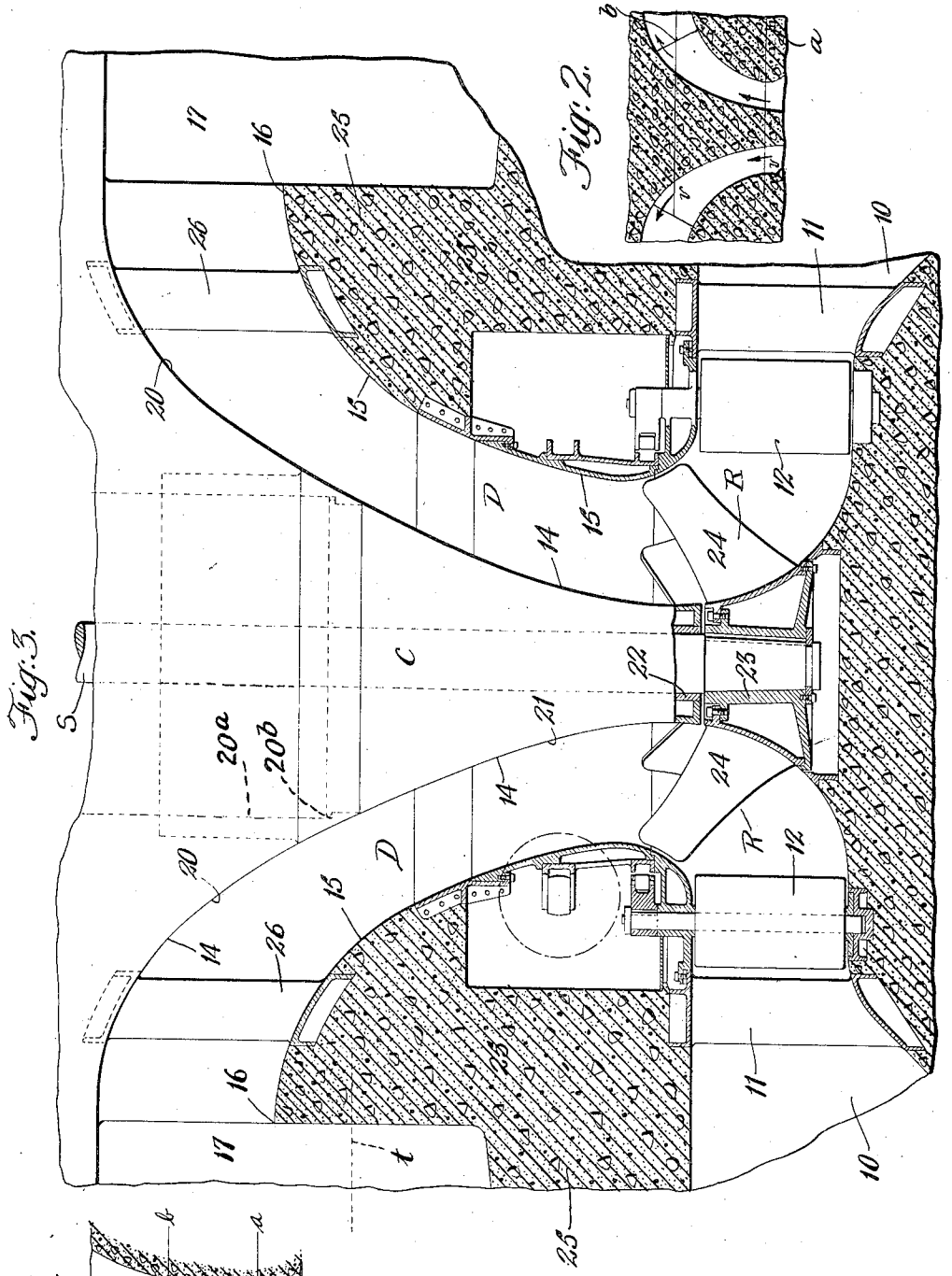
June 22, 1926. **1,590,049**

L. F. MOODY

PROCESS AND APPARATUS FOR UTILIZING ENERGY OF FLOW

Filed August 27, 1921 2 Sheets-Sheet 1



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June 22, 1926. 1,590,049

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PROCESS AND APPARATUS FOR UTILIZING ENERGY OF FLOW

Filed August 27, 1921 2 Sheets-Sheet 2

Fig:4.

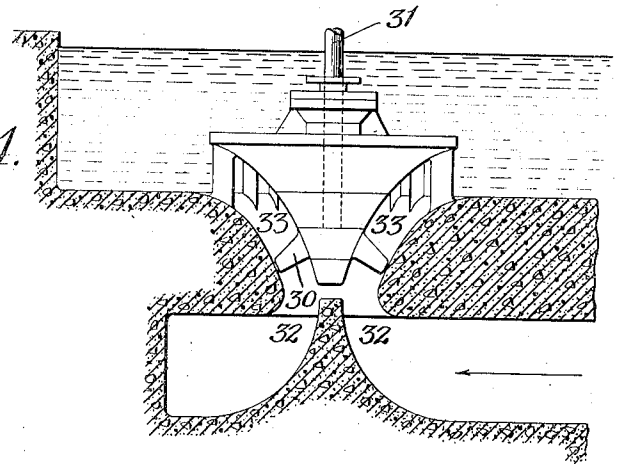
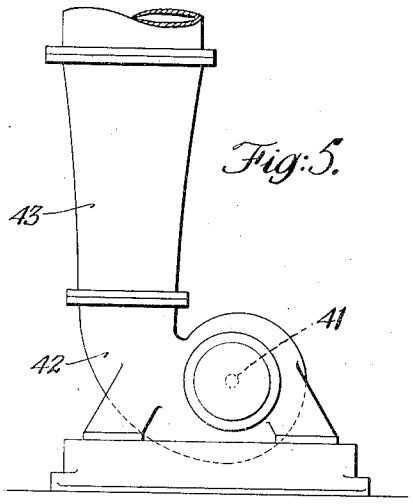


Fig:5.



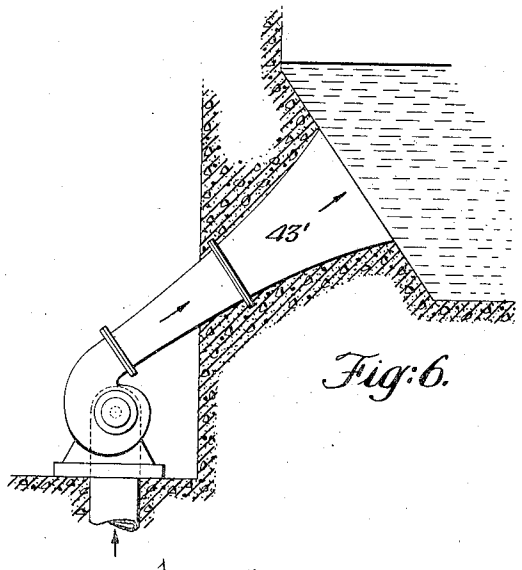
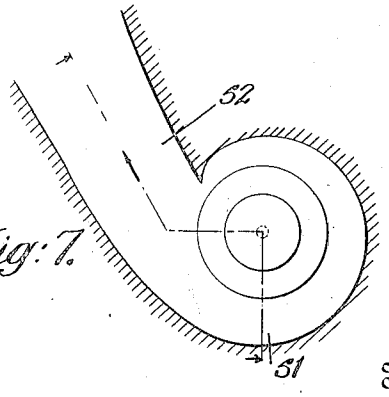


Fig:6.

Fig:7.



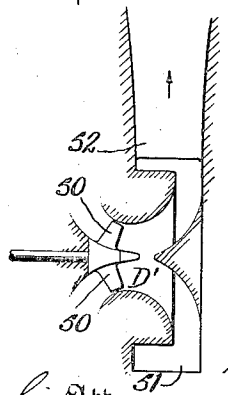


Fig:8.

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UNITED STATES PATENT OFFICE.

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PROCESS AND APPARATUS FOR UTILIZING ENERGY OF FLOW.

Application filed August 27, 1921. Serial No. 496,154.

During the flow of fluid through various kinds of hydraulic apparatus it is frequently desired either to accelerate or to retard the velocity of flow. The acceleration of velocity can be easily and efficiently accomplished, but it has been recognized that the retardation or "deceleration" of velocity has, according to the methods heretofore employed, involved an unavoidable loss of energy. The methods in common use for decelerating the velocity of flow have consisted merely in carrying the flow through an enclosing conduit, the cross-sectional area of which, measured normally to the motion of the stream, increases gradually in the direction of flow. Reliance is placed on this increase in area, and the diverging walls of the conduit, to cause the velocity to decrease. It will be shown below, however, that this method necessarily accomplishes the deceleration at the expense of a loss of a considerable portion of the kinetic energy of the flow; and it is the object of this invention to reduce these losses, and thereby to enable velocity to be decelerated more efficiently.

The method of this application consists in directing the flow upward, and assisting the desired deceleration by the direct downward action of gravity acting upon the flowing mass. Any particle of the stream if moving upward freely and not influenced by impact from the preceding or following particles, nor by viscous or tangential forces from particles on either side, will have its kinetic energy reduced by transformation into potential energy of position—its velocity head being reduced by the exact amount that its elevation above any fixed datum increases. By so forming the enclosing conduit walls that all particles of the stream will decrease in velocity by the definite amount called for by this relation, natural or "gravity deceleration" will be secured, instead of the forced or induced deceleration of the methods heretofore used.

Fig. 1 is a diagrammatic representation of a portion of a vertically directed simple conduit illustrating the invention.

Fig. 2 is a similar view of a spreading conduit.

Fig. 3 is a vertical sectional elevation of a turbine draft tube illustrating the invention, and

Figs. 4 to 8 are diagrammatic illustrations of modifications adapting the invention for use with pumps, turbines, etc.

Consider first a simple conduit in which the flow is substantially parallel to the axis, as in Fig. 1; and at any two sections a and b let the respective cross-sectional areas be A_1 and A, the corresponding velocities v_1 and v, and the elevations of the two sections z_1 and z. For a substantially incompressible fluid such as water the quantity flowing, Q, measured in cubic feet per second, will be the same at all sections in accordance with continuity of flow; so that

$$A_1=\frac{Q}{v_1} \text{ and } A=\frac{Q}{v}.$$

If the conduit is designed in accordance with the principles of this invention, the velocities must have the relation

$$\frac{v_1^2}{2g}+z_1=\frac{v^2}{2g}+z.$$

From these relations, the proper cross-sectional area at any point can be found depending upon the elevation of the point, to carry out this method. For example, if the area A_1 and the velocity v_1 are fixed, the amount for any other area such as A may be computed from the above relations, thus:—

$$A=\frac{v_1 A_1}{\sqrt{v_1^2-2g(z-z_1)}}$$

In order that the benefit of the method of this invention may be fully realized, sufficient space should be available to allow the necessary vertical length of conduit to be secured. If it is desired to decelerate fully by this method, the flow from a given initial velocity v_1 to a given final velocity v_2, the available height of conduit must be equal to the difference of the initial and final velocity heads, that is:—

$$Z_2-Z_1=\frac{v_1^2}{2g}-\frac{v_2^2}{2g}$$

When the initial flow contains whirl or tangential components of velocity about the conduit axis, for instance in the discharge of a high speed turbine runner, the vertical height may in some cases be proportioned in accordance with the total resultant velocity at each point, instead of in accordance with only the vertical components of the velocity. This refers particularly to a tube of the "spreading" type as shown in Fig. 2. If the height is proportioned so as to absorb the entire resultant velocity, the pressure will be

constant from point to point along the lines of flow, except for the small effect of surface friction. In other cases, however, particularly when limited height is available the method of deceleration by gravity may be applied merely to the vertical or meridian component of the initial velocity, leaving the whirl component to be converted by diverting the flow away from the axis and reducing its amount by the use of the principle of constancy of moment of momentum, by which the whirl components will vary inversely as the radial distance from the axis. In such an upwardly directed tube (Fig. 2) we thus have very efficient means of converting both the meridian and whirl components of velocity, the meridian components being decelerated by the method of this invention and the whirl components by the use of a conduit spreading away from the axis and applying the principle of conserving the moment of momentum of the whirling flow.

In some installations it may be desirable to provide a small additional height to offset the tendency of the surface roughness of the conduit walls to produce the effect of divergence or enlargement; but if too much increase in length is allowed, the increase in extent of surface will more than offset any gain. On the other hand in many cases, particularly in small conduits where the surface resistance is comparatively great, it may be advisable to reduce the height a small amount below that corresponding to the difference in velocity heads, in order to minimize the total loss. When the space limits do not permit sufficient vertical height for complete deceleration by gravity, "induced" deceleration or "diffusion" may be added by giving the walls an additional divergence beyond that required by the gravity deceleration; but this additional divergence should not exceed about 4° or 5° if excessive losses are to be avoided.

A conduit having less height than that corresponding to the reduction in velocity head will secure some advantage from the deceleration by gravity, but while the conditions will be better than in a similar tube having horizontal or downward flow, the full benefit of this principle will not be secured if the height is materially less than the difference in velocity heads, since a distinct enlargement or diffusion loss will then occur.

It is of course not desired to reduce the velocity completely to zero since it is necessary to leave a certain final velocity of discharge to carry away the water, but this final velocity may readily be reduced to a small value by a slight increase in height when space is available for this and for the required area of the discharge passages or tailrace.

In Fig. 3 of the drawings a specific embodiment of the invention is shown illustrated in connection with a hydraulic turbine having a vertical shaft S and an upward discharging runner R. The inflow entering by intake 10 passes through the vanes of speed ring 11 and through guide vanes 12 to the runner R from which it discharges upward into the draft tube D formed as an annular expanding passage around the central core C. The core C provides an inner surface 14 formed as a surface of revolution of generally inverted conical form. The outer surface 15 of the draft tube is also formed as a concentric surface of revolution spaced from the inner wall to provide successive outflow areas increasing in accordance with this invention to correspond to the gravity deceleration of the discharge. The outer draft tube surface 15 terminates in a circular ridge or crest 16 preferably above tail water level t so that the discharge from the draft tube D into discharge passage 17 passes above tail water level in the form of a siphon. This siphonic form of draft tube at its crest 16 may carry the outflow above the tailwater level and is particularly adapted to take full advantage of the principle of this invention since it thus permits the draft tube to be of the exactly desired length without requiring an unnecessary lowering of the turbine runner or increased excavation. The use of the siphonic arrangement is in effect equivalent to placing the entire discharge stream in a partial vacuum.

In the turbine installation shown in Fig. 3, the draft tube D is of the spreading type, particularly adapted for a whirling discharge from the runner. The core C has a concrete base 20 with a central bore 20^a and the hollow conical casting 21 is lowered through the bore of this base and suspended from the annular shoulder 20^b of the base as shown. The shaft bearing 22 carried by the lower end of this casting 21 provides a support near the runner R, which is built up of a hub 23 carrying the blades 24 in detachable sections so that the vertical opening above will not have to be large enough to pass the full diameter of the runner, but only the diameter of the hub 23.

The outer wall 15 of the draft tube D is formed by the surrounding portions 25 of the concrete subfoundation and by the liners carried thereby. The whole arrangement is simple and compact providing a continuous columnar support through stay vane rings 11 and 26 and the annular concrete body 25. The outflow passage 17 beyond the crest 16 is large in area having a low velocity of flow.

The gradual and continuous increase in area of the draft tube D provides for the deceleration of the outflow at substantially the same rate that gravity would decelerate

it if freely discharged. The deceleration may therefore be considered as due to the retarding effect of gravity on each particle of the flow. By this deceleration the pressure is reduced below the corresponding static pressure and the pressure reduction varies directly as the depth at each point so that the pressure is substantially constant throughout the gravity deceleration portion of the draft tube. When the runner is depressed to a relatively low elevation the velocity head at its discharge is high in comparison with the net head on the turbine. In the draft tube of this invention therefore substantially constant pressure is maintained in that portion in which the velocity head is high in comparison with the net head.

It is the object of this method of decelerating the velocity to diminish the losses inherent in the ordinary method, which I have termed deceleration by "diffusion", in which the deceleration is produced (or "induced") by the enlargement of area of the enclosing walls alone, without the assistance of the direct action of gravity.

If a jet of water at a considerable velocity is discharged horizontally into a large body of water, the surface of the jet will experience retarding forces from the surrounding water, and the outer portions of the jet will be retarded to lower velocities, resulting in a spreading of the jet in order that it may occupy the necessary area to accommodate the given discharge at the reduced velocity. By this action the entire stream is gradually spread out or "diffused" and its velocity is finally reduced to zero, its original velocity head being dissipated. For instance where a tube discharges into a body of water the jet from the tube can be vividly seen to spread and decelerate the drag of the water on the jet, causing the water to circulate in closed paths around the path of the jet. By enclosing the jet in a gradually enlarging conical passage having a small angle of divergence of its walls, the dissipation of energy will be reduced and the deceleration will be accomplished without the loss of the whole of the initial velocity head. But whether a jet is surrounded by a large body of water or by an enclosing casing only slightly larger than the free jet, any enlarging of cross-section of the stream, and consequently any deceleration, must be initiated by, and accompanied by, resistances acting on the surface of the jet, and consequent losses. Without such action the jet would continue unchanged in area and velocity and there would be no velocity head conversion.

The diffusion loss can be made evident by reversing the flow through a horizontal conical pipe. When the flow is in the direction involving contraction of area the loss of head will be merely that due to hydraulic surface "friction"; but in the direction involving enlargement an additional loss will be observed; the velocities being kept the same. This loss due to enlargement is thus distinct from, and exists in addition to the socalled "pipe friction" or surface resistance loss. It is this enlargement loss, or what I term "diffusion" loss, which it is the object of this invention to reduce by discharging the fluid vertically upward, or at a considerable angle with the horizontal, and by providing a vertical height corresponding to the velocity head, the conversion of which is desired.

The method of this invention is applicable to all points in hydraulic turbines, pumps, ejectors or other hydraulic installations where it is desired to convert kinetic into potential energy of the flowing fluid.

In Fig. 4 the invention is illustrated in connection with a vertical shaft pump having impeller 30 on shaft 31. The flow entering from intake 32 below passes upward through the runner and into the decelerating passage 33 formed to convert the kinetic energy of the flow into gravity head in accordance with the principle of this invention. This decelerator 33 thus takes the place of a diffuser in the pump discharge and attains a much more efficient conversion of the kinetic energy of the discharge with a resulting increased efficiency for the pump as a whole.

In Fig. 5 a horizontal shaft pump is shown in vertical elevation with the runner on shaft 41 discharging into a volute casing 42 in which the outflow is collected and directed vertically upward into the conical decelerator 43 formed in accordance with this invention to give a lowering of the flow velocity corresponding to the vertical elevations at successive points.

In Fig. 6 the axis of the discharge decelerator 43′ is shown as inclined between the vertical and horizontal positions. In this inclined decelerator successive sections are formed to correspond to the deceleration of the flow at the mean elevations of the respective sections.

In Figs. 7 and 8 a horizontal shaft turbine is shown having a runner 50 with substantially axial discharge into a draft tube D′. This draft tube D′ is of the spreading type turning the flow and expanding it to convert the energy of the whirl velocity into pressure head and delivering it to the expanding spiral collector passage 51 opening upward into the decelerator passage 52 formed in accordance with this invention to expand accordingly as the velocity of the outflow is lowered an amount corresponding to the action of gravity.

Instead of decelerating the velocity of a fluid stream by enlargement of the cross-sectional area of the enclosing conduit walls

without regard to the general direction of flow as it affects the elevation of successive sections, this invention so relates the velocity head and the elevation head of successive sections that the velocity head will be converted into elevation head, or gravity head. Therefore instead of depending solely upon the retarding effect of slowly moving water reacting upon the faster moving water, as in an ordinary diffuser in which the velocity head is converted into pressure head, the deceleration of the stream is assisted by the direct action of gravity upon the fluid particles, so proportioning the surrounding conduit walls that the deceleration will take place at substantially constant pressure, the velocity head being reduced at a rate definitely corresponding to the increase in elevation of successive sections of the stream. By enclosing the stream by walls proportioned in accordance with the reduction in velocity head corresponding to this principle, a conduit is provided in which the deceleration may be considered to be produced by gravity rather than by diffusion. As applied to hydraulic turbines this principle secures the reconversion of velocity head of the water discharged from the runner into effective elevation head in a manner so much more efficient than any heretofore applied that notable improvements may be effected in the design and performance of turbines particularly increases in their efficiencies and a notable extension in the range of available specific speeds.

It is estimated that decelerators capable of converting velocity head into effective head with a loss of less than ten percent of the velocity head can be constructed by the use of these principles, and the principle of this invention will be applicable with advantage in many situations where the deceleration was heretofore usually accomplished in downward directed passages.

I claim:—

1. A tube for transforming kinetic energy of flow into potential energy, the cross sectional areas of said tube at successive vertical points being regularly enlarged, in accordance with the vertical elevation of said points above any given datum, so that the velocity is so related to the elevation at each section that the sum of the velocity head and elevation above said datum will remain substantially constant.

2. A hydraulic conduit having areas so proportioned that for a definite quantity of fluid flowing the velocity computed by dividing the quantity by the area is so related to the elevation of the section that the sum of the velocity head and elevation above any arbitrary datum will remain substantially constant for each section.

3. A hydraulic conduit for transforming kinetic energy of flow into potential energy arranged so that the difference in elevation between its inlet and discharge ends is equal to or greater than the difference in the velocity heads of the entering and discharging water.

4. A hydraulic conduit for transforming kinetic energy of flow into potential energy arranged so that the difference in elevation between its inlet and discharge ends is equal to or greater than the difference in the velocity heads of the entering and discharging water, and having inlet and discharge areas proportioned in accordance with said velocity heads.

5. A hydraulic conduit for transforming kinetic energy of flow into potential energy arranged so that the difference in elevation between its inlet and discharge ends is equal to or greater than the difference in the velocity heads of the entering and discharging water, said velocity heads being computed in accordance with said inlet and outlet sections.

6. In a hydraulic machine or apparatus, means for decelerating the velocity of flow comprising an upwardly directed conduit having successive areas proportioned to maintain the sum of the velocity head and elevation substantially constant.

7. A hydraulic conduit for transforming kinetic energy of flow into potential energy arranged so that the difference in elevation between its inlet and discharge ends is equal to or greater than the difference in the velocity heads of the entering and discharging water, said velocity heads being computed to include the velocity components in planes containing the axis of the conduit.

8. In a hydraulic machine or apparatus, means for decelerating the velocity of flow comprising an expanding conduit having a substantially constant pressure throughout.

9. In a hydraulic machine or apparatus, means for decelerating the velocity of flow comprising an expanding conduit in which the difference in pressure at one end and the other is substantially less than the pressure head corresponding to the height of the conduit from one end to the other.

10. In a hydraulic machine or apparatus, means for decelerating the velocity of flow comprising an expanding conduit in which the variation in pressure is substantially less than the pressure head corresponding to the height of the conduit, and a discharge passage from said conduit discharging below the water surface and having an area such that the velocity head is low compared with the velocity head in said conduit.

11. In a hydraulic machine or apparatus, means for decelerating the velocity of flow comprising an expanding conduit having substantially constant pressure throughout and of sufficient height to decelerate the major portion of the velocity.

12. In a hydraulic turbine, a draft tube in which the elevations of successive sections increase to maintain substantially constant pressure throughout the portion in which the velocity heads are high in comparison with the head on the turbine.

13. A draft tube having its cross-sectional area increasing upward so that it is adapted to decelerate the velocity of outflow from a turbine runner with only such energy losses as are due to pipe friction.

14. In a hydraulic machine or apparatus, means for decelerating the velocity of flow comprising a conduit adapted to decelerate the meridian component of velocity at a rate corresponding to the rate of deceleration by gravity.

15. In a hydraulic machine or apparatus, means for decelerating the velocity of flow comprising a conduit adapted to decelerate the meridian component of velocity at a rate corresponding to the rate of deceleration by gravity, and having a spreading flow outward away from the axis of the conduit to decelerate the velocity of whirl.

16. A conduit constructed and arranged to convert velocity head into elevation head without substantial change in intensity of pressure at successive points in the conduit.

17. An upwardly directed conduit continuously enlarging in cross sectional area at a rate corresponding to the deceleration due to gravity and so formed that the loss of head for a given quantity of fluid flowing per second is independent of the direction of flow.

18. The method of converting kinetic energy of flow into potential energy comprising directing the flow upwards and enclosing it within walls forming a conduit, the cross-sectional area of which enlarges in the direction of flow an amount sufficient to reduce the velocity from one point to another in such proportion that the velocity head diminishes by the same amount that the elevation increases.

19. The method of converting kinetic energy of flow into potential energy comprising directing the flow upward and guiding it between walls on expanding lines such that the pressure is maintained substantially the same.

20. The method of converting kinetic energy of flow into potential energy comprising directing the flow upward and guiding it between walls on expanding lines such that the pressure at the lower portion of the stream is substantially the same as that at the upper portion of the stream.

21. The method of converting kinetic energy of flow into potential energy comprising directing the flow upward and guiding it between walls on expanding lines such that the sum of the velocity head and elevation is substantially constant.

22. The method of converting kinetic energy of flow into potential energy comprising directing the flow upward and guiding it between walls on expanding lines such that the sum of the velocity head and elevation is substantially the same at the upper portion of the stream as at the lower.

23. A hydraulic conduit for transforming kinetic energy of flow into potential energy, in which the decrease in velocity head from one section to another is not greater than the increase in elevation of the second section above the first.

24. A hydraulic conduit for transforming kinetic energy of flow into potential energy in which the decrease in velocity head from the entrance to the discharge section is not greater than the increase in elevation of the discharge section over the entrance section.

25. A hydraulic conduit for transforming kinetic energy of flow into potential energy in which the decrease in velocity head from the entrance to an intermediate section of said conduit is not greater than the increase in elevation of said intermediate section above the entrance.

26. In a hydraulic machine or apparatus a velocity decelerator comprising an expanding conduit arranged to carry the flow through an increase in elevation, the cross-sectional areas at the entrance and discharge ends of said decelerator being so proportioned that said increase in elevation is equal to a major portion of the difference in velocity heads at said entrance and discharge sections.

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