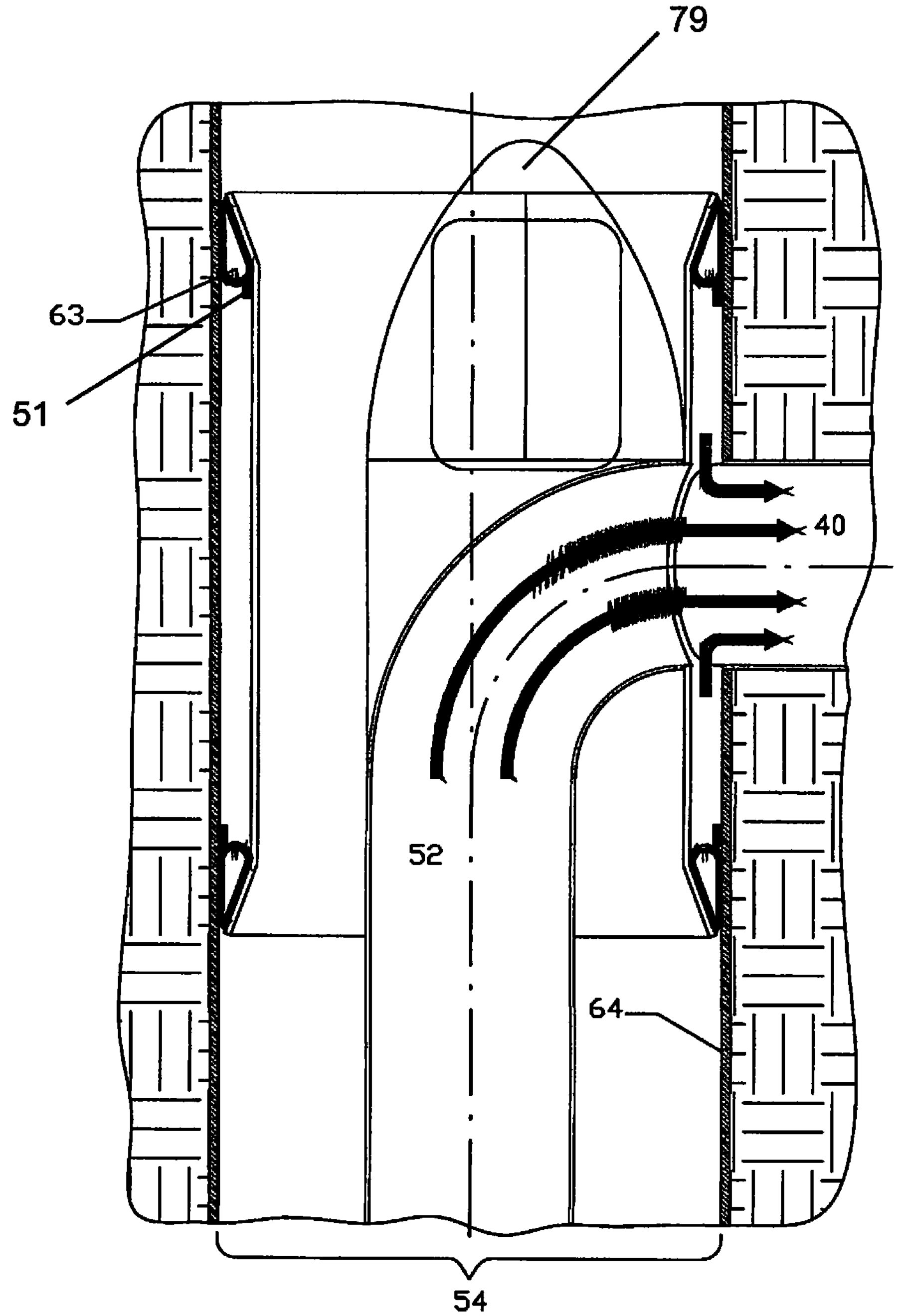

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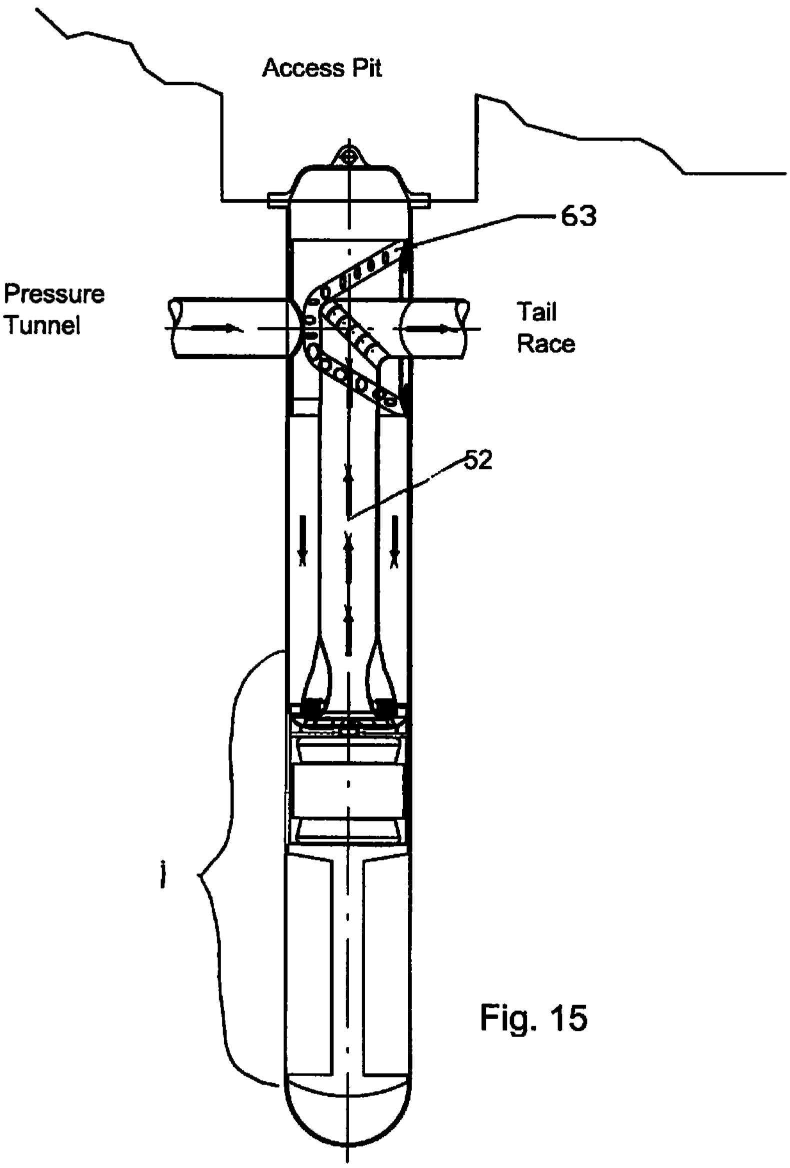

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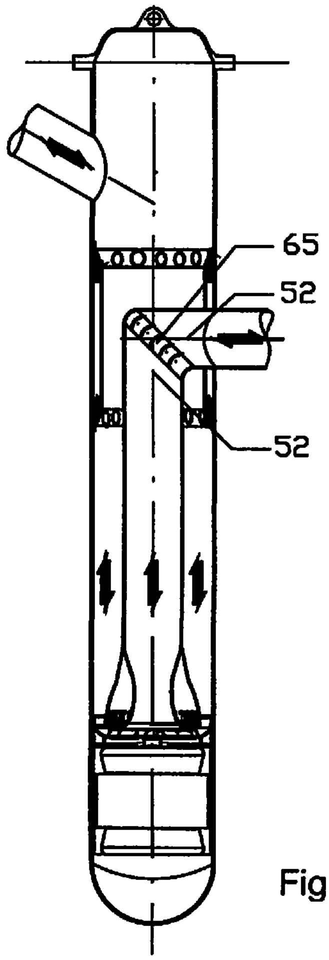

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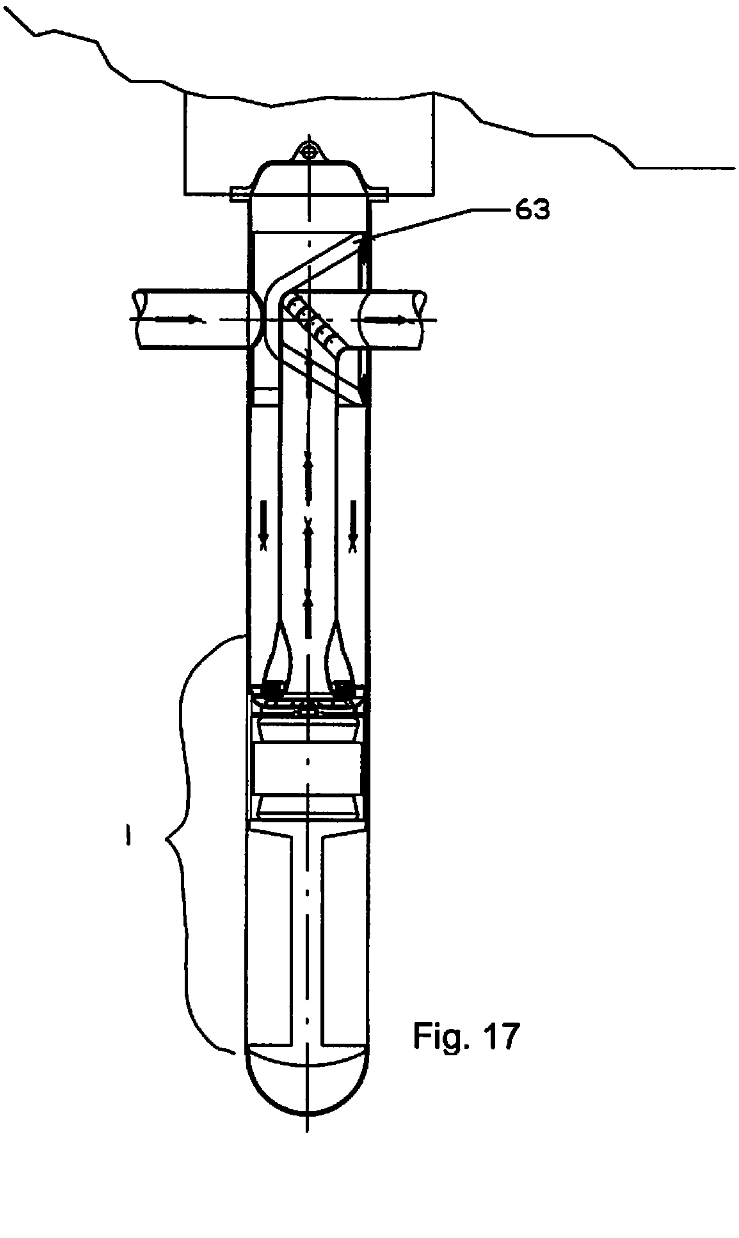

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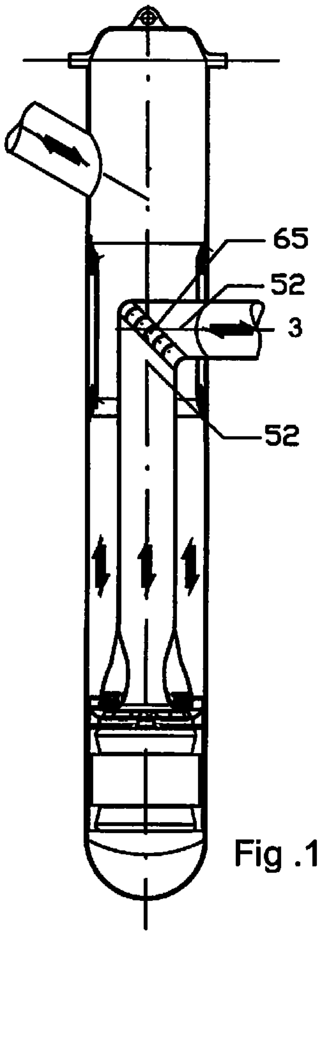
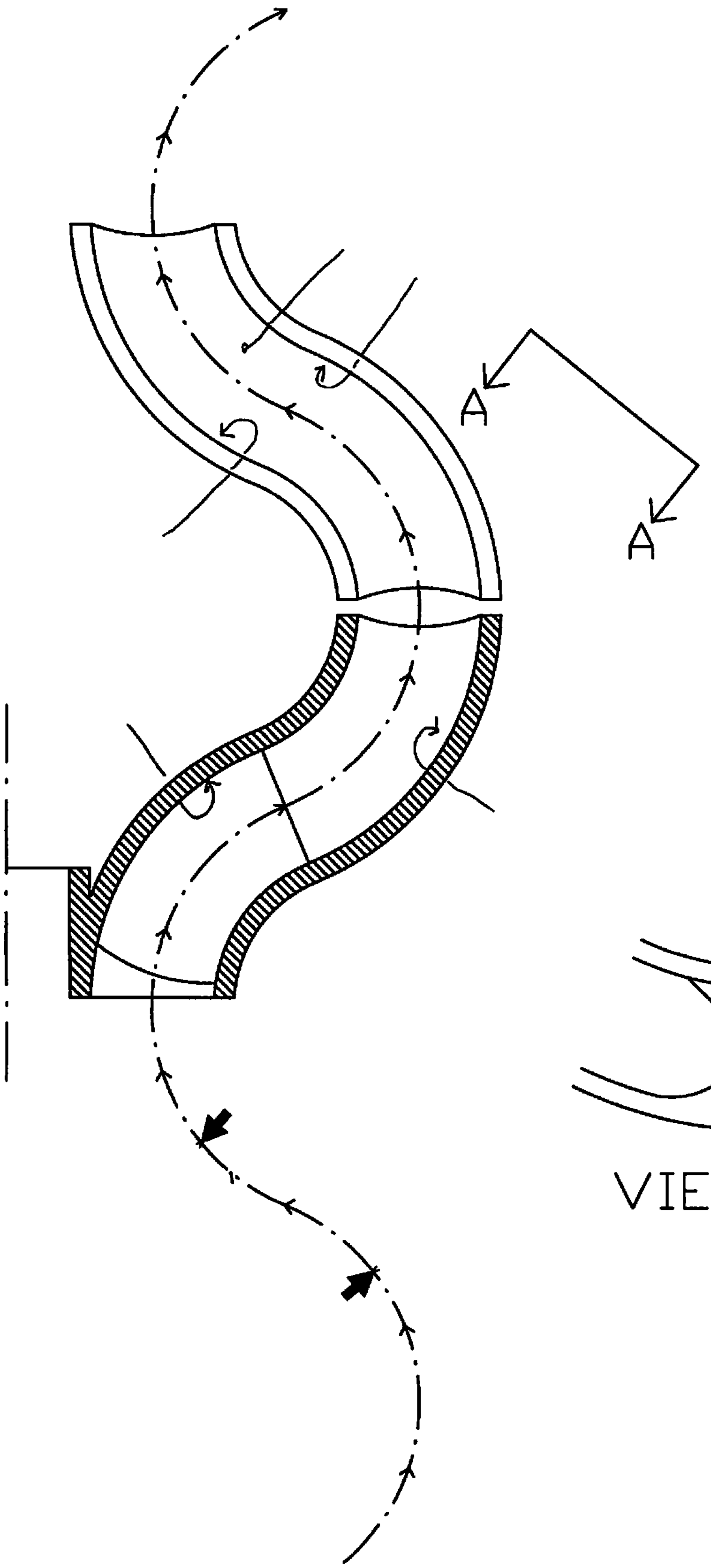


Fig .18



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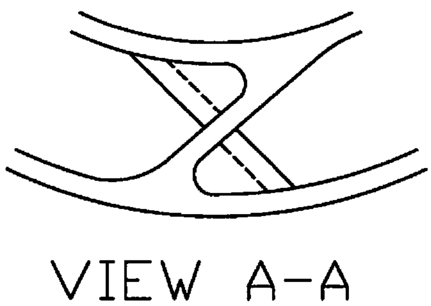

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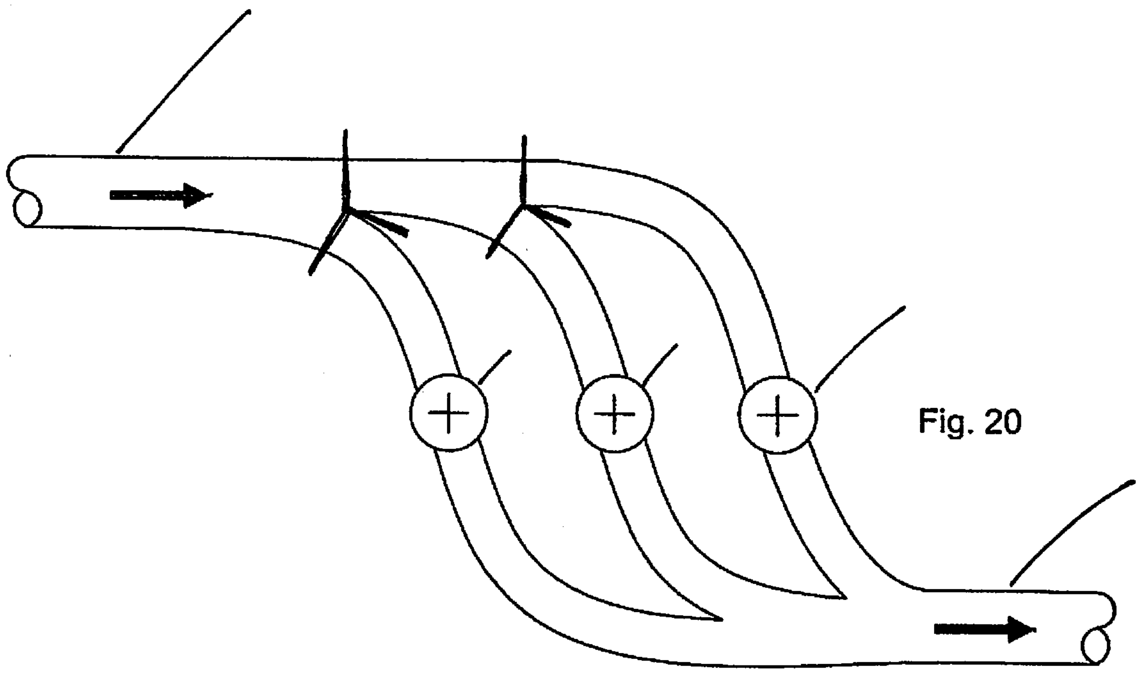

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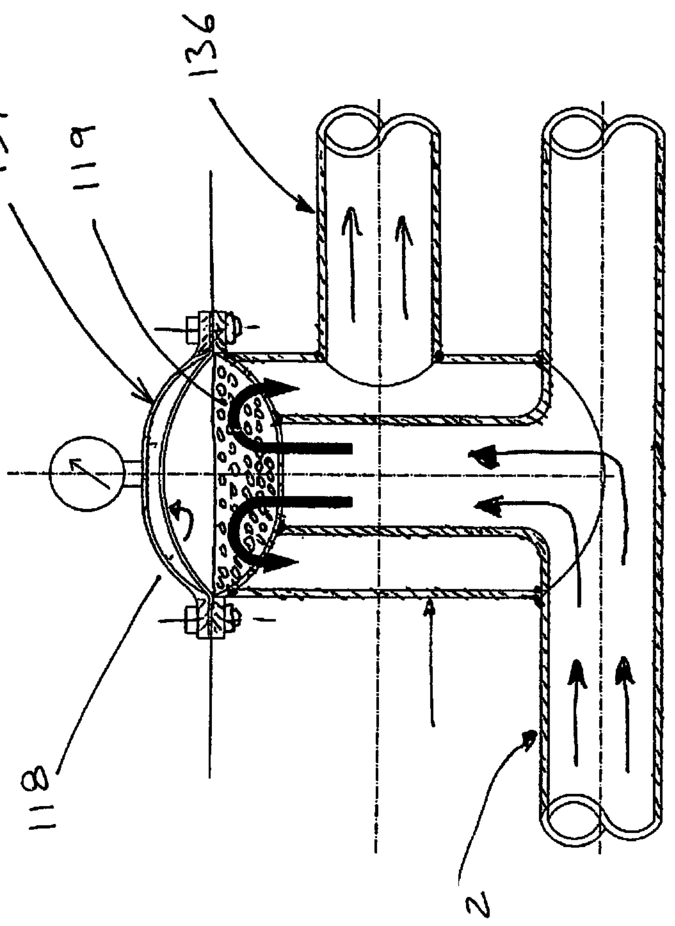

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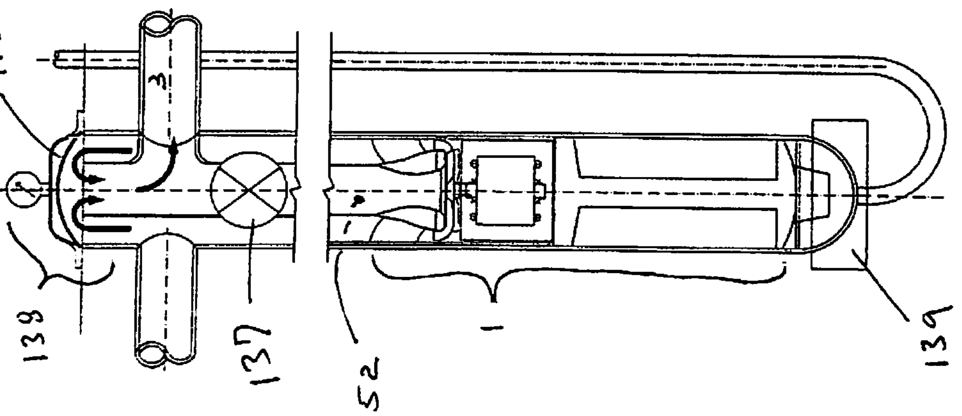

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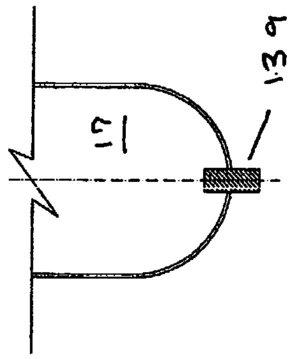

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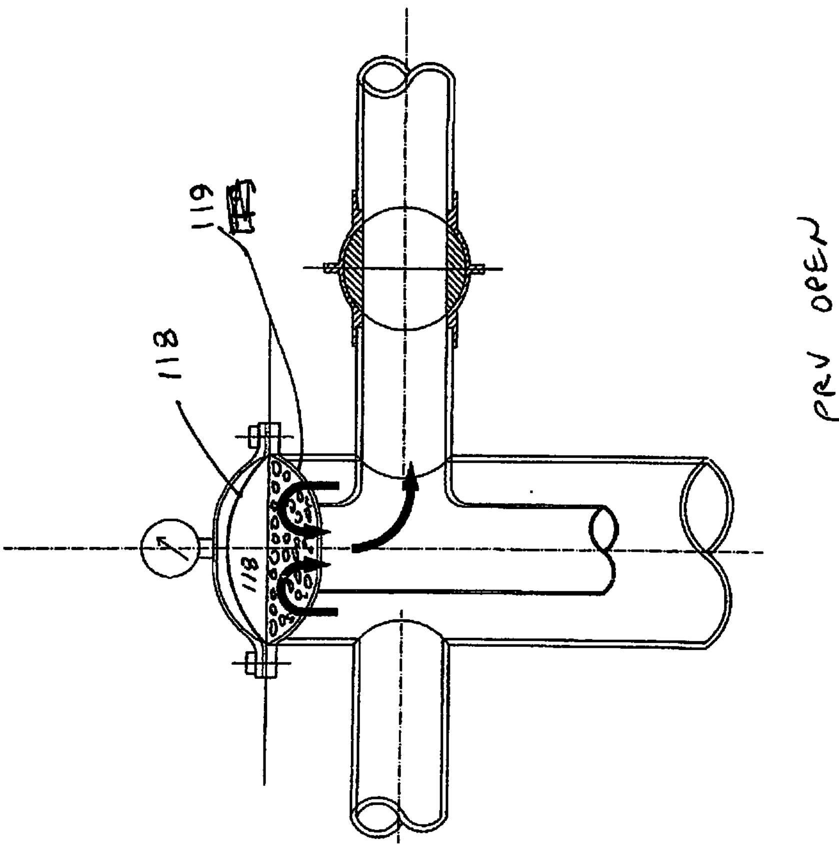

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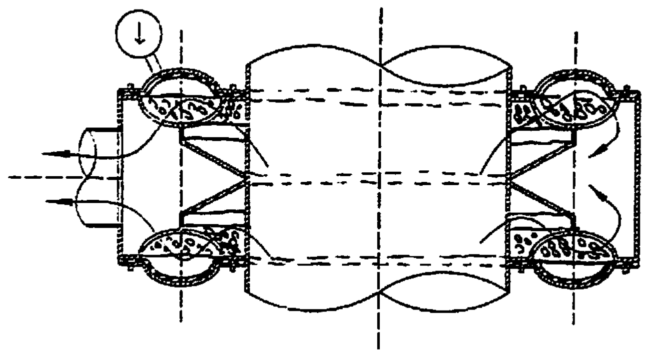

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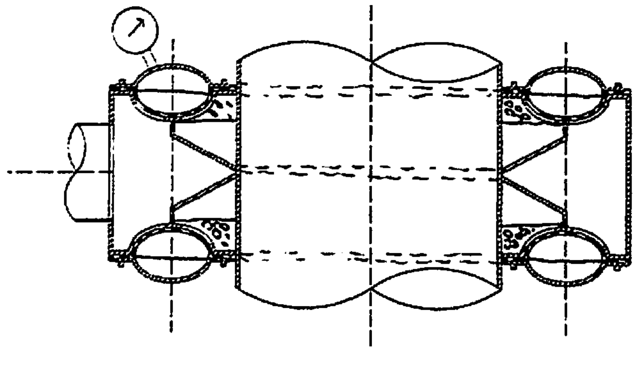
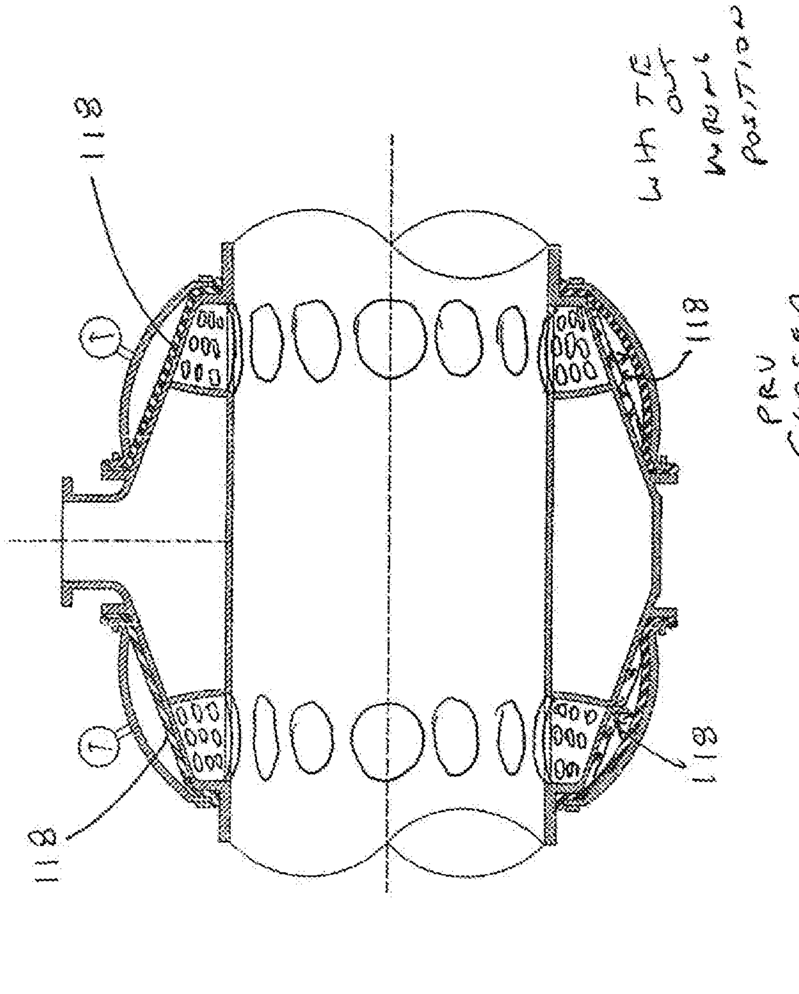


Fig. 24a PRV CLOSED



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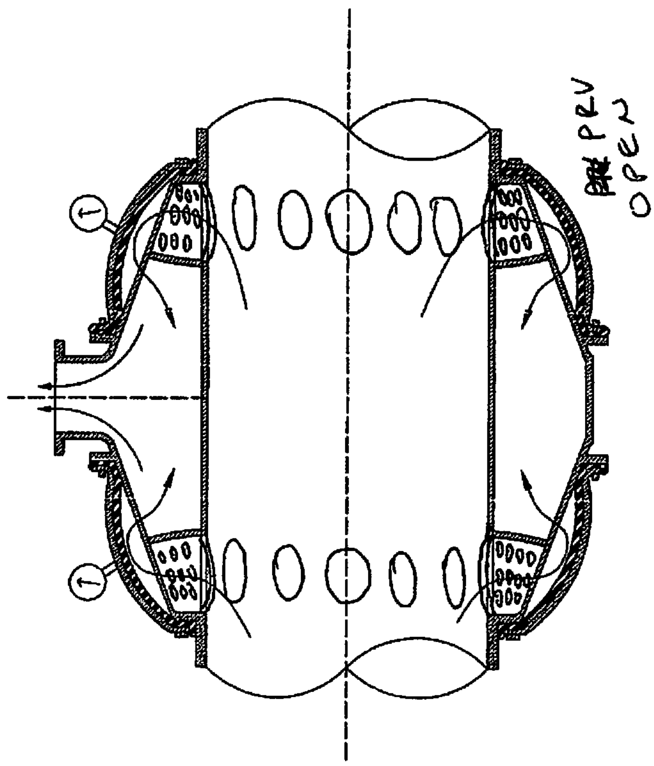

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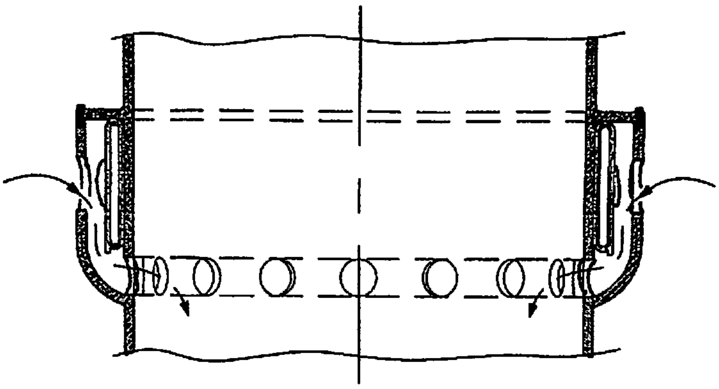

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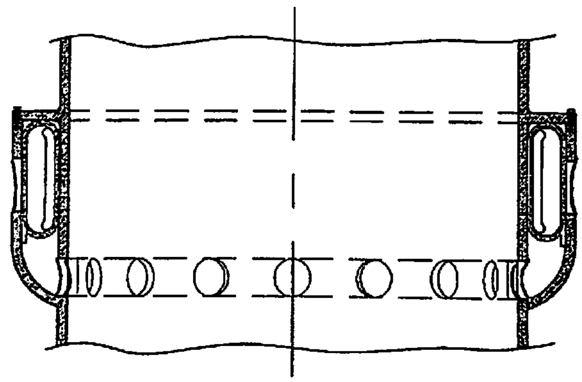

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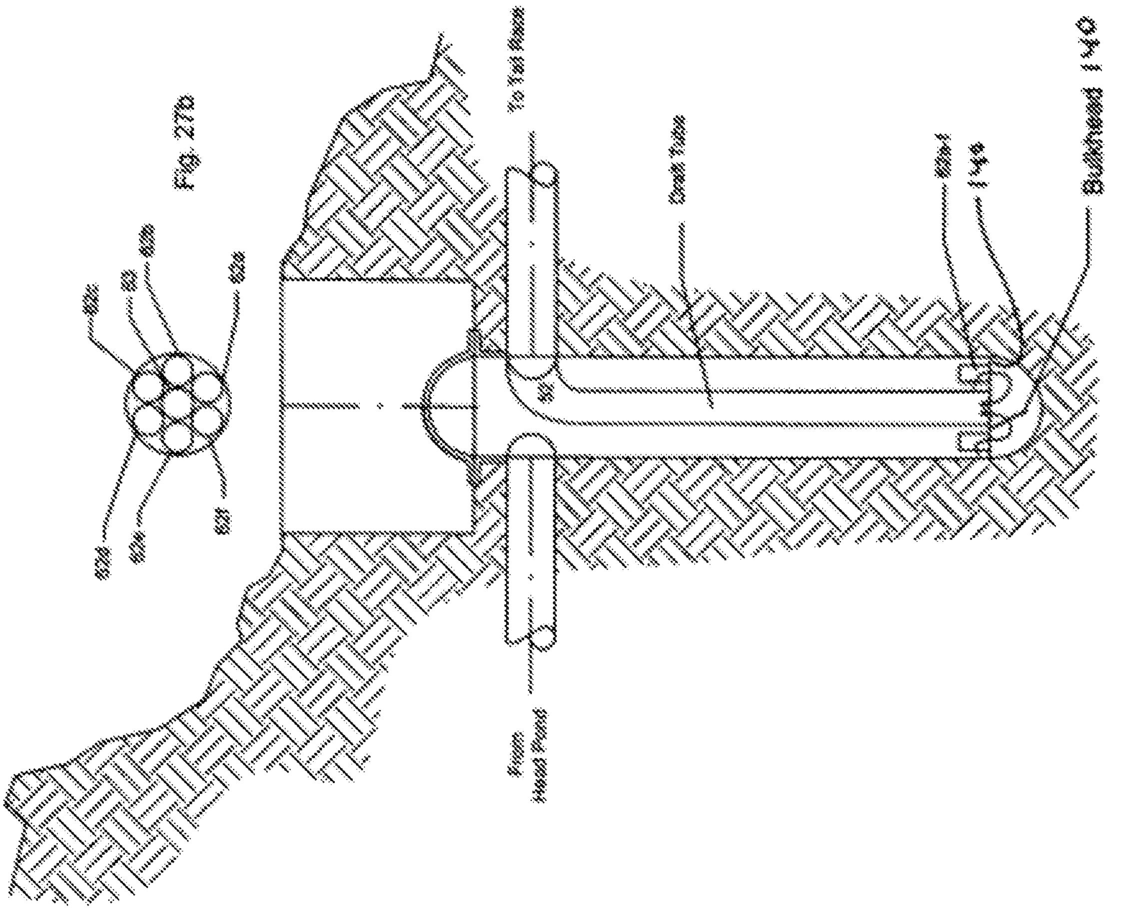

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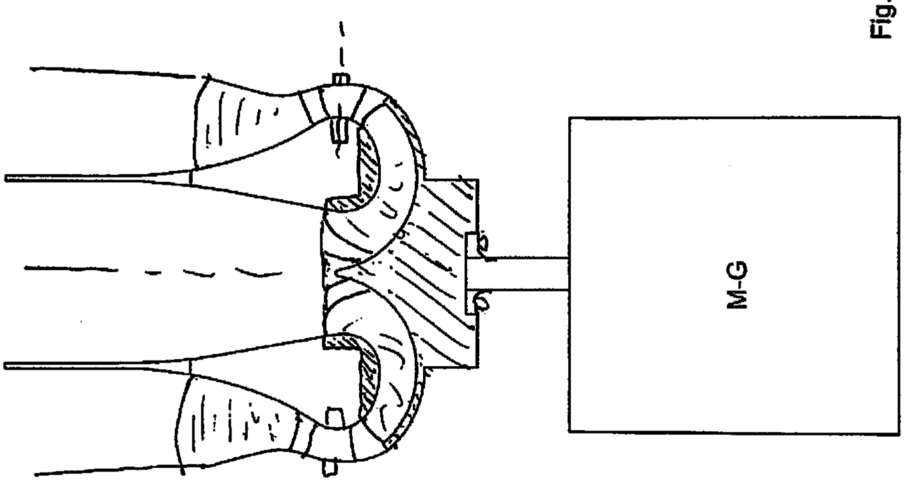

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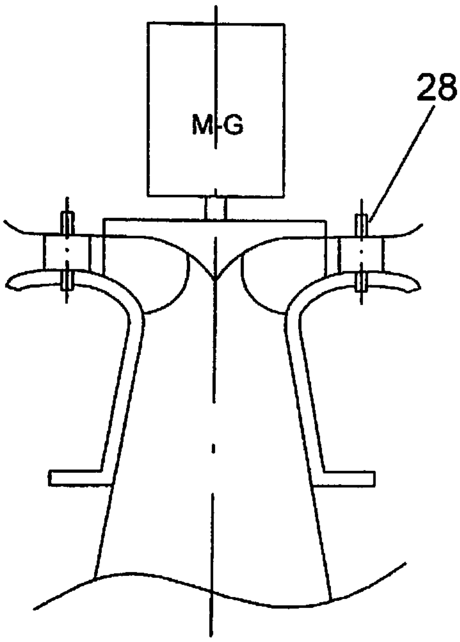

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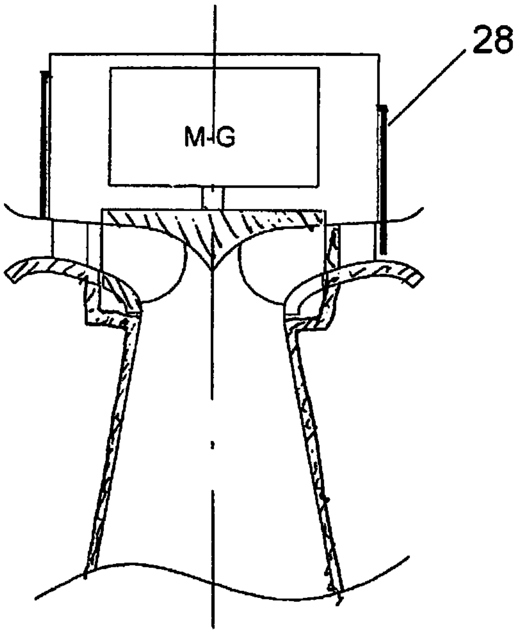

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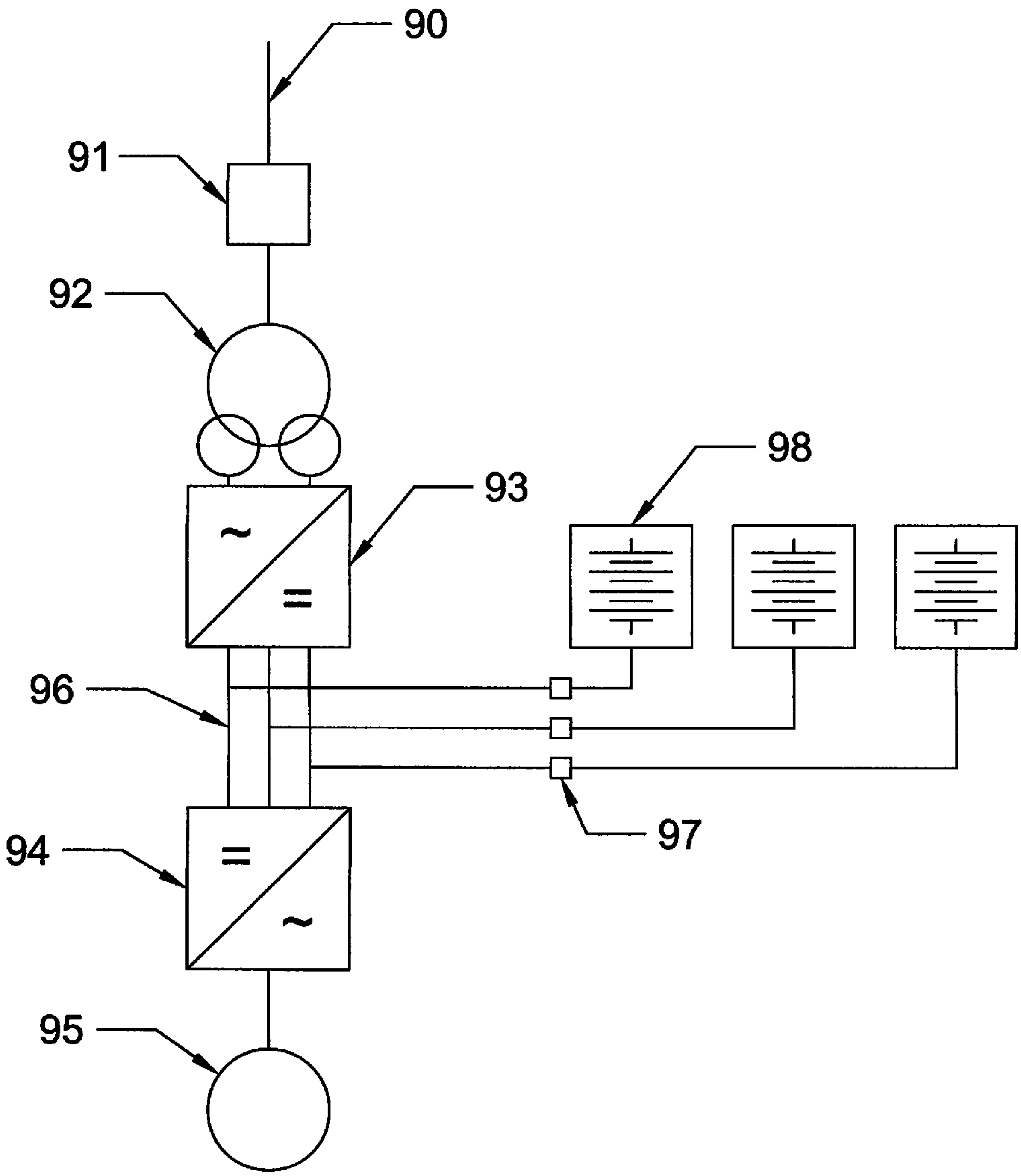

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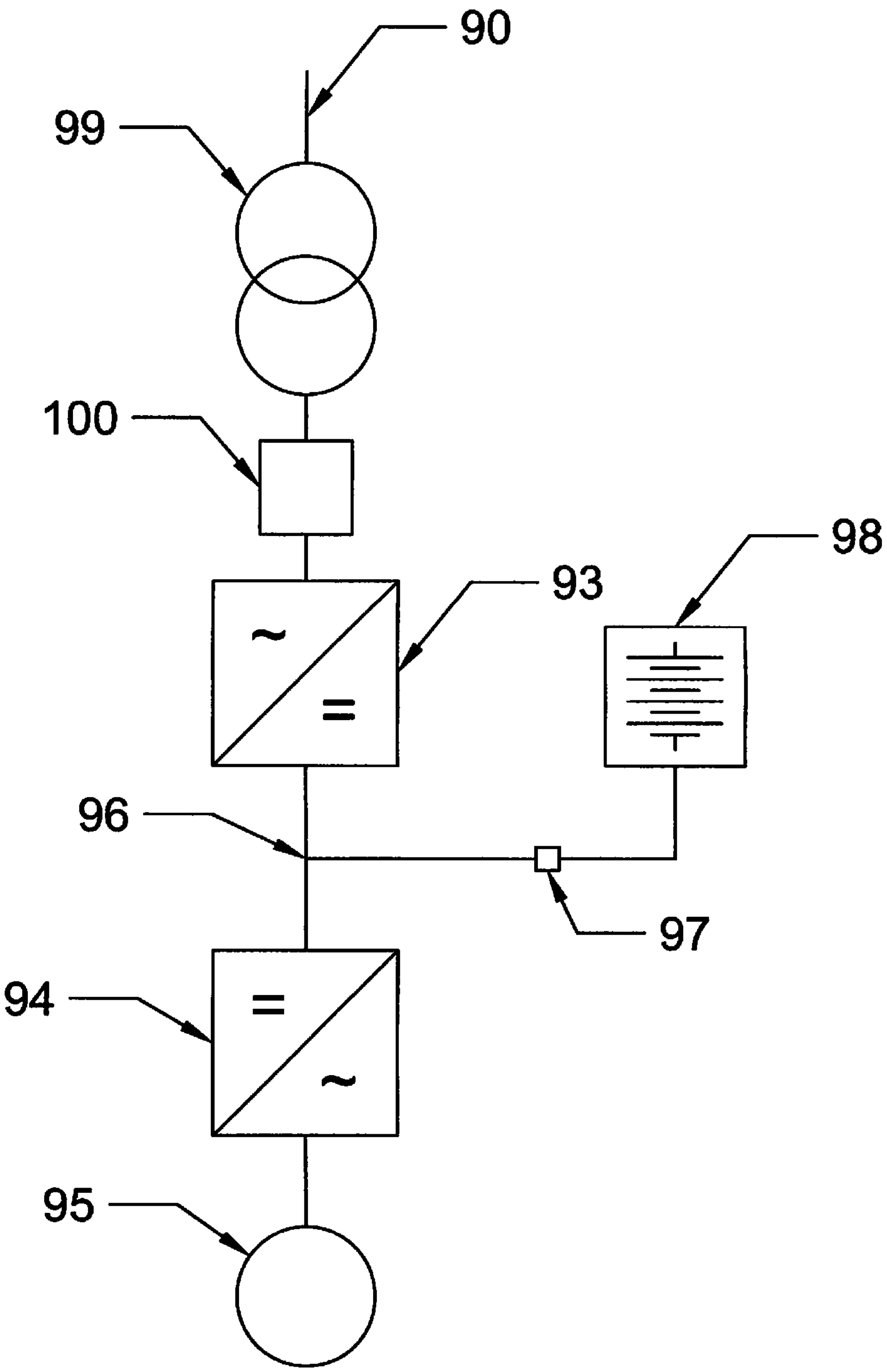

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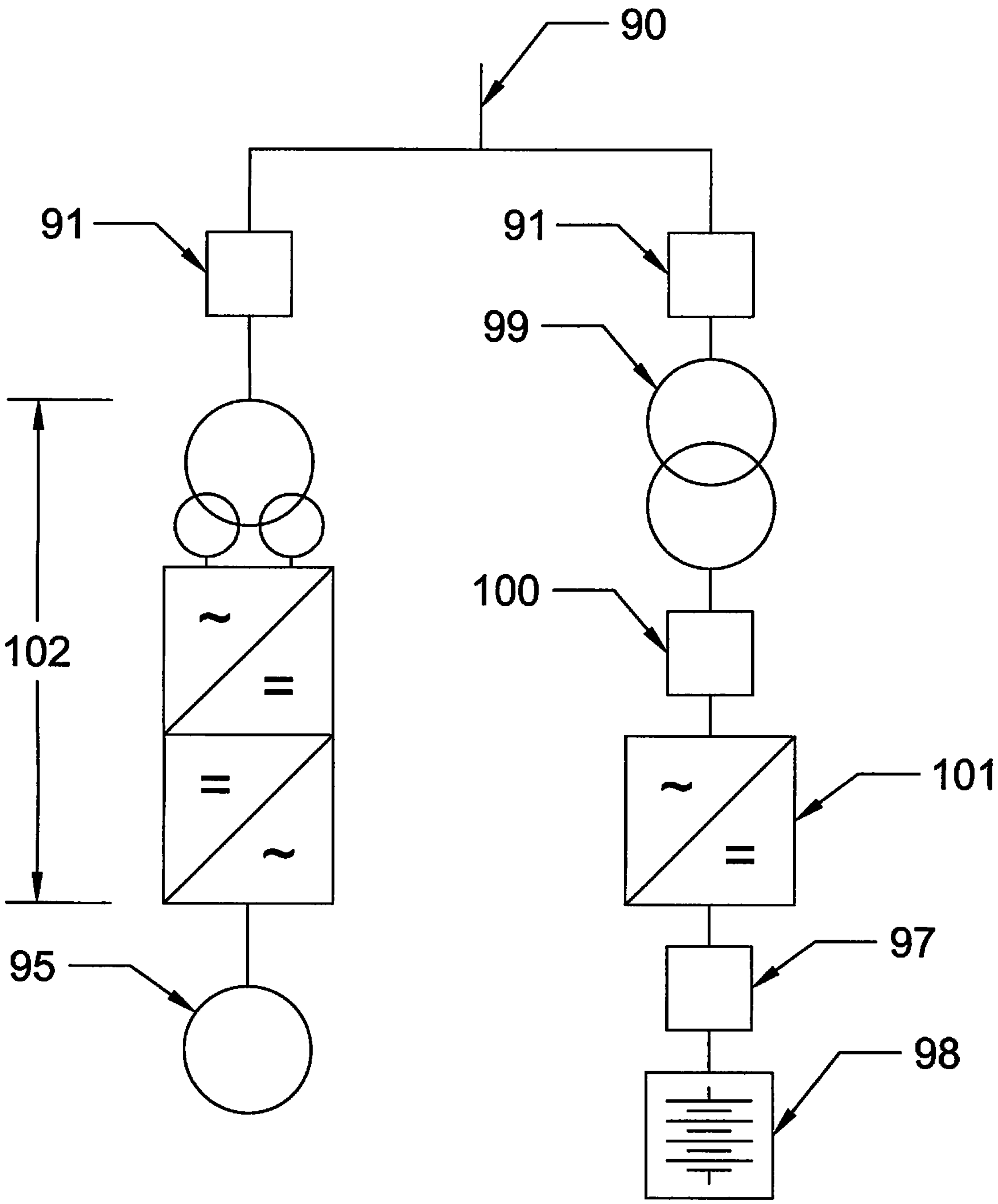

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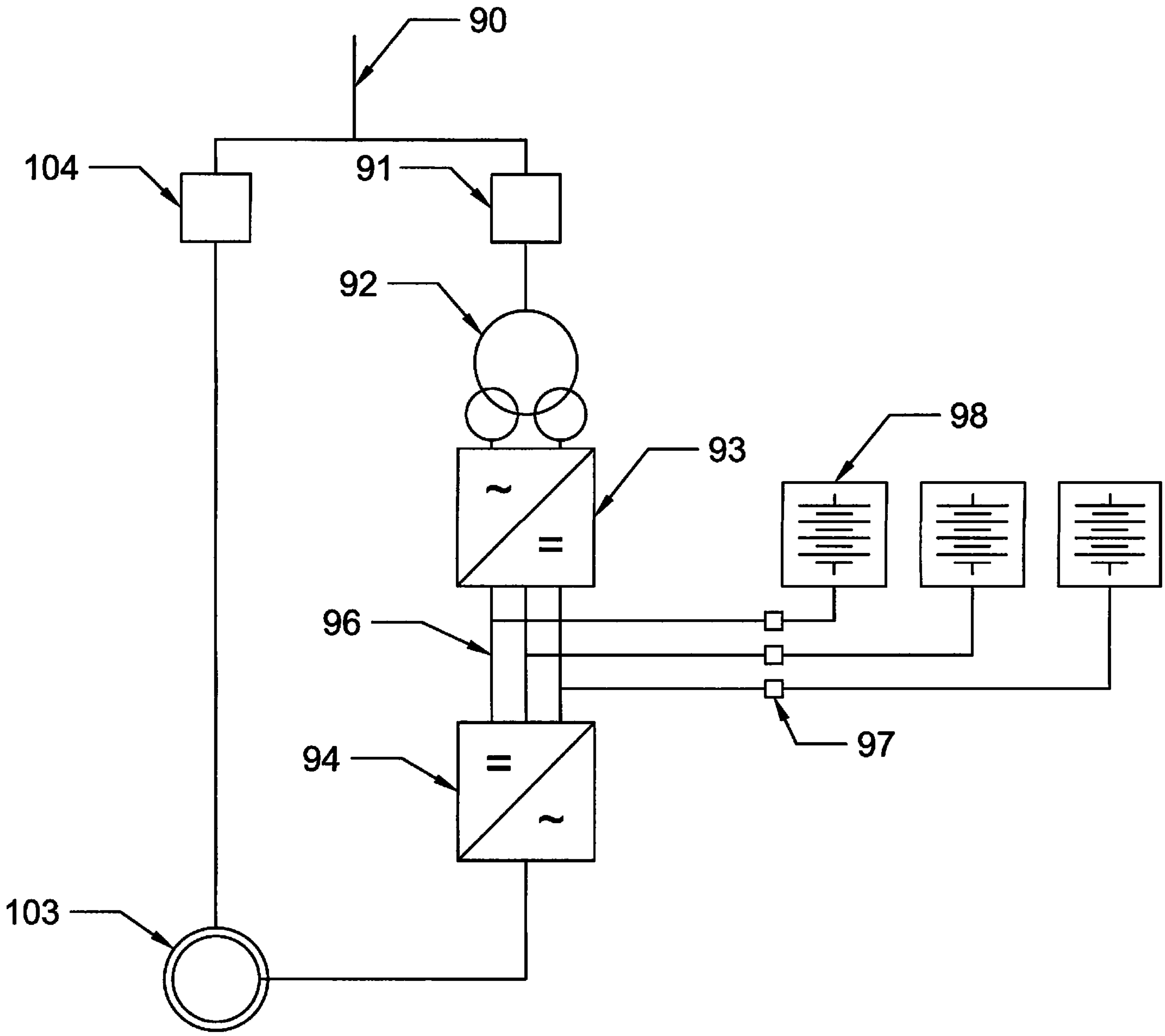

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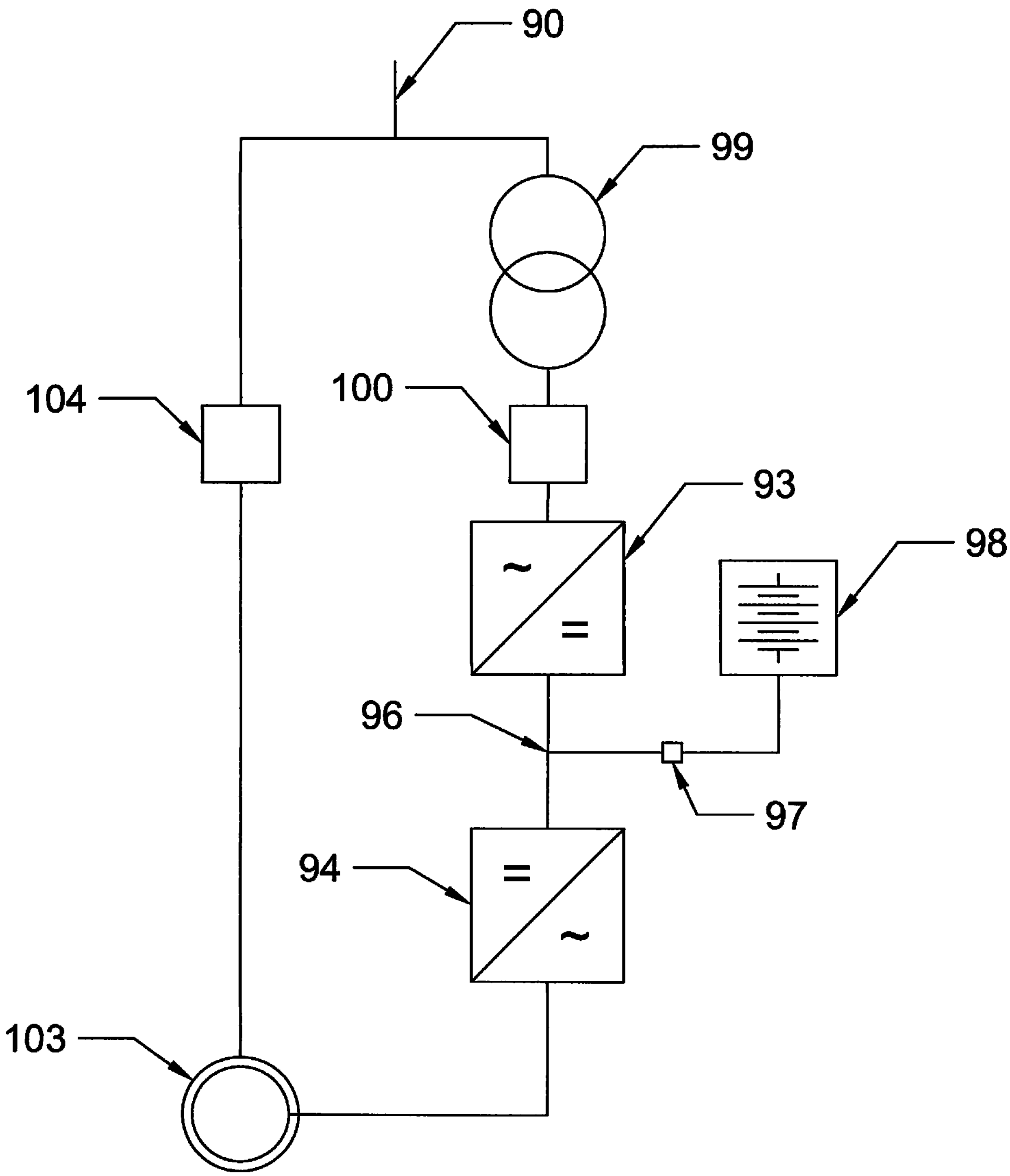

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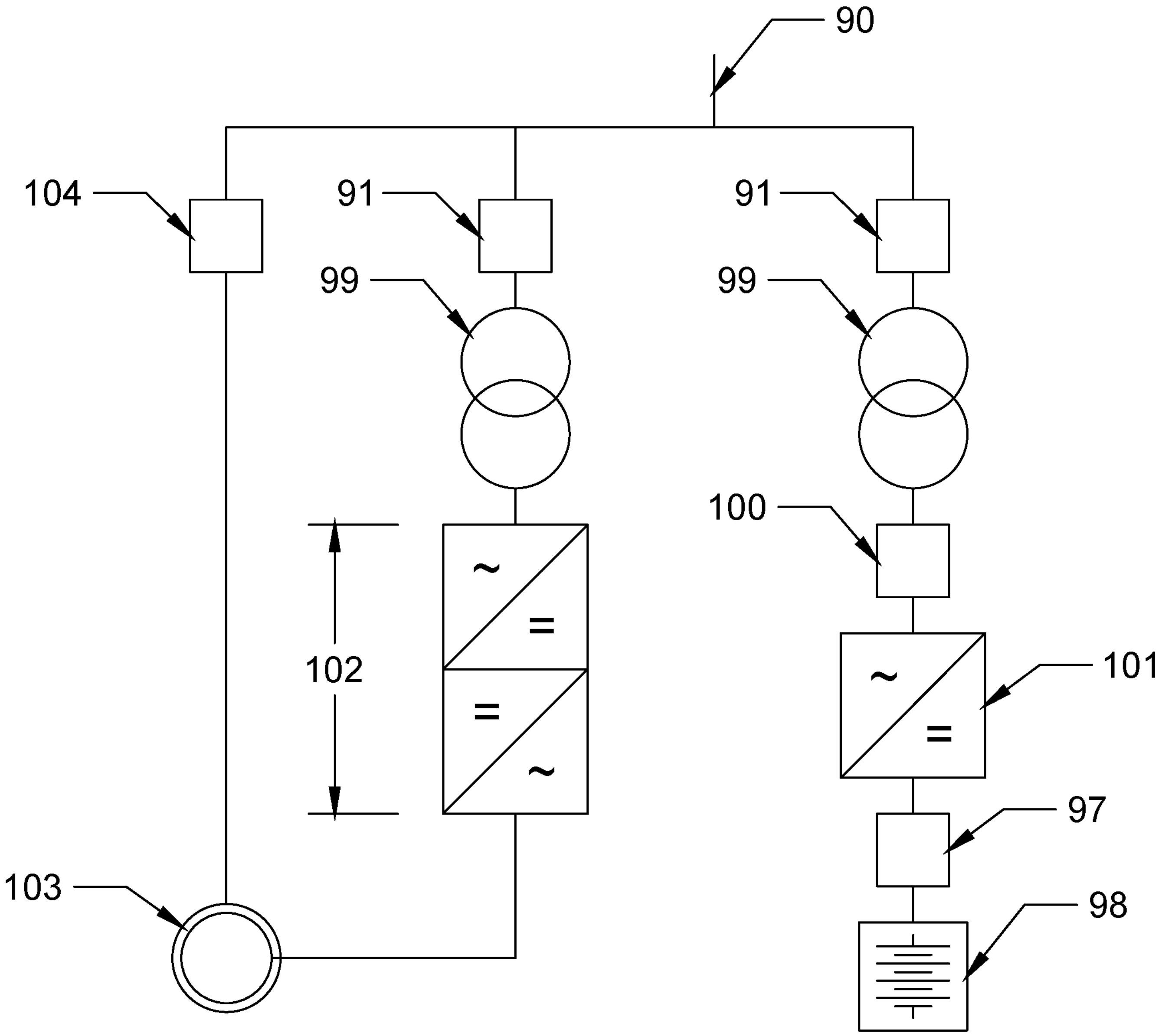

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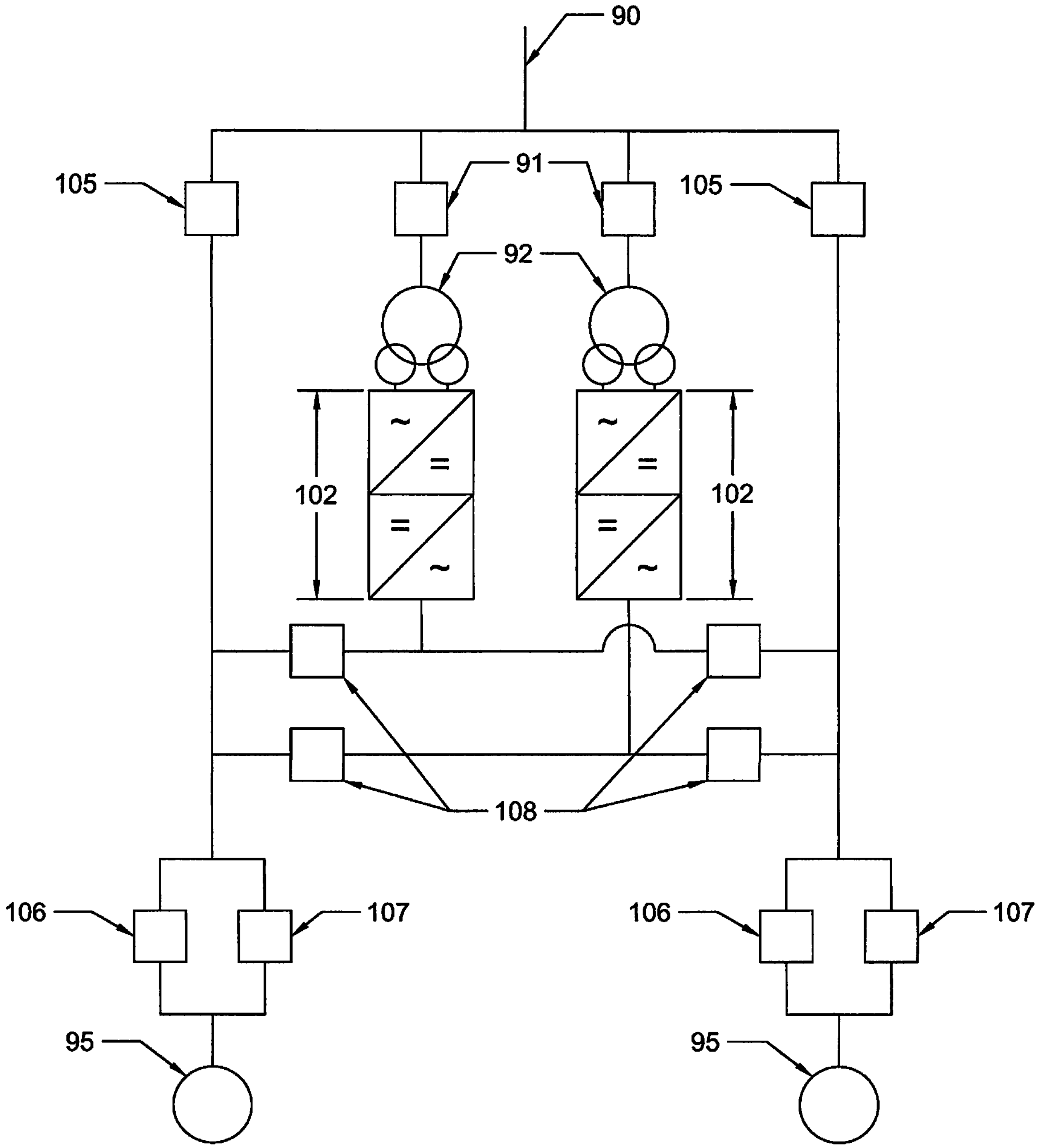

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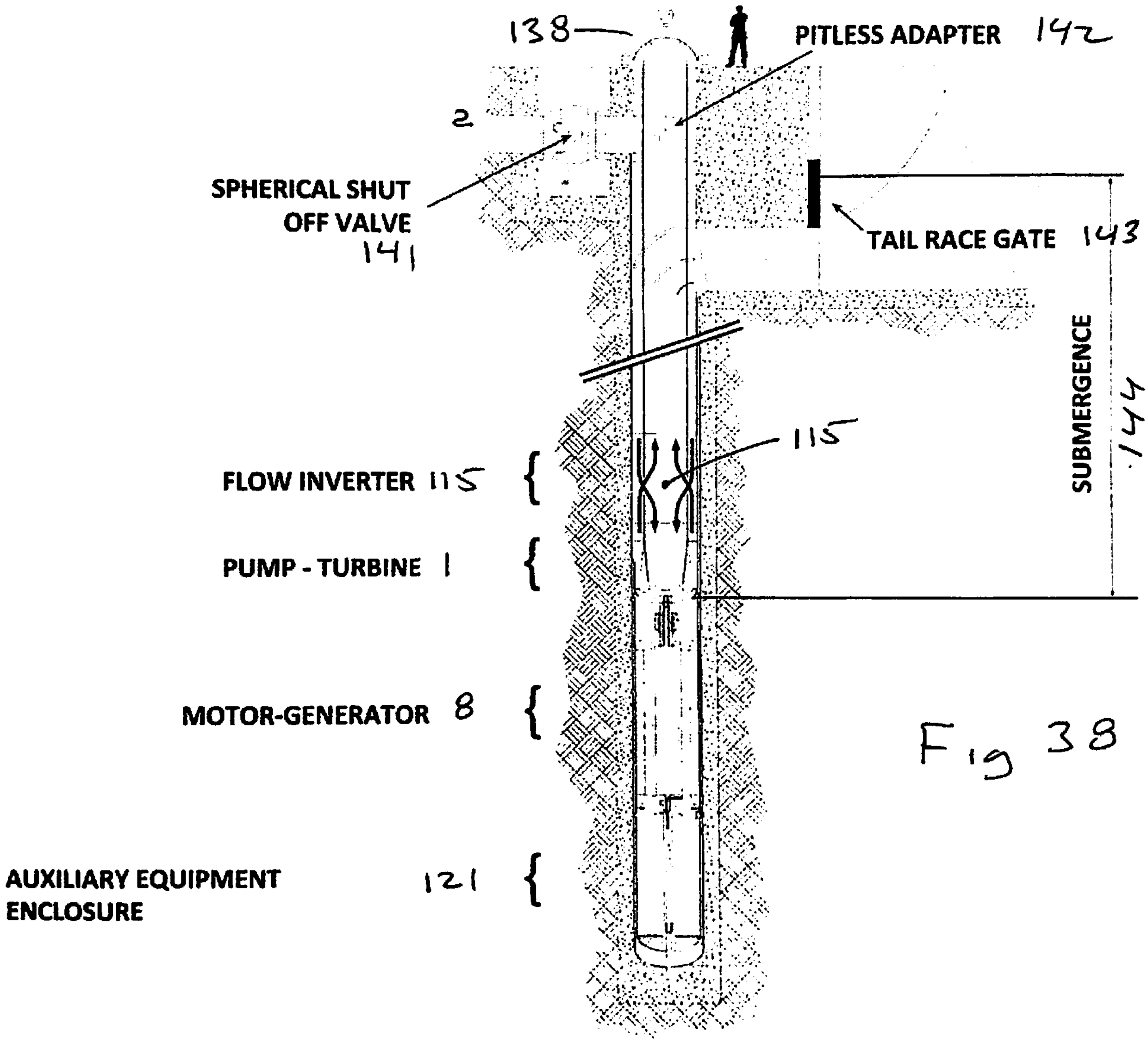

138
PITLESS ADAPTER 142
2
SPHERICAL SHUT OFF VALVE 141
TAIL RACE GATE 143
SUBMERGENCE 144
115
FLOW INVERTER 115
PUMP - TURBINE 1
MOTOR-GENERATOR 8
AUXILIARY EQUIPMENT ENCLOSURE 121

Fig 38

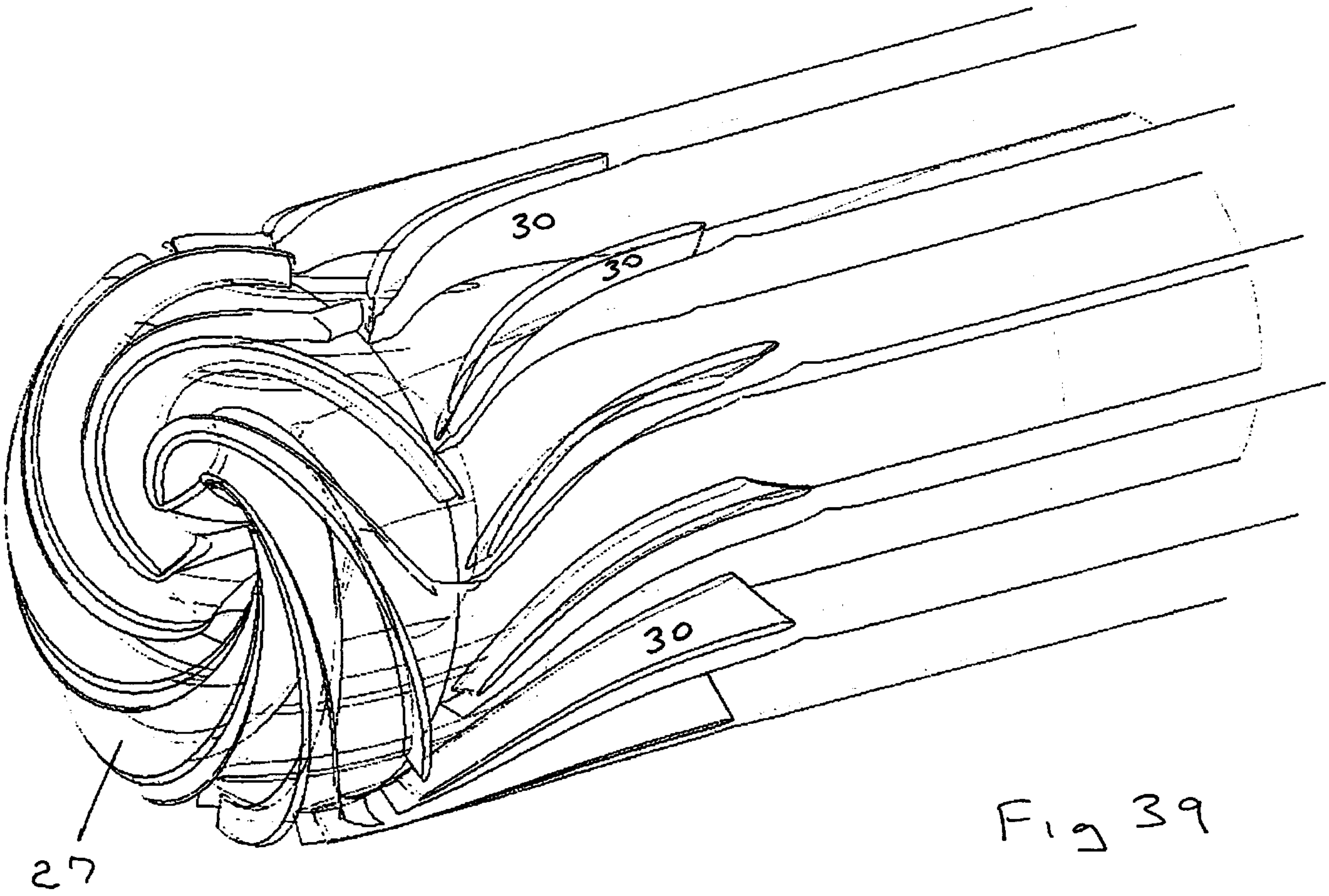


Fig 39

H	300.000	300.000	[m]
DISCHARGE	42.276	36.992	[m^3/s]
SPEED	741.622	857.700	[r.p.m]
SHAFT POWER	111.00	106.134	[MW]
BEST EFF.	95.168	94.551	[%]
$\sigma_{\text{critical estimated}}$	0.19	0.23	[-]

Fig 40c

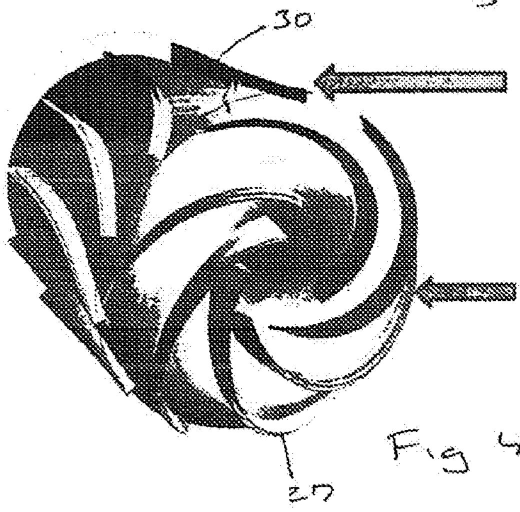


Fig 40b

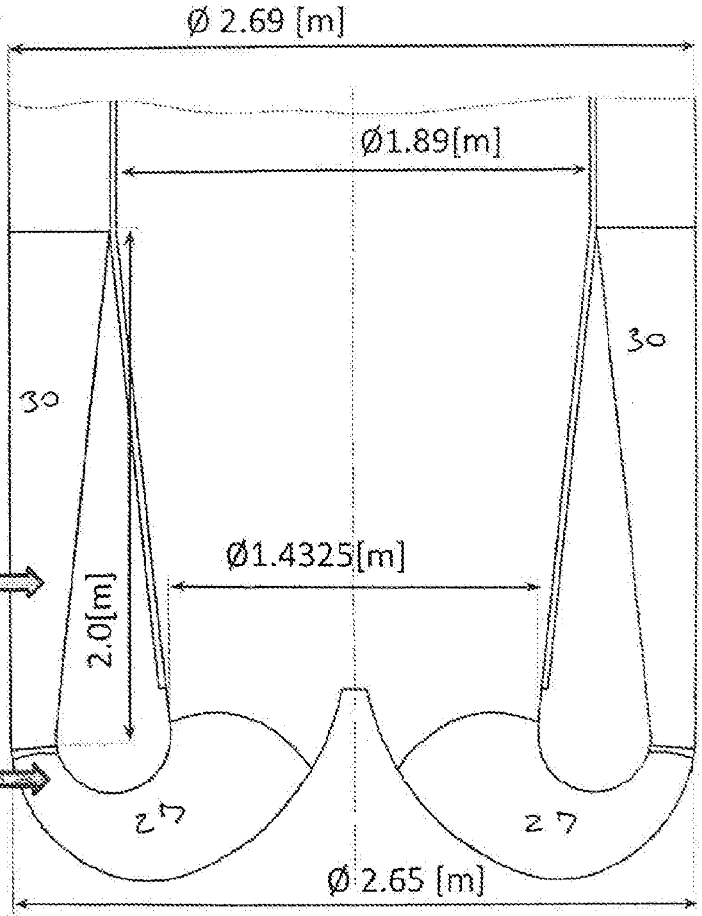


Fig 40a

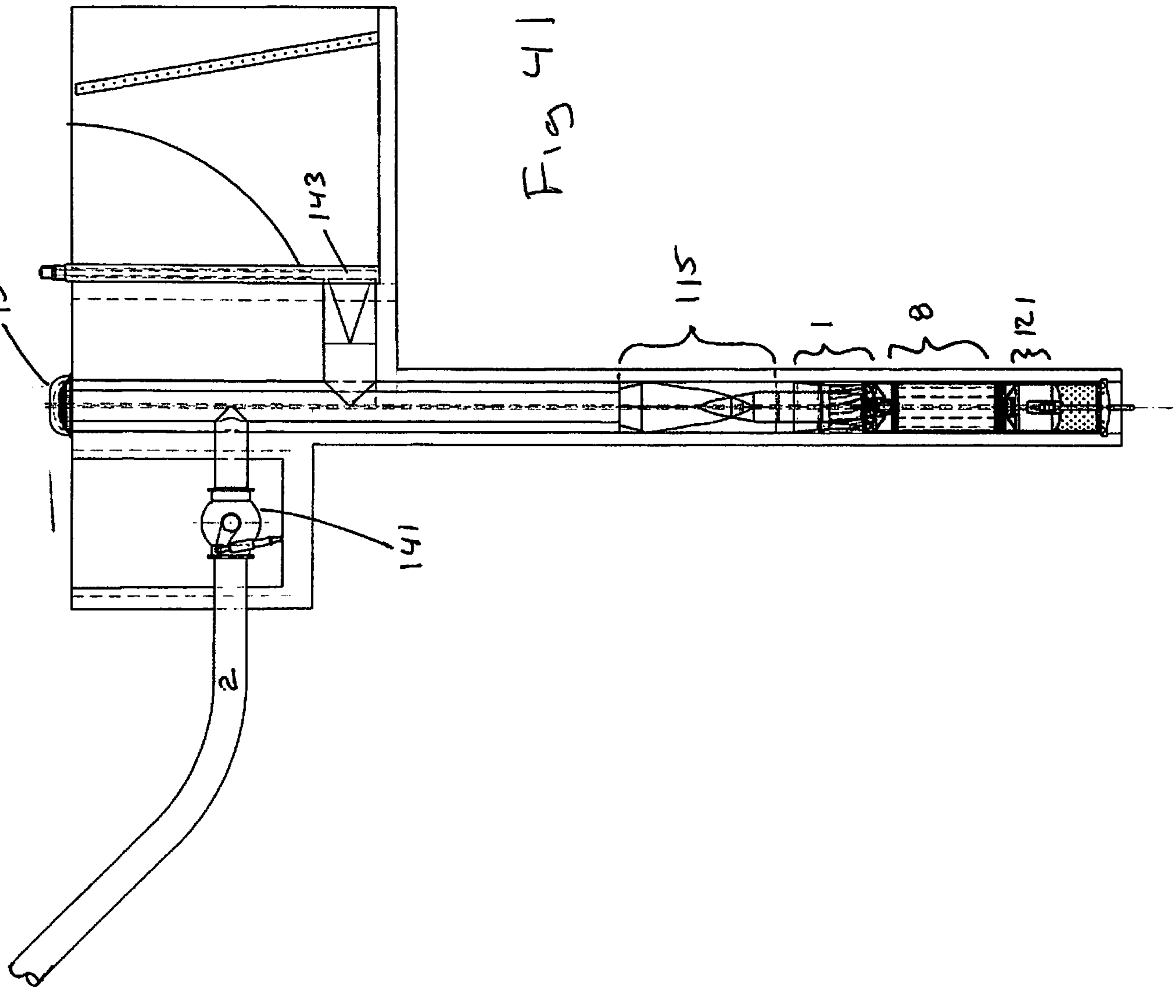


Fig 41

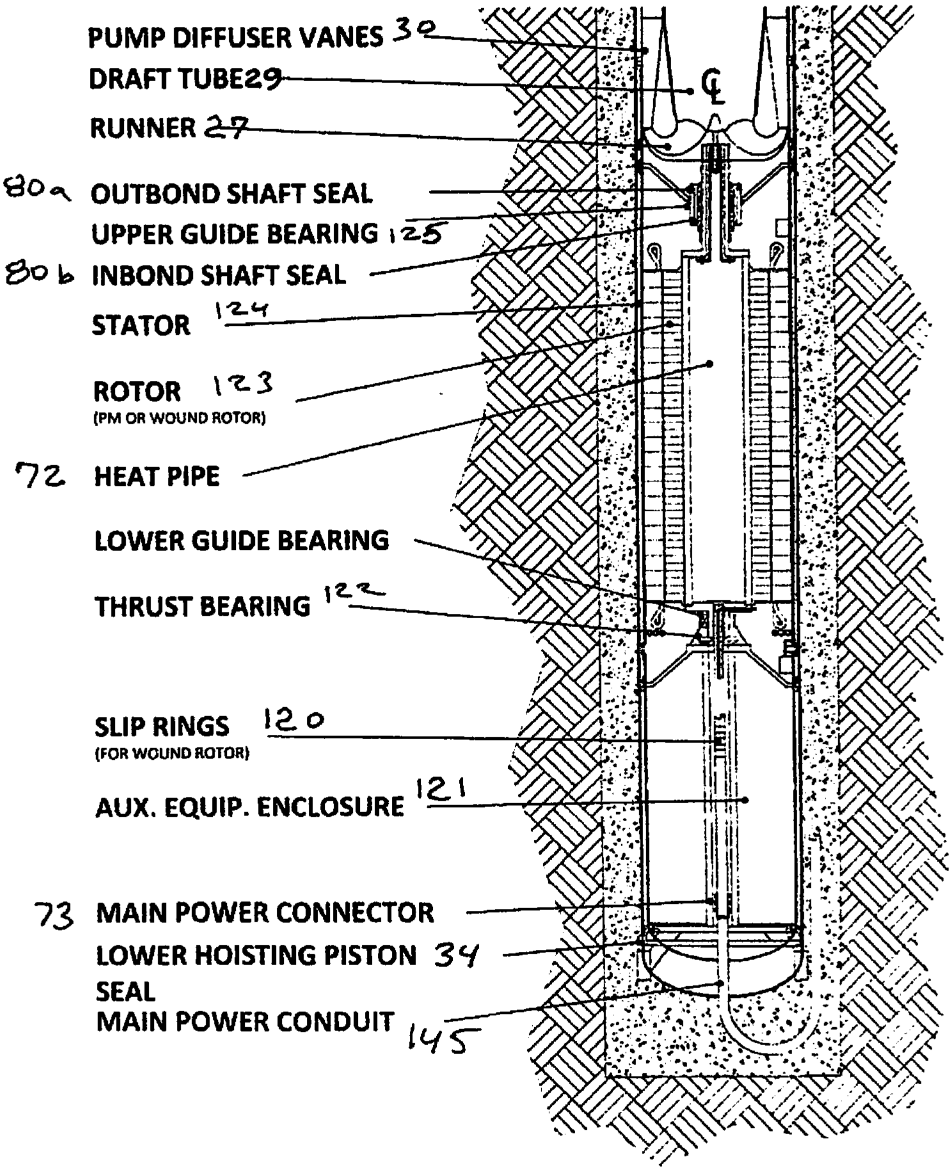
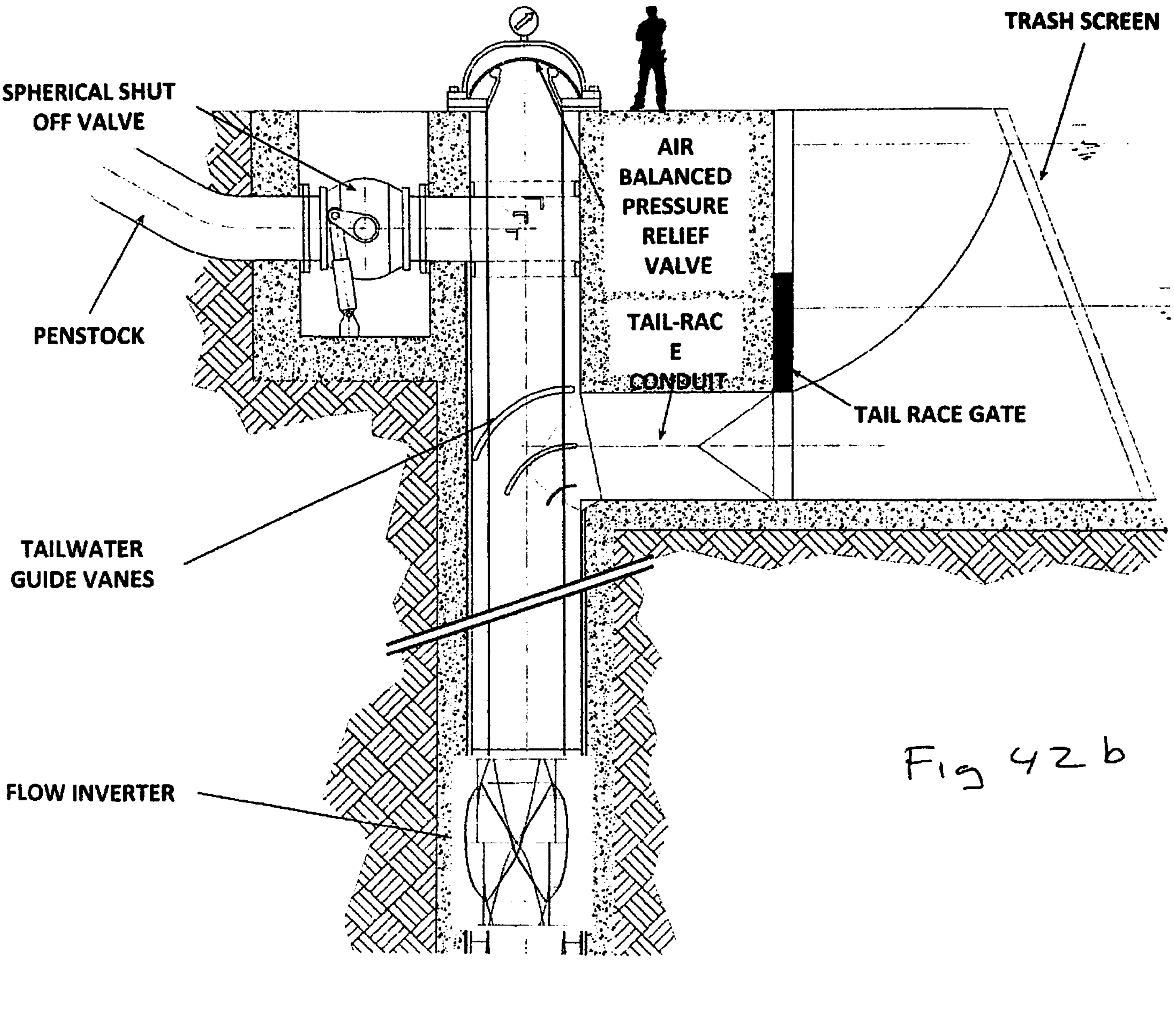

PUMP DIFFUSER VANES 30
DRAFT TUBE29
℄
RUNNER 27
80a OUTBOND SHAFT SEAL
UPPER GUIDE BEARING 125
80b INBOND SHAFT SEAL
STATOR 124
ROTOR 123
(PM OR WOUND ROTOR)
72 HEAT PIPE
LOWER GUIDE BEARING
THRUST BEARING 122
SLIP RINGS 120
(FOR WOUND ROTOR)
AUX. EQUIP. ENCLOSURE 121
73 MAIN POWER CONNECTOR
LOWER HOISTING PISTON 34
SEAL
MAIN POWER CONDUIT 145

Fig 42a



SPHERICAL SHUT OFF VALVE
PENSTOCK
AIR BALANCED PRESSURE RELIEF VALVE
TAIL-RACE CONDUIT
TRASH SCREEN
TAIL RACE GATE
TAILWATER GUIDE VANES
FLOW INVERTER

Fig 42b

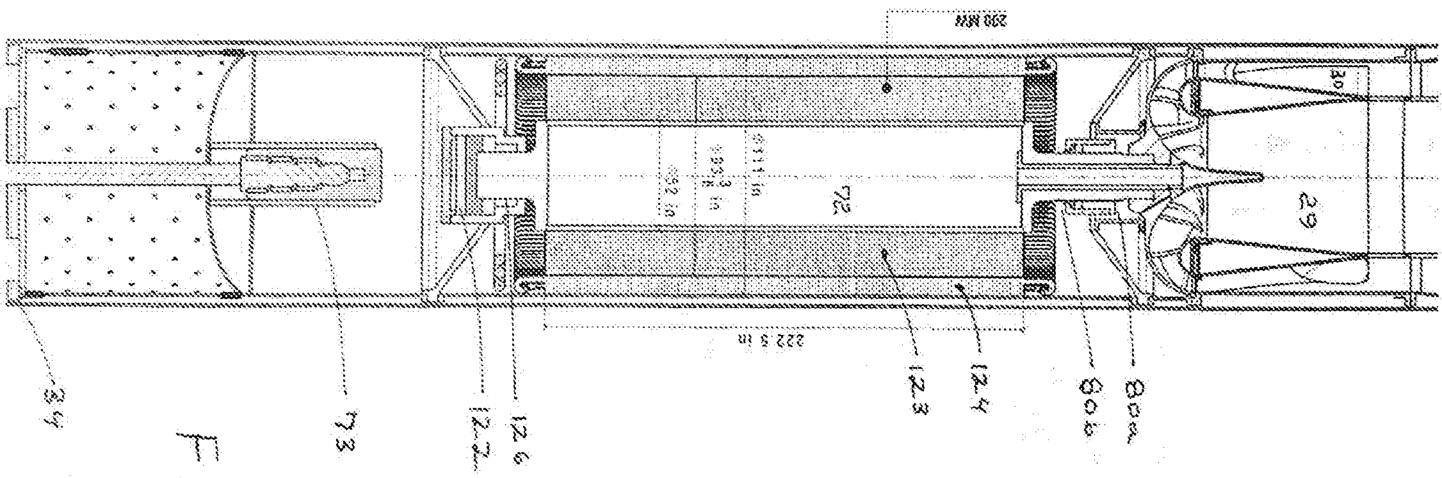


Fig 43

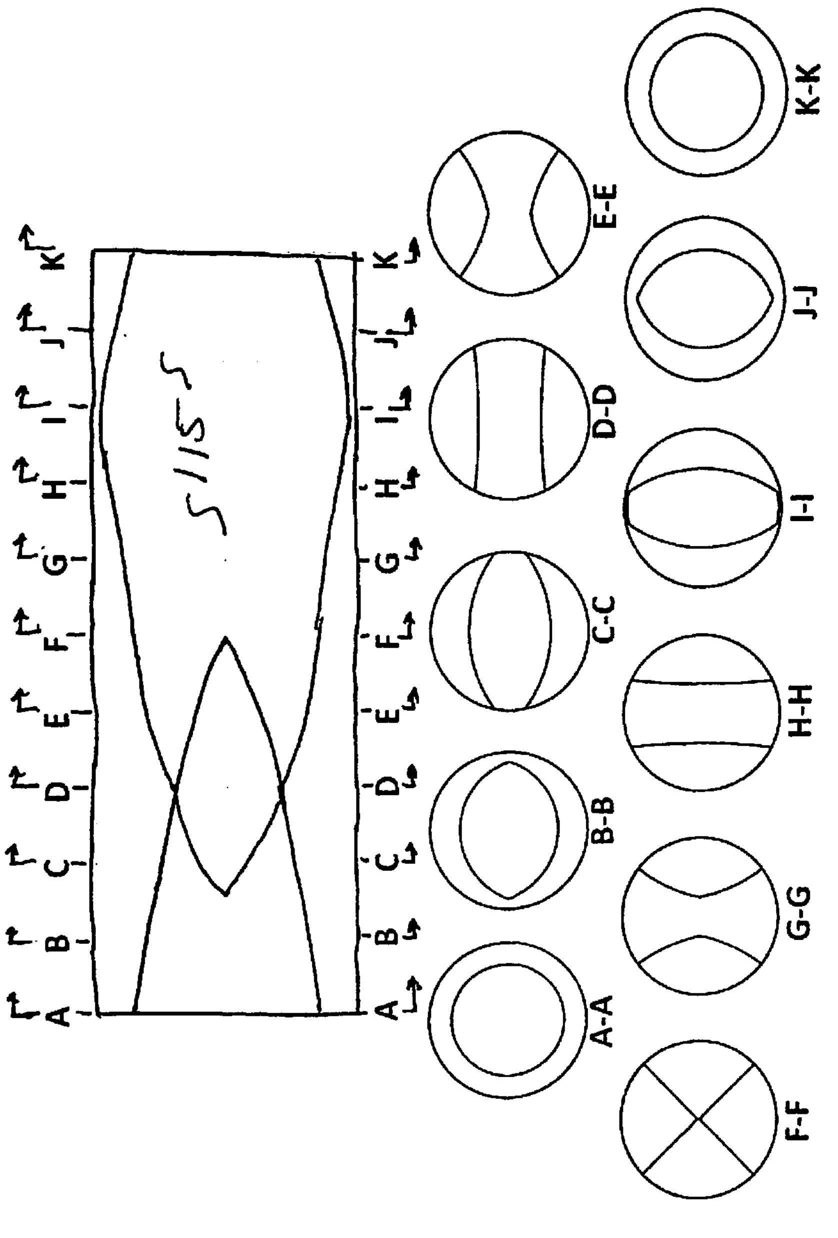


Fig 44a

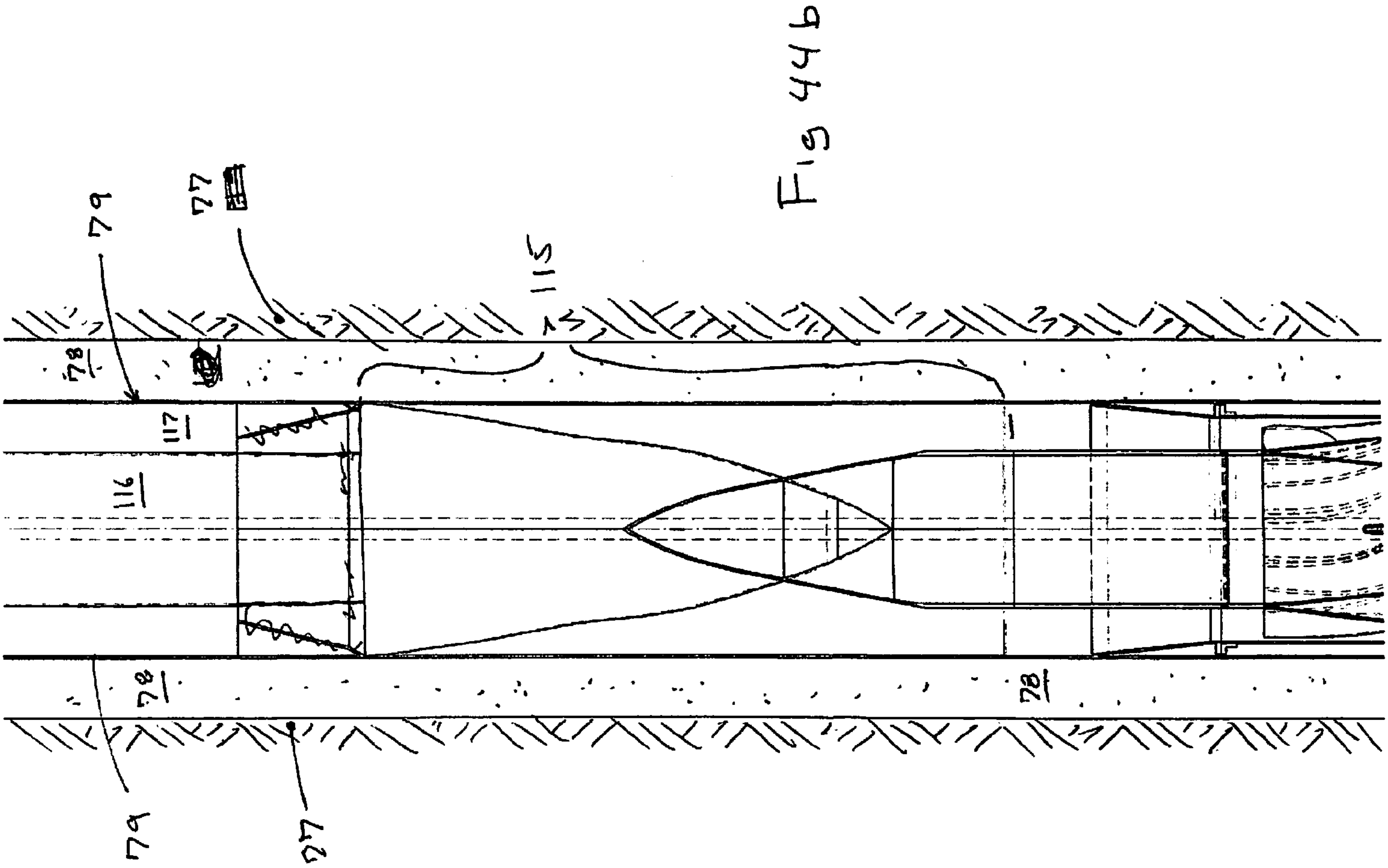
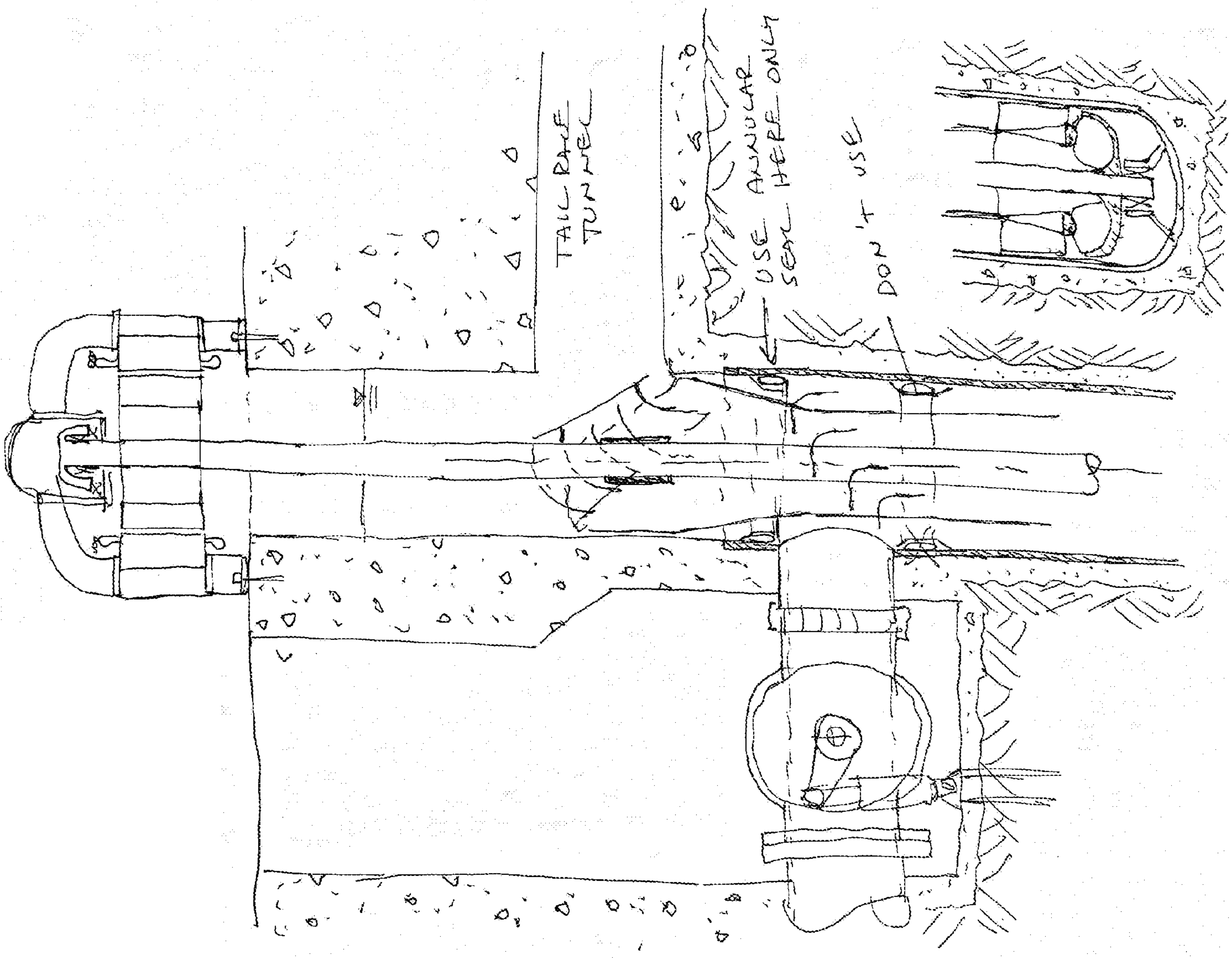
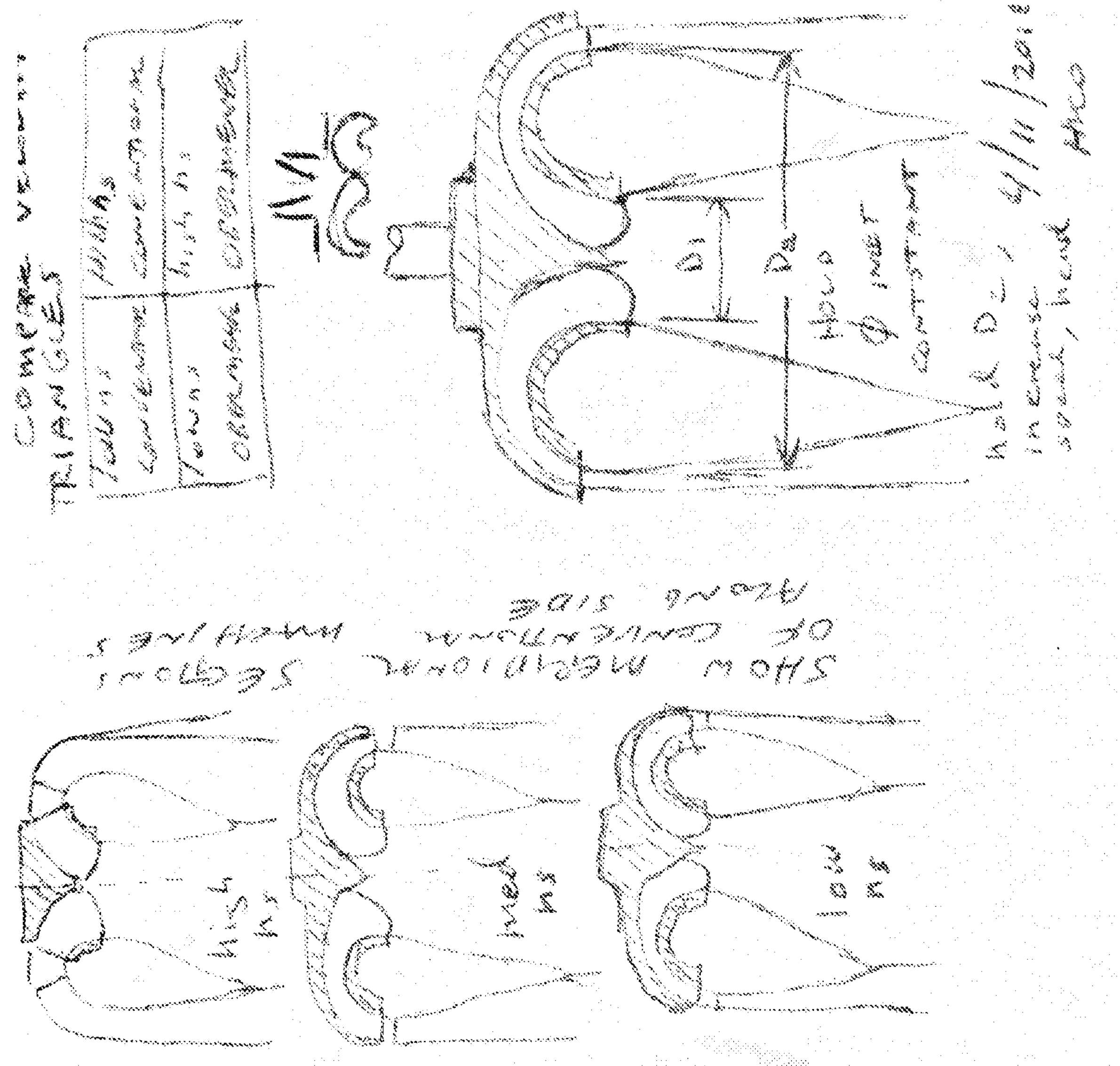


Fig 44b


TAIL RACE TUNNEL
USE ANNULAR SEAL HERE ONLY
DON'T USE


COMPARE VENTURI
TRIANGLES
D1
D2
HOLD
Φ INLET
CONSTANT
4/11/2016
SHOW MERIDIONAL SECTIONS
OF CONVENTIONAL MACHINES
ALONG SIDE
high ns
med ns
low ns

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 18/30310

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - E02B 9/00, F03B 13/06, F03B 13/10 (2018.01)
CPC - F03B 3/103, Y02E 10/223, Y02E 10/226, Y10S 415/91, Y02E 60/17

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History Document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
See Search History Document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History Document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- A	RU 54379 U1 (Rostislavovich et al.) 27 June 2006 (27.06.2006) Entire document, especially Abstract, Specification, Fig 1.	1, 4, 6 --- 2, 3, 5, 7-10, 13-18
X	US 4,804,855 A (Obermeyer) 14 February 1989 (14.02.1989) Entire document, especially Abstract, Specification, Fig 1A.	11, 12
A	Catalog entitled 'Goulds Pumps - Vertical Turbine Pumps' (ITT Corporation) 2012, pgs 11 & 12. [Retrieved from the internet] <URL:https://www.gouldspumps.com/ittgp/medialibrary/goulds/website/Literature/Brochures/Product%20Bulletins/Alphabetical/Goulds_Vertical_Reader.pdf?ext=.pdf>	1-18
A	Report entitled "Evaluation of the Feasibility and Viability of Modular Pumped Storage Hydro (m-PSH) in the United States" (Adam Witt et al.) September 2015, Entire document. [Retrieved from the internet] <URL:https://hydrowise.ornl.gov/sites/default/files/2017-06/Evaluation_of_the_Feasibility_and_Viability_of_Modular_Pumped.pdf>	1-18
A	US 2,246,472 (Sharp) 17 June 1941 (17.06.1941) Entire document, especially Abstract, Specification, Figs 1-7.	1-18
A	US 9,683,540 B2 (Winkler et al.) 20 June 2017 (20.06.2017) Entire document, especially Abstract, Specification, Figs 1, 2.	1-18

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 July 2018	26 JUL 2018

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774