March 8, 1932. L. F. MOODY 1,848,738

HYDRAULIC TURBINE

Filed Nov. 23, 1923 2 Sheets-Sheet 1

Fig:1.

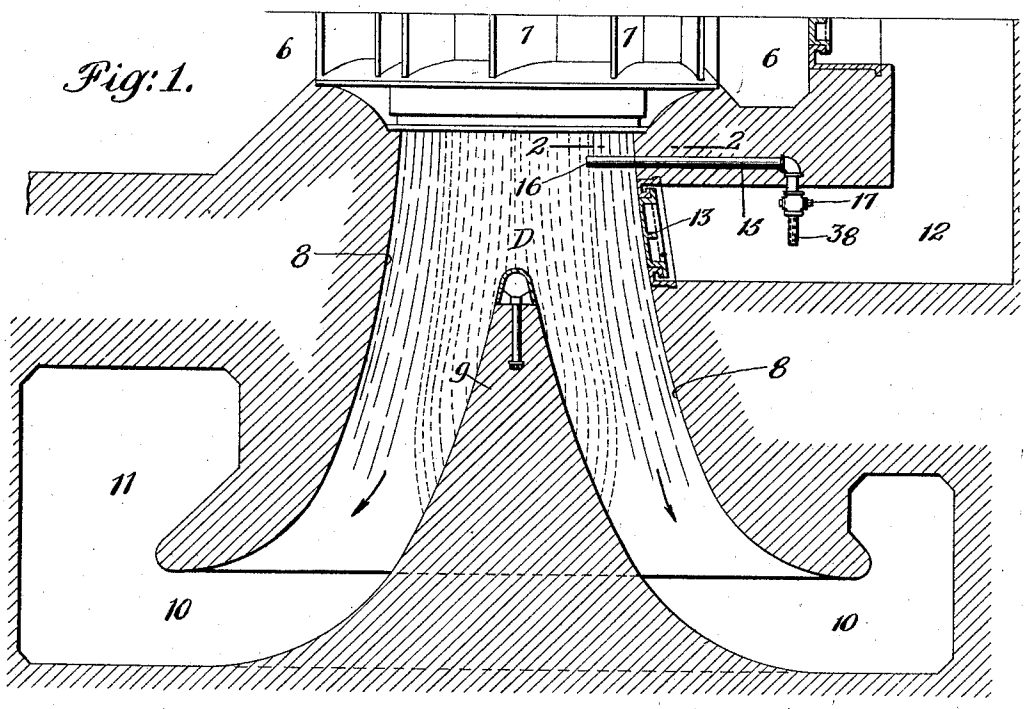

Fig:2.

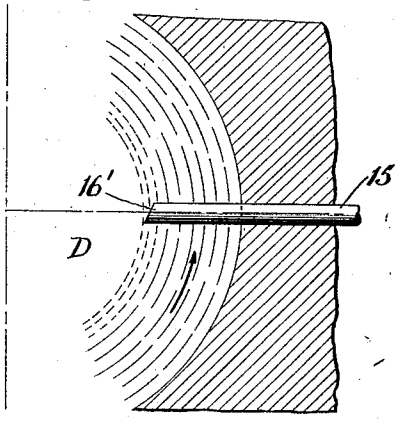

Fig:3.

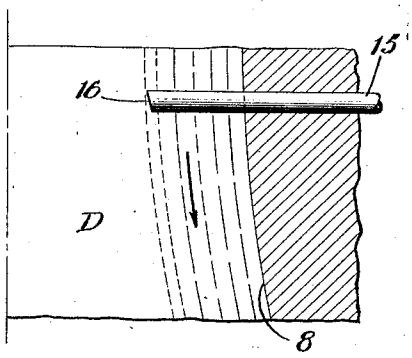

Fig:4.

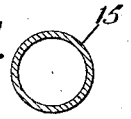

Fig:5.

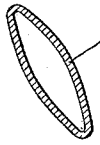

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Fig: 6.

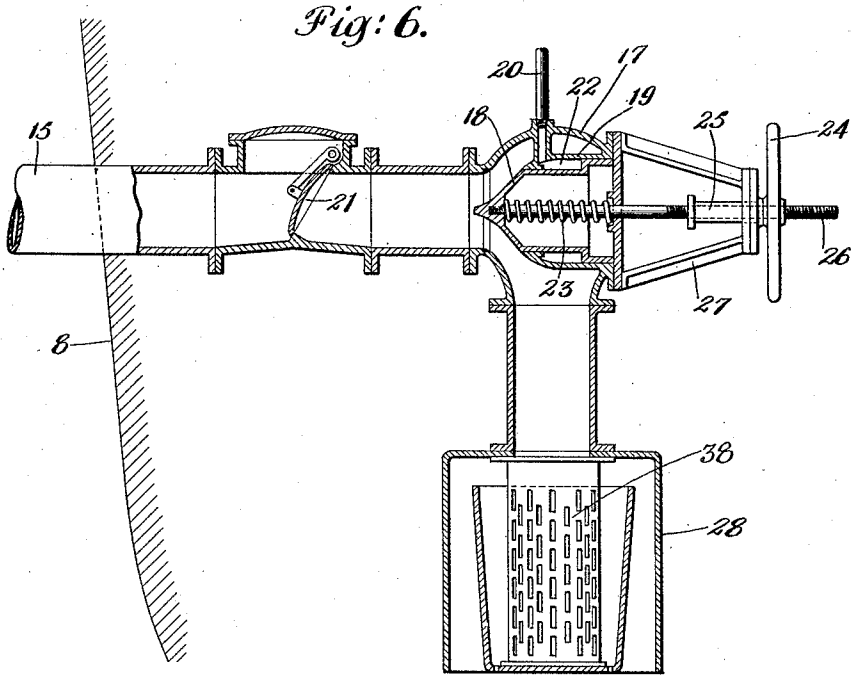
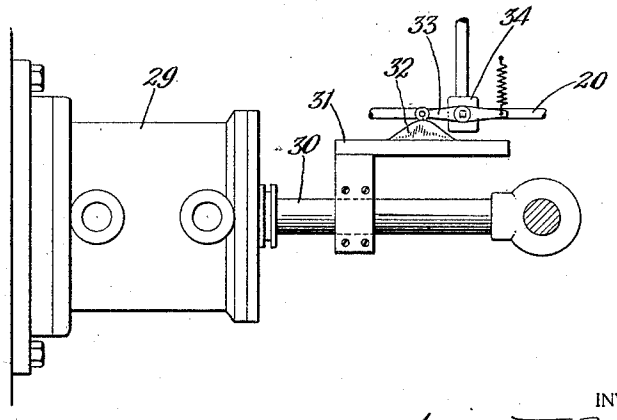


Fig: 7.



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UNITED STATES PATENT OFFICE

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HYDRAULIC TURBINE

Application filed November 23, 1923. Serial No. 676,479.

This invention relates to rotary hydraulic machines and particularly to hydraulic turbines and their draft tubes.

In some turbine installations and under some conditions of operation, particularly at gate openings less or greater than normal or when the tailwater level is abnormally low, trouble sometimes develops from unstable flow in the draft tube causing vibration of the turbine or powerhouse structure or unsteady operation of the turbine. These conditions may result from insufficient margin of absolute pressure in the draft tube to maintain a continuous body of liquid throughout the tube, that is, an excessive draft head resulting from the combination of height of turbine above tailwater, velocity head of the water discharged by the runner, and draft tube efficiency, in comparison with the barometric pressure. Trouble from this source may thus be due to a greater conversion of velocity head into pressure head by the draft tube than the height of the turbine above tailwater permits. On the other hand, a draft tube of unfavorable form, such as an elbow tube, may set up large eddies which cause hydraulic impact or shocks.

In either case, or whenever disturbances occur within a draft tube, I have found that the region particularly subject to the formation of an objectionable void and to the setting up of unstable conditions of flow is that in and around the axis of the tube, and that the tendency toward vibration and disturbances may be overcome by admitting air to the central portion of the tube, this air being admitted at a limited rate by properly proportioning or controlling the air passages.

In the accompanying drawings illustrating the invention

Fig. 1 is a vertical sectional view of a typical turbine installation embodying the invention.

Fig. 2 is a horizontal sectional view taken on the line 2—2 of Fig. 1.

Fig. 3 is an enlarged vertical sectional view of a detail.

Figs. 4 and 5 are cross sectional views of different forms of pipe admitting air into the draft tube.

Fig. 6 is a sectional view of a detail showing an arrangement of control and check valves in the air supply and

Fig. 7 is a plan view of one of the operating cylinders of the turbine showing a method for actuating the control valve of Fig. 6.

In the specific embodiment of the invention shown in the drawings the flow entering by intake 6 passes through the inflow guide vanes 7 and the runner, not shown, and is discharged by the runner into the draft tube D having the outer wall 8 and the inner conical core 9 both flaring outwardly to spread and decelerate the flow in annular form and discharging it through the outlet 10 into the collecting and discharge chamber 11 leading to tailwater. A passage 12 and manhole 13 is provided to give access to the interior of the draft tube D.

In turbines of high and moderate specific speed types there is a tendency under some conditions of operation, particularly at part gate or when operating under heads below normal, for the discharge from the runner to take place in an annular ring at the outer wall of the draft tube, leaving the space within occupied by water not advancing toward the discharge. Under such part-gate or reduced head operation the relative velocity of discharge from the runner buckets is reduced to such an extent in comparison with the velocity of the runner vanes that the discharged water contains large rotational components of velocity about the runner axis. There is therefore a tendency to set the water in the central region of the draft tube into rotation, and for the tangential velocity components to increase at points nearer the axis according to the law of the free vortex, namely, that the tangential velocity varies inversely as the radius. This relation cannot exist throughout the space since it would call for an infinite velocity at the axis; the tendency is however for the rotational velocity to become so high at points near the axis that the velocity head approaches the limit set by the barometric pressure and the elevation above tailwater, and the flow then endeavors to separate and to form a vortex leaving a void around the axis filled with air or vapor. This tendency toward "cavitation"

is likely to cause unstable operation or vibration. When there is such a tendency toward cavitation, it is useful to supply air to the central space to avoid instability, shocks or vibration troubles.

In draft tubes of elbow types trouble is likely to occur from the formation of eddies due to the rotational velocities; and in tubes of symmetrical type such as the "spreading" tube shown in the figures the ability of the tube to convert the velocity head of rotation into pressure head may in some instances cause excessive vacuum in the draft tube at part gate, since the absolute velocity of discharge from the runner may be greater at part gate than at normal gate. In either case it is frequently useful to admit air to the tube and thus to avoid the effects of cavitation or to cushion the impacts or shocks due to turbulence. When air is merely admitted to the outer flow lines through the outer wall of the draft tube, there is a tendency for the flow in the outer portion of the tube to carry the air away before it can penetrate to the central portion so that the desired relief is not secured. Moreover, the centrifugal force of the whirling water in the draft tube causes an increase of absolute pressure at the outer wall which opposes the flow of air into the tube at this point. I have found that the supplying of a suitable amount of air to the inner portion of the tube will overcome any objectionable tendency toward shocks and vibration without interfering with the outer flow lines or impairing the power output or efficiency of the turbine.

I, therefore, provide a pipe or hollow vane-shaped extension 15 having its end 16 approaching inward from the outer wall 8 of the draft tube and opening into the inner or substantially central portion of the draft tube as shown for instance in the drawings. By this means, the air is carried through the rapidly moving annular body of water and admitted into the inner portion of the tube. A valve 17 is provided for the pipe 15 to control the rate of flow of the air. A check valve may also be provided in the air pipe so that it will close during any condition tending to set up a back flow and will thus prevent the discharge of water from the draft tube. For instance, as shown in Fig. 6 pipe 15 may be provided with a check valve 21 and a control valve 17. This check valve will close during any condition tending to set up a back flow and will thus prevent the discharge of water from the draft tube. When the pressure within pipe 15 is less than that of the atmosphere, the check valve will open and permit the flow of air at a rate controlled by the valve 17. Valve 17, as shown, is of the needle or plunger type, which is suitable for reducing the flow of air while permitting the flow to take place smoothly. The valve contains the plunger 18 sliding within the cylinder 19. The plunger may be opened by the admission of fluid, such as water or compressed air, through pipe 20 to the space 22, overcoming the effect of the spring 23. The valve may be closed by exhausting pressure from the pipe 20 and allowing the spring 23 to force the plunger to the left.

In addition to the fluid and spring control just described, the valve is provided with mechanical hand control consisting of a hand wheel 24 carrying the sleeve 25 engaging the threaded stem 26. When the valve is desired to be under fluid control, the hand wheel 24 is backed off to the end of the stem allowing the sleeve 25 to slide freely through the yoke 27. At 28 is shown a muffler or silencer through which air is admitted to the control valve and comprises an outer casing and a tapered inner casing therein, thereby forming inner and outer converging passages. This muffler may consist of a series of baffles and a slotted cylindrical diaphragm, as shown, or other suitable means.

Fig. 7 shows in plan view one of the turbine operating cylinders 29 for moving the turbine gates through the rod 30. On this rod is fitted an arm 31 carrying a cam 32. At any desired position of the gates, the cam may be adjusted to actuate a lever 33 attached to the stem of a two-way cock 34. When this cock is opened, pressure fluid is admitted to pipe 20 which is connected by suitable piping with the pipe 20 of Fig. 6. Instead of spring 23 fluid pressure can, if desired, be admitted to the interior of the plunger for closing the valve 17. Instead of the fluid operated valve 17, a valve operated by electric motor or mechanically operated valve can be used where more convenient. Instead of being actuated by the turbine gates, the fluid or electric or other means can be controlled by hand from the switchboard or other suitable point or the valve may be automatically actuated by the pressure within the draft tube.

When vibration within the draft tube tends to develop at some partial gate opening of the turbine, the fluid or electrically operated valve, such as 17, may be arranged to be automatically actuated by the turbine gate mechanism in a manner similar to that shown, so that air will be admitted to the draft tube whenever the turbine gates are within a predetermined range of opening. Any convenient source of fluid pressure, such as water from the penstock or from the governor system or air from the accumulator tanks, may be used.

The pipe 15 may draw its supply of air from any suitable source such as the passage 12, or if desired, its inlet may be placed outside the building or in a separate chamber arranged to shut off from the powerhouse any noise created by the suction of air into the end of the pipe. The entrance end of the pipe

15 will preferably be provided with a silencer or muffler, such for example, as the peripherally slotted cylinder 38 shown in the drawings, in order to avoid the hissing or whistling of the entering air.

The end of the pipe discharging the air into the draft tube may be formed in any desired manner to increase the "suction" or aspiration effect. As shown in Fig. 3 for instance the end 16 of the pipe 15 instead of being tangential may be bevelled or inclined so as to extend diagonally across the flow which usually has rotational or whirling components in a horizontal plane around the axis as indicated by the arrow (Fig. 2). This diagonal inclination of the edge of the end orifice will increase the "suction" effect. As shown in Figs. 1 and 3 the direction of the bevelling of the end 16 of the pipe in addition to being inclined horizontally will usually be also inclined downward and outward as seen in a vertical plane so as to increase the suction effect of the downward meridian components of the flow.

The pipe 15 may be extended into the draft tube any desired distance or it may be made adjustable to have this distance varied. The pipe may be circular in cross section as shown in Fig. 4 or generally oval or vane shaped in section as shown at 15′ in Fig. 5. This latter form will give a narrower pipe with less resistance to the flow during normal operation when its longer axis is arranged approximately to coincide with the normal lines of flow of the water in the draft tube.

With this air inlet extending inward to a point within the outer wall of the draft tube the air is carried through the swiftly moving stream of water at the outside and is introduced into the central region of the tube which is filled with water not partaking of the general flow. In this central space the water is, of course, subject to turbulence and local reversal of flow with a tendency at times to the formation of a void near the axis, that is, a cavity where air or vapor may collect. The use of the air inlet of this invention is effective in eliminating the tendency toward shocks and vibration without affecting the efficiency of the turbine or its power output.

As a means of introducing air into the body of flowing fluid in a conduit for the purpose of filling voids or cushioning hydraulic shocks, the air inlet means here described may also be applied to other hydraulic machines, particularly certrifugal pumps.

I claim:

1. In a rotary hydraulic machine the combination with a runner and a water conduit containing water flowing with rotational velocity components about the axis of the conduit, of an air inlet extending within the flow in said conduit and adapted to pass air into the interior of the body of water therein.

2. In a rotary hydraulic machine the combination with a water conduit containing a runner, of an air inlet extending within the flow in said conduit and adapted to pass air into the interior of the body of water therein.

3. In a rotary hydraulic machine the combination with a water conduit containing a runner, of an air inlet extending inward from a side toward the central portion of said conduit and adapted to pass air into said portion.

4. In a hydraulic turbine the combination of a draft tube and an air inlet passing through a portion of the water stream within said draft tube and opening at an intermediate point within the body of water in said draft tube.

5. In a hydraulic turbine the combination with a water conduit containing a runner, of an air inlet extending inward from the outer wall toward the central portion of said conduit and adapted to pass air into said portion.

6. In a hydraulic turbine the combination with a water conduit containing a runner, of an air inlet extending inward from the outer wall to a point intermediate between the center and the outer wall of said conduit and adapted to pass air into said conduit.

7. In a dydraulic turbine the combination with a water conduit containing a runner, of an air inlet extending through the flow to a point intermediate between the center and the outer wall of said conduit and adapted to pass air into said conduit.

8. In a hydraulic turbine the combination of a draft tube and an air inlet passing through a portion of the water stream within said draft tube and opening at an intermediate point within the body of water in said draft tube, said inlet terminating in an end obliquely inclined to the flow.

9. In a hydraulic turbine the combination with a water conduit containing a runner, of an air inlet extending within the central portion of said conduit and adapted to pass air into said portion and means for automatically admitting air through said inlet upon occurrence of predetermined conditions in said conduit.

10. In a hydraulic turbine the combination with a water conduit containing a runner, of a stationary air inlet extending within the flow in said conduit and adapted to pass air into the interior of the body of water therein, and adjustable means for controlling the rate of flow of air into said conduit.

11. In a hydraulic turbine the combination with a water conduit containing a runner, of a stationary air inlet extending within the flow in said conduit and adapted to pass air into the interior of the body of water therein, and means for opening or closing said inlet to the admission of air, said means being controlled by the position of the turbine gates.

12. In a hydraulic turbine the combination

with a water conduit containing a runner, of a stationary air inlet extending within the flow in said conduit and adapted to pass air into the interior of the body of water therein, and remotely controlled valve means for opening or closing the admission of air to said inlet, said means being operated from any convenient point.

13. In a hydraulic turbine the combination with a water conduit containing a runner, of an air inlet extending within said conduit and adapted to pass air into the interior of the body of water therein, said inlet passage being equipped with means for decreasing the sound of the entering air comprising a chamber providing an enlarged compartment at the entrance end of said inlet.

14. In a hydraulic turbine the combination with a water conduit containing a runner, of an air inlet extending inward toward the central portion of said conduit and adapted to pass air into said portion and means for automatically admitting air through said inlet upon occurrence of predetermined pressure conditions in said conduit, and sound decreasing means at the entrance to said inlet.

15. In a hydraulic turbine the combination with a water conduit containing a runner, of an air inlet extending within said conduit and adapted to pass air into the interior of the body of water therein, and means for automatically closing said inlet upon the occurrence of a tendency toward a reversal of flow in order to prevent the discharge of water therefrom.

16. In a hydraulic turbine the combination with a water conduit containing a runner, of an air inlet extending inward toward the central portion of said conduit and adapted to pass air into said portion and means for automatically admitting air through said inlet upon occurrence of predetermined pressure conditions in said conduit and automatically closing said inlet to prevent reverse flow therein.

17. In a hydraulic turbine the combination with a runner and a draft tube receiving the flow from said runner, of an air inlet extending inward from the outer wall toward the central portion of said draft tube and adapted to pass air into said portion.

18. In a hydraulic turbine the combination with a runner and a draft tube receiving the flow from said runner, of an air inlet extending inward to a point intermediate between the axis and the outer wall of said draft tube and adapted to pass air into said portion.

19. In a hydraulic turbine the combination with a runner and a draft tube receiving the flow from said runner, of an air inlet extending within the central portion of said draft tube and adapted to pass air into said portion and means for automatically admitting air upon occurrence of predetermined conditions in said draft tube.

20. In a hydraulic turbine the combination with a runner and a draft tube receiving the flow from said runner, of an air inlet extending inward through the flow toward the central portion of said draft tube and adapted to pass air into said portion, said draft tube having a central core with an annular passage around it.

21. In a hydraulic turbine the combination of a draft tube and an air inlet passing through a portion of the water stream within said draft tube and opening at an intermediate point within the body of water in said draft tube, said inlet comprising a hollow vane-shaped member positioned to give small resistance to the flow.

22. In a hydraulic turbine the combination with a water conduit containing a runner, of an air inlet extending inward toward the central portion of said conduit and adapted to pass air into said portion and means for automatically admitting air through said inlet upon occurrence of predetermined conditions in said conduit comprising spring-controlled check valve means.

23. In a hydraulic turbine the combination with a water conduit containing a runner, of an air inlet extending within the central portion of said conduit and adapted to pass air into said portion and means for automatically admitting air through said inlet upon occurrence of any desired degree of pressure difference between the pressure in said conduit and that of the air outside.

24. In a hydraulic turbine the combination with a water conduit containing a runner, of a stationary air inlet admitting air to the central portion of the conduit and adapted to pass air into the body of water therein, said inlet passage being equipped with means for decreasing the sound of the entering air.

25. In a hydraulic turbine the combination with a water conduit containing a runner, of a stationary air inlet admitting air to the central portion of the conduit and adapted to pass air into the body of water therein, said inlet passage being equipped with means for decreasing the sound of the entering air and comprising a plurality of openings.

26. In a hydraulic turbine the combination with a water conduit containing a runner, of a stationary passage having at least a portion thereof converging to form an air inlet admitting air to the central portion of the conduit and adapted to pass air into the body of water therein, said inlet passage having a plunger valve therein for admitting air through said inlet.

27. In a hydraulic turbine the combination with a water conduit containing a runner, of a stationary air inlet passage admitting air to the central portion of the conduit and adapted to pass air into the body of water

therein, said inlet passage being equipped with converging means for decreasing the sound of the entering air, and a plunger valve within said inlet passage for admitting air through said inlet.

28. In a hydraulic turbine the combination with a water conduit containing a runner, of a stationary air inlet admitting air to the central portion of the conduit and adapted to pass air into the body of water therein, said inlet passage being equipped with means for decreasing the sound of the entering air comprising a plurality of restricted openings.

29. In a hydraulic turbine the combination with a water conduit containing a runner, of a stationary air inlet admitting air to the central portion of the conduit and adapted to pass air into the body of water therein, said inlet passage being equipped with means for imposing a resistance to the flow of air therethrough in order to provide low velocities and consequent avoidance of the creation of sound waves.

30. In a hydraulic turbine the combination with a water conduit containing a runner, of a stationary air inlet admitting air to the central portion of the conduit and adapted to pass air into the body of water therein, said inlet passage being equipped with means for imposing a resistance to the flow of air therethrough in order to provide low velocities and consequent avoidance of the creation of sound waves comprising a plurality of tortuous passages for the air flow.

31. In a hydraulic turbine the combination with a water conduit containing a runner, of a stationary air inlet admitting air to the central portion of the conduit and adapted to pass air into the body of water therein, said inlet passage having an opening in contact with the moving water in the turbine so formed as to make the velocity head of said water effective in reducing the pressure at said opening below the static pressure in the water and permitting drawing air into the turbine when the water pressure is above that of the atmosphere.

32. In a hydraulic turbine the combination with a water conduit containing a runner, of an air inlet extending inward toward the central portion of said conduit and adapted to pass air into said portion, and plunger valve means for automatically admitting air through said inlet upon occurrence of predetermined conditions in said conduit and independently of the turbine speed.

33. In a hydraulic turbine, the combination comprising a water conduit containing a runner, an air inlet adapted to pass air into said conduit below said runner, and means for admitting air through said inlet automatically only upon occurrence of a predetermined part gate operation.

34. In a hydraulic turbine, the combination comprising a water conduit containing a runner, gate operating mechanism for said turbine including a servo-motor, an air inlet adapted to pass air into said conduit, and means admitting air through said inlet automatically upon occurrence of a predetermined position of said servo-motor, said automatic means including a valve and a cam movable with said servo-motor adapted to effect actuation of said valve when reaching a predetermined position in the servo-motor movement.

35. In a hydraulic turbine, the combination comprising a water conduit containing a runner, a passage for admitting air to said conduit, and an inlet for said passage equipped with means for decreasing the sound of the entering air comprising a plurality of converging passages.

36. In a hydraulic turbine, the combination comprising a water conduit containing a runner, a passage for admitting air to said conduit, and an inlet for said passage equipped with means for decreasing the sound of the entering air comprising a plurality of converging passages disposed in opposite directions and communicating with each other.

37. In a hydraulic turbine, the combination comprising a water conduit containing a runner, a passage for admitting air to said conduit, and an inlet for said passage equipped with means for decreasing the sound of the entering air comprising a plurality of concentric converging passages.

38. In a hydraulic turbine, the combination comprising a water conduit containing a runner, an air inlet adapted to pass air into said conduit, and means for admitting air through said inlet automatically only upon occurrence of a predetermined part gate operation, said means including a power actuated remote control valve mechanism operated in accordance with the part gate operations.

39. In a hydraulic turbine, the combination comprising a water conduit containing a runner, an air inlet adapted to pass air into said conduit, and means for admitting air through said inlet automatically only upon occurrence of a predetermined part gate operation, said means including a pressure fluid operated valve and control means therefor.

40. In a hydraulic turbine, the combination comprising a water conduit containing a runner, an air inlet adapted to pass air into said conduit, and means for admitting air through said inlet automatically only upon occurrence of a predetermined part gate operation, said means including a spring operated valve for said inlet.

41. In a hydraulic turbine, the combination comprising a water conduit containing a runner, an air inlet adapted to pass air into said conduit, and means for admitting air through said inlet automatically only upon occurrence of a predetermined part

gate operation, said means including a spring operated valve for said inlet and power means for operating the valve against the action of said spring.

42. In a hydraulic turbine, the combination comprising a water conduit containing a runner, an air inlet adapted to pass air into said conduit, and means for admitting air through said inlet automatically only upon occurrence of a predetermined part gate operation, said means including a valve for said inlet and means for operating the same in one direction by pressure fluid and in the other direction by a spring.

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