

March 10, 1925.

1,529,632

F. NAGLER

HYDRAULIC TURBINE

Filed Dec. 22, 1921

4 Sheets-Sheet 1

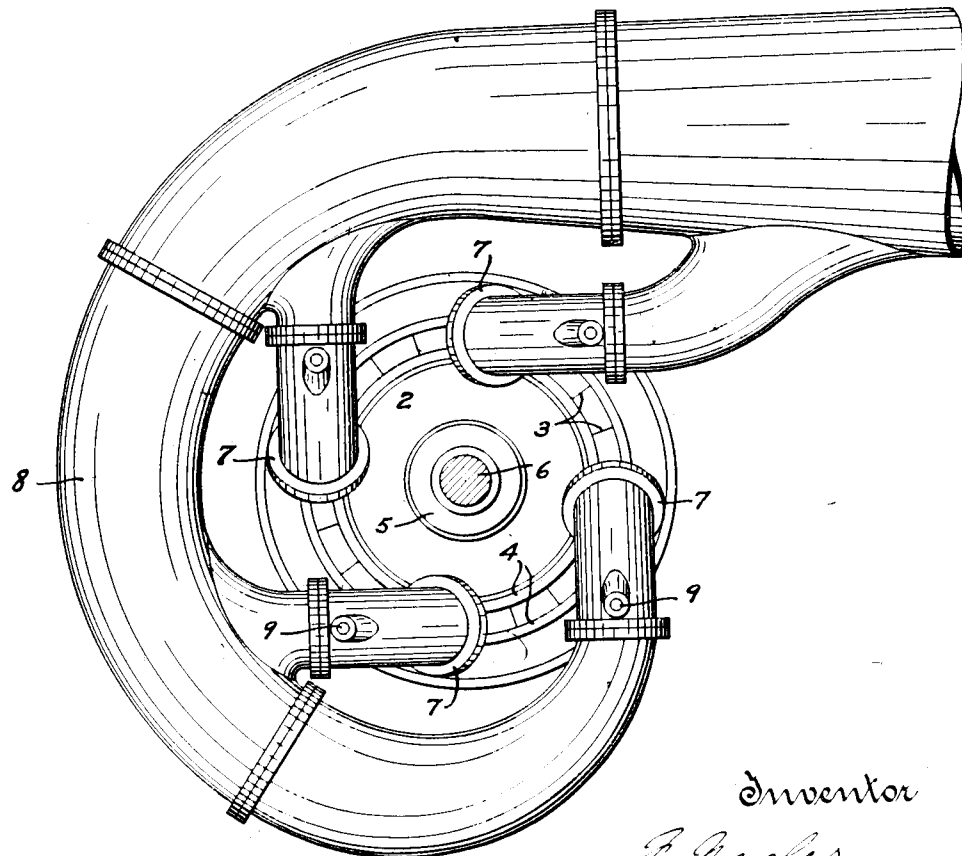
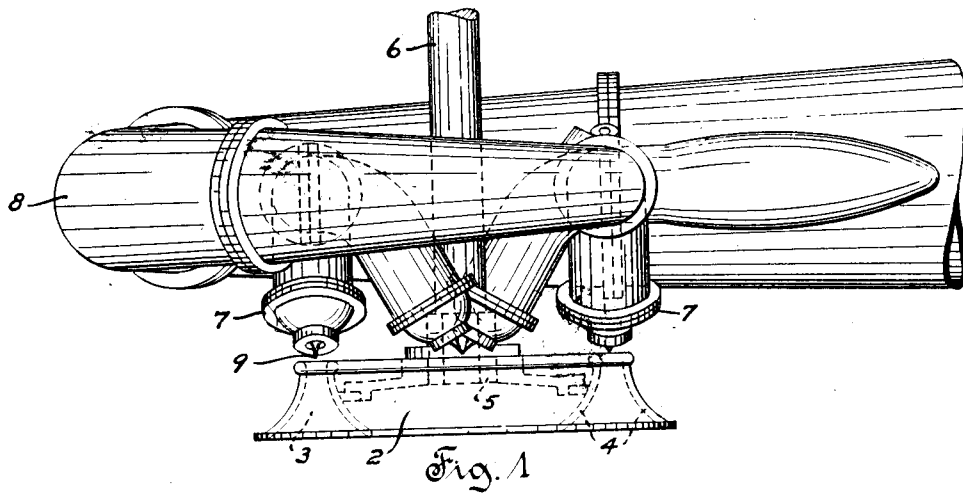


Fig. 2

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4 Sheets-Sheet 2

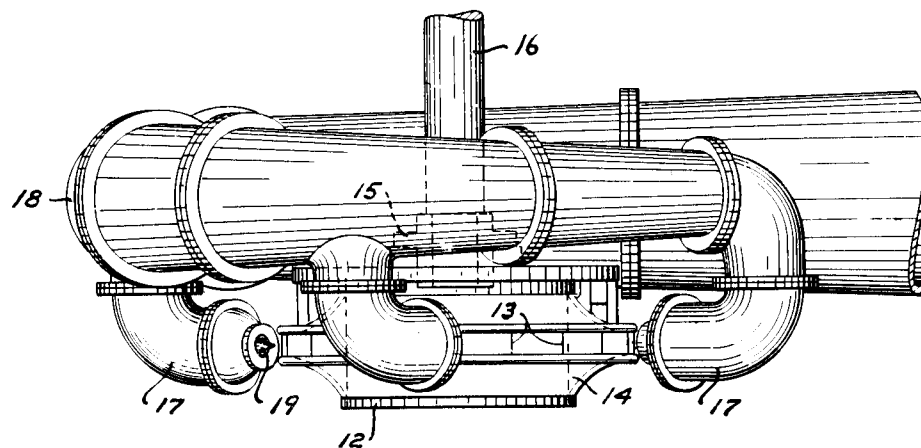


Fig. 3

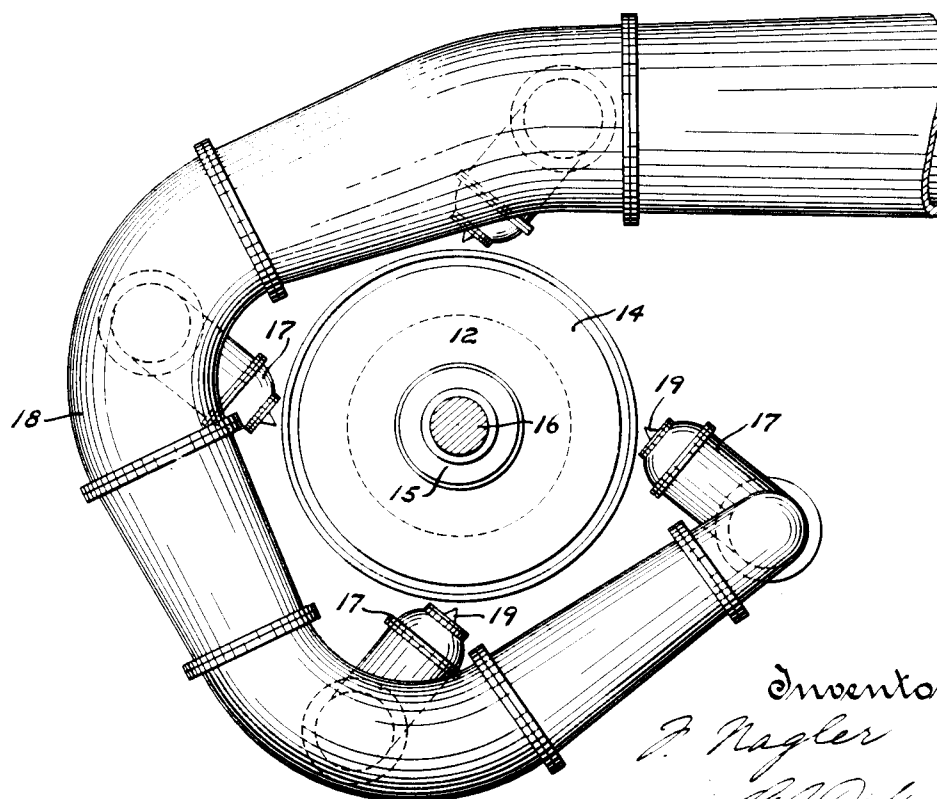


Fig. 4

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4 Sheets-Sheet 3

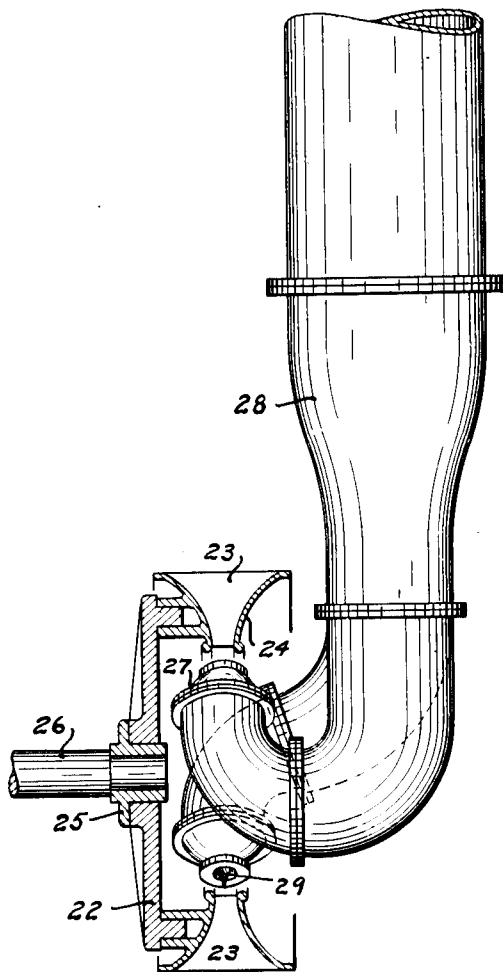


Fig. 5

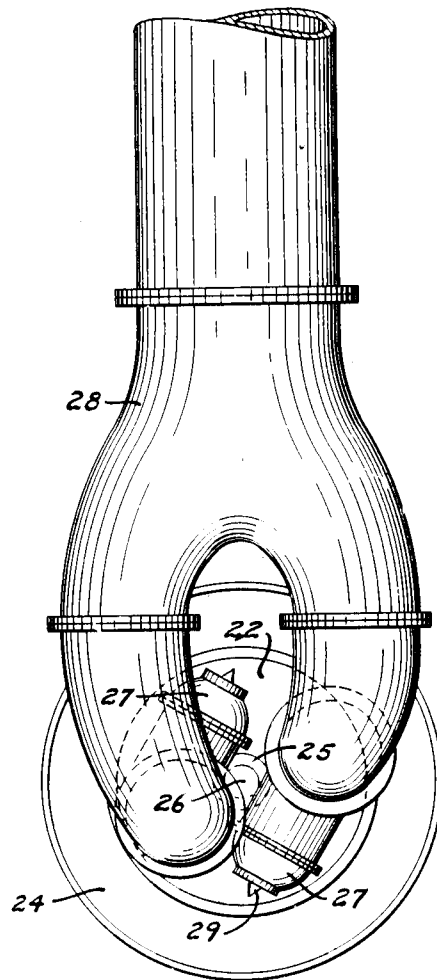


Fig. 6

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1,529,632

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4 Sheets-Sheet 4

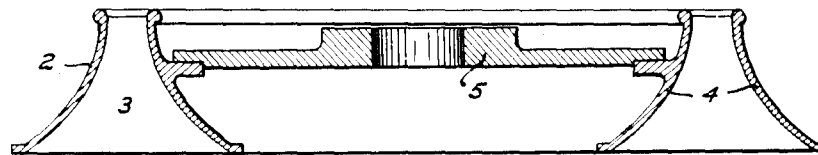


Fig. 7

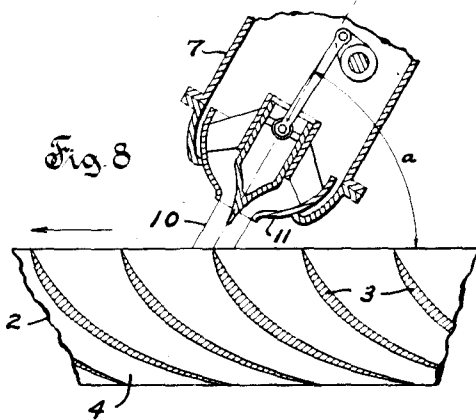


Fig. 8

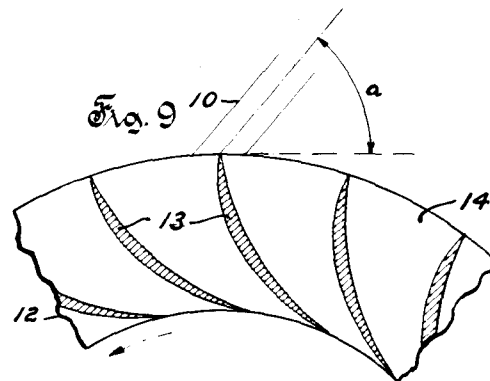


Fig. 9

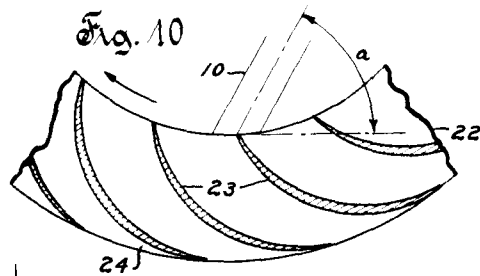


Fig. 10

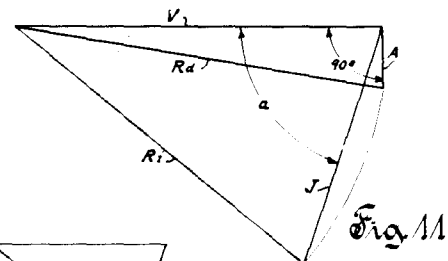
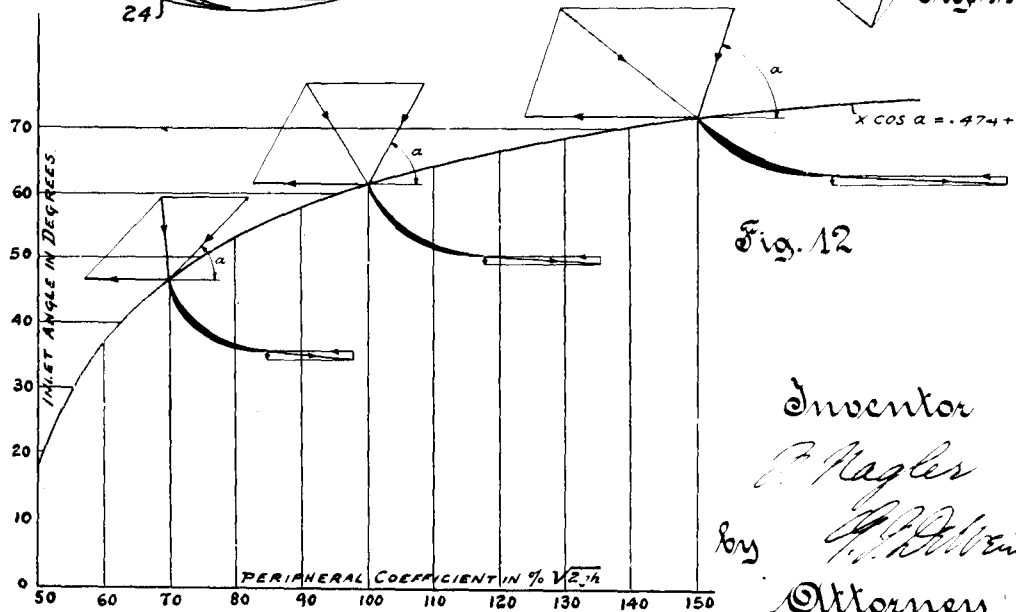


Fig. 11



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UNITED STATES PATENT OFFICE.

FORREST NAGLER, OF WAUWATOSA, WISCONSIN, ASSIGNOR TO ALLIS-CHALMERS MANUFACTURING COMPANY, OF MILWAUKEE, WISCONSIN, A CORPORATION OF DELAWARE.

HYDRAULIC TURBINE.

Application filed December 22, 1921. Serial No. 524,080.

To all whom it may concern:

Be it known that FORREST NAGLER, a citizen of the United States, residing at Wauwatosa, in the county of Milwaukee and State of Wisconsin, has invented certain new and useful Improvements in Hydraulic Turbines, of which the following is a specification.

This invention relates in general to improvements in the art of converting hydraulic potential energy into kinetic energy appearing as torque on a rotating shaft, and relates more specifically to improvements in the construction and operation of hydraulic turbines of the type in which rotation of the wheel is effected by causing one or more free jets of water traveling at high velocity to impinge against the successive wheel buckets.

An object of the invention is to provide a hydraulic turbine of the impulse type which is simple in construction, efficient in operation, and which is capable of attaining relatively high specific speeds. Another object of the invention is to provide an improved method of converting hydraulic kinetic energy into mechanical kinetic energy.

It has heretofore been proposed to transform hydraulic kinetic energy into useful work, by delivering one or several free jets of water traveling at high velocity, against the successive buckets of a water wheel. In the prior commercial water wheels of the impulse type, the jets were delivered against the buckets in substantially tangential directions relatively to the line of travel of the wheel at the point of impact, and it has not heretofore been commercial practice to dispose the jet at an angle greater than 30° relatively to the point of impact in cases where the inlet working face of the bucket was not reflexed nor tangent with reference to an axial plane. Heretofore the available peripheral velocity or specific speed of the wheel was limited, and it was impossible to secure a peripheral wheel velocity which was materially greater than 50 per cent of the velocity of the jet, without enormously increasing the exit losses. Due to the fact that in the prior tangential impulse wheels, the jet was disposed in or near the line of travel of the buckets at the point of impact,

it has been found impracticable to utilize but a very limited number of non-interfering jets without making the wheel of very large diameter, thus greatly limiting the capacity of the prior wheels of this type. The prior tangential impulse wheels were also objectionable due to loss in efficiency resulting from the fact that the jet was directed at right angles to the buckets only at one instant during rotation of the wheel. The specific speeds attainable with the prior tangential impulse wheels were further limited due to mechanical difficulties which prevented reducing the ratio between jet and wheel diameter, below a definite value. The inlet portions of the working surfaces of the prior impulse wheels were moreover so directed as to prohibit the attainment of high specific speeds with the use of a jet set at an angle greater than 45° relatively to the line of travel of the buckets at the point of impact. These and other conditions have heretofore prevented construction of efficient impulse wheels operating with relatively high specific speeds.

One of the more specific objects of the present invention is to provide an impulse water wheel in which a peripheral velocity equal to or greater than the jet velocity, is readily attainable with maximum efficiency and with minimum exit loss. This result is secured by delivering one or more jets against the buckets of a wheel at an angle between 45° and 90° relatively to the line of travel of the buckets at the points of impact, and by so forming the bucket surfaces that the energy of the impinging jets is most effectively converted. Another specific object of the present invention is to provide an impulse wheel of relatively small dimensions in which a large number of jets or even a continuous free annular jet, may be utilized in order to produce conversion of a maximum amount of energy in a single wheel, and to further produce exceedingly high specific speeds. Still another specific object of the present invention is to provide a relatively simple impulse wheel of maximum efficiency in which the exit losses may be reduced to a minimum. A further specific object is to provide a bucket structure for impulse wheels which will permit attainment of higher specific speeds

than those attainable with the prior impulse wheels, and which will also enable delivery of the jet against each bucket at a substantially constant angle for a relatively great angular displacement of the wheel. These and other specific objects of the present invention will be clearly apparent from the accompanying disclosure.

A clear conception of several embodiments of the present invention and of the operation of devices constructed in accordance therewith, may be had by referring to the drawings accompanying and forming a part of this specification in which like reference characters designate the same or similar parts in the various views.

Fig. 1 is a side elevation of a vertical impulse wheel wherein the jets are delivered downwardly and transversely through the wheel.

Fig. 2 is a top view of the vertical impulse wheel disclosed in Fig. 1.

Fig. 3 is a side elevation of a vertical impulse wheel through which the jets are delivered inwardly from the outside.

Fig. 4 is a top view of the vertical impulse wheel illustrated in Fig. 3.

Fig. 5 is a transverse vertical section through a horizontal impulse wheel through which the jets are delivered outwardly from within.

Fig. 6 is an end elevation of the impulse wheel illustrated in Fig. 5.

Fig. 7 is a central vertical section through an axial cross flow impulse wheel rotor.

Fig. 8 is an enlarged fragmentary sectional view of an axial cross flow impulse water wheel, showing a nozzle embodying jet direction and cross-section changing means.

Fig. 9 is an enlarged fragmentary sectional view of an inward cross flow impulse water wheel.

Fig. 10 is an enlarged fragmentary sectional view of an outward cross flow impulse water wheel.

Fig. 11 is a diagram illustrating the derivation of mathematical equation forming a basis for calculation of wheels embodying the present invention.

Fig. 12 is a diagram illustrating the application of the mathematical equation in the construction of wheels embodying the present invention.

While the present invention has been illustrated herein as applied to purely axial cross flow, outward cross flow, and inward cross flow wheels, it will be obvious that the principles are also applicable to wheels in which the jet travel is in directions other than those illustrated, as in wheels of the mixed type combining more than one direction of flow, and it is not contemplated to limit the scope of the invention by the several specific disclosures. The term cross flow is em-

ployed herein to define a wheel in which the major component of the jet velocity is perpendicular to the line of travel of the wheel at the point of impact.

Referring specifically to Figs. 1, 2, 7 and 8, it will be noted that the example of turbine therein illustrated comprises a rotor or wheel 2, a vertical main shaft 6, a horizontal conduit 8 for conducting water to the wheel, and a series of four nozzles 7 for directing cylindrical free jets 10 of water from the conduit 8 and downwardly through the rotor 2. The rotor 2 comprises a hub 5 attached directly to the main shaft 6, and a series of buckets 3 confined between flaring side walls 4, associated with the hub 5. The buckets 3 have shallow curved working surfaces all portions of which are inclined in the same direction relatively to the plane of travel of the wheel. The nozzles 7 are preferably provided with means such as deflecting hoods 11 and needles 9 for varying either the direction or the size of the free jets 10 delivered therefrom, and as illustrated, are adapted to deliver jets 10 at angles α greater than 45° and less than 90° relatively to the plane of rotation of the rotor 2. The specific construction of jet direction and size varying means forms no part of the present invention. The type of water wheel illustrated in these figures is herein designated as axial cross flow, because the jets 10 are directed transversely relatively to the plane of rotation of the wheel and preferably have a major velocity component parallel to the turbine axis.

Referring specifically to Figs. 3, 4 and 9, it will be noted that the embodiment therein illustrated comprises generally a wheel or rotor 12, a vertical main shaft 16, a horizontal conduit 18 for conducting water to the wheel, and a series of four nozzles 17 for directing cylindrical free jets 10 of water from the conduit 18 and inwardly through the rotor 12. The rotor 12 comprises a hub 15 attached directly to the main shaft 16, and a series of buckets 13 confined between flaring side walls 14, associated with the hub 15. The buckets 13 have shallow curved working surfaces all portions of which are inclined in the same direction relatively to the line of travel of the wheel at the place of impingement of the jets. The nozzles 17 are preferably provided with means such as deflecting hoods and needles 19 for regulating the flow of water therefrom, and as illustrated are adapted to deliver free jets 10 with their axes at angles α greater than 45° and less than 90° , relative to the line of travel of the buckets 13 at the point of impact. The type of wheel illustrated in these figures is herein designated as inward cross flow, because the jets 10 are directed inwardly through the wheel and toward the axis of rotation, the axes of the

jets lying in the plane of rotation of the wheel and the major velocity component of each jet preferably extending radially of the wheel.

5 Referring specifically to Figs. 5, 6 and 10, it will be noted that the embodiment therein illustrated comprises generally a wheel or rotor 22, a horizontal main shaft 26, a vertical conduit 28 for conducting
10 water to the wheel, and a pair of nozzles 27 for directing cylindrical free jets 10 of water from the conduit 28 and outwardly through a rotor 22. The rotor 22 comprises a hub 25 attached directly to the main shaft 26,
15 and a series of buckets 23 confined between flaring side walls 24, associated with the hub. The buckets 23 have shallow curved working surfaces all portions of which are inclined in the same direction relative to the
20 line of travel of the wheel at the point of impingement of the jets. The nozzles 27 are preferably provided with means such as deflecting hoods and needles 29 for regulating the flow therefrom, and as illustrated,
25 are adapted to deliver free jets 10 with their axes at angles α greater than 45° and less than 90° , relative to the line of travel of the buckets 23 at the point of impact. The type of water wheel illustrated in these
30 figures is herein designated as outward cross flow, because the jets 10 are directed outwardly through the wheel and away from the axis of rotation, the axes of the jets lying in the plane of rotation of the wheel
35 and the major velocity component of each jet coinciding with a radius of the wheel.

In each of the embodiments illustrated, namely the axial cross flow wheel, the inward cross flow wheel, and the outward
40 cross flow wheel, the important factors are: First, the disposition of the jets 10 so that a stream line, such as the jet axis, of any of the jets 10, forms an angle α greater than 45° with the line of travel of
45 the buckets at the point of impingement of the stream line with the bucket, and second, the construction of the bucket so that the inlet portion of the working surfaces is visible by a normal view from the jet side
50 of the wheel, that is with all portions of the working surfaces inclined in the same direction relatively to the line of travel of the bucket. The number of jets 10 may be varied, to meet variations in the desired con-
55 ditions of operation, and the means for regulating the jets 10 may also be altered in construction without affecting the present invention. In order to produce a turbine of maximum efficiency, the exit loss should
60 be a minimum, a condition which is attained when the discharge flow is approximately at right angles to the line of travel of the discharge edges of the buckets at the point of discharge, but the discharge flow may be
65 forward or rearward a slight amount with-

out too great a sacrifice of energy. The advantages of the present invention are clearly analyzed by reference to Figs. 11 and 12 which disclose graphical analyses of the features of the invention.

Referring to the diagram of Fig. 11:

V, the peripheral velocity of the wheel, is equal to

$$X\sqrt{2gh}$$

where X is a variable representing the peripheral velocity in per cent of

$$\sqrt{2gh},$$

the velocity due to head; where g , is the acceleration due to gravity in feet per second, and h , is the head in feet;

A, the absolute exit velocity from the wheel, is assumed to be equal to 5%

$$\sqrt{2gh},$$

and is further assumed to be directed perpendicularly relative to the line of travel of the buckets at the point of exit. These assumed values produce a desirable exit velocity diagram, but they may vary throughout a considerable range, the present values having been assumed merely because they represent good practice, and in order to provide a convenient basis for stating mathematical relations. The invention is not to be considered as limited by the assumption of these definite exit characteristics as they have no particular bearing upon the cross
100 flow principle.

J, the velocity of the jet, is assumed to be equal to 95%

$$2gh,$$

this assumption being based upon the fact that the practical coefficients of circular jet nozzles of the needle type vary between 95% and 98%. The jet is directed at an angle α relatively to the line of travel of the bucket at the point of impingement.

The angle α is the angle between any stream line of the jet and the line of travel of the point on the wheel which the stream line impinges, and the discharge angle is assumed to be 90° as previously stated.

Then Rd , the relative discharge velocity, is equal to

$$\sqrt{V^2 + A^2}$$

since Rd is the hypotenuse of a right triangle having V and A as its sides, and

Ri , the relative inlet velocity, is equal to

$$\sqrt{J^2 + V^2 - 2VJ \cos \alpha}$$

But Rd equals Ri , whence by substituting equivalents,

$$V^2 + A^2 \text{ is equal to } J^2 + V^2 - 2VJ \cos \alpha.$$

By canceling V^2 and substituting equivalents,

$$.0025(2gh) = .9025(2gh) - 2X\sqrt{2gh}.95\sqrt{2gh} \cos a$$

By collecting terms and simplifying $X \cos a = .474 + B$, where B is a constant the value of which depends upon the assumed values A, J and the exit angle.

It will be understood that other values than 5% of the

10 $\sqrt{2gh}$

for the discharge loss, and 90° for the discharge angle, may be assumed in order to meet varying commercial requirements without altering in principle, the method of determining the values X and a , and without greatly affecting the actual jet inlet angle a . It will also be obvious that by assuming a desirable peripheral velocity X, the angle a and the blade angle necessary to produce such coefficient may be readily determined with the foregoing equation and diagram. For simplicity this equation and analysis are based on the axial cross flow condition, but with slight modification may be made to apply likewise to inward, outward or mixed flow.

Referring to Fig. 12, it will be noted that diagrams have been drawn for values of X of 70 per cent, 100 per cent and 150 per cent. With the assumed value of X=70 per cent, the angle a is approximately 47°, with a value of X=100 per cent the angle a is approximately 62° and with a value of X=150 per cent it is approximately 72°. So also for any other assumed values of X, the jet angles a and the bucket inlet and discharge angles, may be readily determined, and reversely, for any assumed angles a or bucket inlet and discharge angles, the values X may be readily determined from a cosine curve based on the equation, $X \cos a = B$. The inlet and discharge angles of the bucket surfaces are readily determinable after the values X and angle a have been obtained, by merely completing the velocity diagrams as illustrated. The diagram of Fig. 12 also illustrates the relatively small exit loss regardless of the magnitude of the angle a or of the value X, and also indicates that an exceedingly high speed of rotation is attainable without sacrificing efficiency. It is also obvious from this diagram that peripheral velocities greater than 50%

55 $\sqrt{2gh}$

could not be utilized with prior impulse wheels having jet angles a less than 30°, without enormous exit losses, and that the blade inlet angle should be acute relatively to the wheel travel. The diagram of Fig. 12 also illustrates that with the present invention, the jet or stream flow always has

a rearward relative component relatively to the line of travel of the bucket at the point of impingement, this component increasing rapidly as the peripheral coefficient increases. The curve of Fig. 12 is a constant efficiency curve which clearly indicates that for the higher specific speeds, the jet angles a are above 45°.

It has been found that single jet tangential impulse wheels of the prior art are capable of producing specific speeds up to a definite maximum value. Wheels embodying the feature of the present invention, will permit attainment of specific speeds at least twice as great as the maximum attainable with the prior wheels, for assumed values of X=100 per cent, and three times as great for assumed values of X=150 per cent. Such relatively high specific speeds are attainable by retaining the same limits of ratio of wheel diameter to jet diameter, that are necessary in the prior tangential impulse wheels. This ratio can, however, be greatly reduced with the cross flow type of impulse wheel on account of the fact that in the improved wheel the buckets may be permitted to overlap to a greater extent. Such overlapping is impracticable in the tangential impulse wheels because overlapping of the buckets will prevent efficient impingement of the jet thereagainst and will also prevent proper attachment of the buckets to the supporting structure. By thus reducing the ratio of wheel diameter to jet diameter, the diameter of the wheel may be reduced to a minimum thus enabling attainment of still higher specific speeds with the same quantity of water delivered against the buckets. The present invention furthermore permits attainment of relatively high specific speeds with maximum conversion of energy in a single wheel, due to the fact that a relatively large number of jets may be utilized thereby increasing the quantity of water delivered against the buckets beyond that permitted with a tangential wheel. When utilizing a plurality of jets, they should all be delivered against the wheel at the same angle a , and the jets should be spaced apart sufficiently to avoid interference with adjacent jets. While the cylindrical form of jet 10 is perhaps preferred, because of its relatively high efficiency and because of the fact that simple and efficient means for regulating such jets have heretofore been devised, any other form of jet may be employed. It has been found that the present invention permits the use of eight or ten jets on wheels of relatively small diameter and it will be apparent that the number of jets may be readily increased to such an extent that a single an-

ular jet is produced. When utilizing such a single annular jet, means for properly directing the stream lines, should, however, be provided. It will thus be noted that this invention permits attainment of exceedingly high specific speeds such as present commercial practice demands.

During normal operation of the cross flow wheel, the free jets 10 are delivered against the buckets in a direction such that the angle α is between 45° and 90° . As the rotor is open to the atmosphere, or at least has the same pressure on the inlet and discharge sides thereof, there is no drop in pressure in the water flowing through the wheel. In this respect the impulse wheel differs from the reaction or Francis type of wheel. The jets 10 in passing through the wheel have their velocity energy transformed into torque on the rotating wheel and are delivered from the exit edges of the buckets with a very slight percentage of remaining energy.

The speed of the wheel is readily controllable by varying the direction of the jets, such regulation being effected by means of structure such as illustrated in Fig. 8, and without removing the jets 10 from the buckets. It will be obvious that by inclining the jets 10 at a very slight angle relatively to the line of travel of the buckets at the point of impact, the jets may be entirely prevented from passing through the wheel thereby reducing the energy conversion to a minimum. This result is attainable due to the forward inclination of the inlet portions of the bucket impact surfaces.

It should be understood that it is not desired to limit the present invention to the exact details of construction and to the exact steps of the process herein shown and described, for various modifications within the scope of the claims may occur to persons skilled in the art.

It is claimed and desired to secure by Letters Patent:

1. In a hydraulic turbine, a rotor comprising a series of buckets revoluble about an axis, means for delivering a free jet of water against the successive buckets of said series so that said jet forms a variable angle of from thirty to ninety degrees relative to the line of travel of said buckets at the point of impingement, and means for adjusting said jet delivery means to vary the jet angle between said limits.

2. In a hydraulic turbine, a rotor comprising a series of buckets revoluble about an axis, means for delivering a free jet of water against the successive buckets of said series so that said jet forms a variable angle of from thirty to ninety degrees relative to the line of travel of said buckets at the point of impingement, means for adjusting said jet delivery means to vary the jet angle be-

tween said limits, and means for adjusting said jet delivery means to vary the cross sectional area of said jet.

3. In a hydraulic turbine, a rotor comprising an annular series of buckets revoluble about an axis, means for delivering a plurality of independent free jets of water against the successive buckets of said series so that each of said jets forms a variable angle of from thirty to ninety degrees relative to the line of travel of said buckets at the point of impingement, and means for adjusting said jet delivery means to vary the jet angles between said limits.

4. In a hydraulic turbine, a rotor comprising an annular series of buckets revoluble about an axis, means for delivering a plurality of independent free jets of water against the successive buckets of said series so that each of said jets forms a variable angle of from thirty to ninety degrees relative to the line of travel of said buckets at the point of impingement, means for adjusting said jet delivery means to vary the jet angles between said limits, and means for adjusting said jet delivery means to vary the cross sectional areas of said jets.

5. In a hydraulic turbine, a rotor comprising buckets revoluble about an axis, means for delivering a free cylindrical jet of water against said buckets so that said jet forms an angle greater than thirty and less than ninety degrees relative to the line of travel of said buckets at the point of impingement of said jet thereon whereby said turbine has a relatively high specific speed, and means for varying the jet angle between said limits.

6. In a hydraulic turbine, a rotor comprising buckets revoluble about an axis, means for delivering a free cylindrical jet of water against said buckets so that said jet forms an angle greater than thirty and less than ninety degrees relative to the line of travel of said buckets at the point of impingement of said jet thereon whereby said turbine has a relatively high specific speed, means for varying the cross sectional area of said jet, and means for varying the jet angle between said limits.

7. In a hydraulic turbine, a rotor comprising a series of buckets revoluble about an axis, a nozzle spaced from said buckets and adapted to deliver a free cylindrical jet of water against the successive buckets so that said jet forms an angle between thirty and ninety degrees relative to the line of travel of said buckets at the point of impingement of said jet thereon whereby said turbine has a relatively high specific speed, and means for adjusting said jet delivery means to vary the jet angle between said limits.

8. In a hydraulic turbine, a rotor comprising a series of buckets revoluble about

an axis, a nozzle spaced from said buckets and adapted to deliver a free cylindrical jet of water against the successive buckets so that said jet forms an angle between
 5 thirty and ninety degrees relative to the line of travel of said buckets at the point of impingement of said jet thereon whereby said turbine has a relatively high specific

speed, means for adjusting said nozzle to vary the cross sectional area of said jet, and 10 means for adjusting said nozzle to vary the jet angle between said limits.

In testimony whereof, the signature of the inventor is affixed hereto.

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