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NOZZLE PLATE

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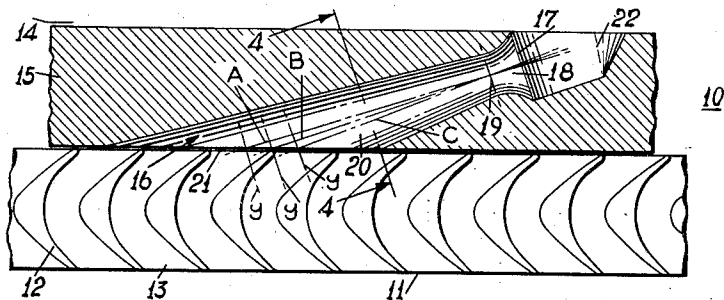


Fig. 2

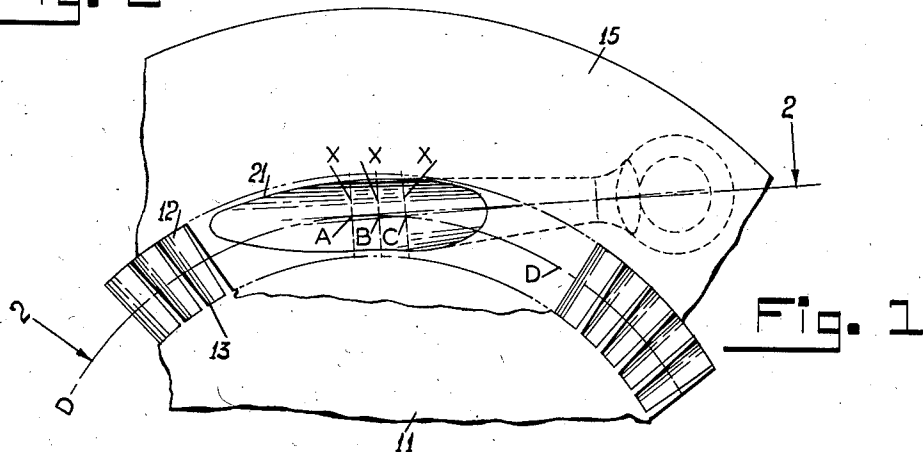


Fig. 1

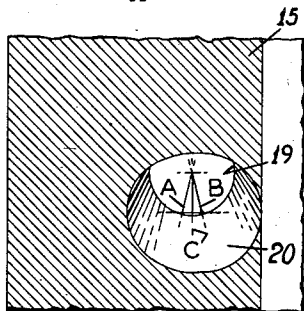
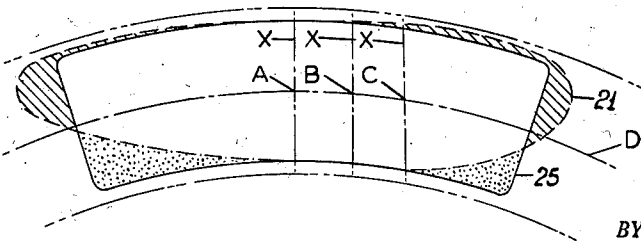


Fig. 4

Fig. 3



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1

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NOZZLE PLATE

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This invention relates to a novel nozzle plate for fluid turbines.

The nozzle plate of a fluid turbine separates the motive fluid inlet compartment from the turbine wheel and includes at least one nozzle through which the motive fluid passes to the passages between the turbine blades. The efficiency of the nozzle as such is of importance but it is equally important that the jet issuing from the nozzle be properly directed and properly cover the interblade passageways, especially in the case of partial admission of the motive fluid as in such case the motive fluid losses have a profound effect on the overall efficiency of the turbine. These motive fluid losses, or end losses, include scavenge and eddy losses during filling and emptying of the interblade passageways and losses due to the diffusion of the motive fluid at the nozzle discharge, this being primarily encountered in reaction type machines.

The ideal nozzle is one that provides maximum nozzle efficiency, under the operating conditions and design limitations, and terminates in an outlet hole shaped and proportioned to result in a minimum of motive fluid losses, i. e., the jet is properly directed to completely fill the interblade passages in registry with it without expansion or compression of any portion of the jet. The ideal nozzle is of square cross-section; theory in the general case, indicates the outlet hole as rectangular. In the specific case of turbines provided with a circular series of blades, the ideal outlet hole is a section of an annulus concentric with the blade pitch circle whose ends are parallel to the blade edges and whose medial line coincides with the portion of the pitch circle covered by said outlet hole.

Such a squared and arcuate ideal nozzle involves a great deal of highly skilled handwork in its production and its excessive cost can only be justified in special applications. Many attempts have been made to produce satisfactory nozzles cheaply by machine operations. The success of these attempts is limited to applications involving large blade pitch diameters; in applications involving small pitch diameters, as in small high speed turbines, they are not satisfactory.

Nozzles of circular cross-section have been proposed which can be cheaply made by simple machine operations. The efficiency of these nozzles as such is acceptable but the motive fluid losses may attain considerable magnitude. The elliptical outlet hole of a circular nozzle is of substantially uniform width for only a limited portion of its length and its major axis cannot be made to coincide with the blade pitch circle. Hence, the reduction in jet efficiency which results from improper filling of the interblade passageways and possibly even overshooting of the blade tips must be accepted as inherent in circular nozzles. Circular nozzles have also been used in closely spaced groups for greater and better blade coverage. The jet produced by grouped circular nozzles is made up of a plurality of separate adjacent jets all differently directed so that the action of the motive fluid on the blades as they move through the nozzle area is not uniform but

2

is intermittent. Also, the series arrangement of elliptical outlet holes does not provide an outlet hole of more uniform width than the single elliptical outlet hole.

The grouped circular nozzles, when closely spaced to accommodate larger volume flows, are increasingly difficult to arrange with their axes tangent to the pitch circle. This condition is exaggerated as the nozzle arrangement and/or the pitch circle are made smaller; resulting in an increasing tendency to overshoot the annulus of the interblade passageways. Even overlapping the lower ends of adjacent grouped nozzles does not materially improve operations.

It is the principal object of this invention to provide a nozzle plate construction having a nozzle therein formed entirely by inexpensive and simple machine operations, said nozzle approaching the ideal nozzle in nozzle efficiency and motive fluid losses and being equally well suited for use in connection with turbine wheels or small or large blade pitch circles.

It is also a principal object of this invention to provide a nozzle plate construction having a nozzle formed therein, by inexpensive and simple machine operations, which has a circular throat and an elongated outlet hole with an expanding outlet section therebetween defined entirely by surfaces of revolution, said outlet hole being of substantially uniform width for the major portion of its length and the medial line thereof approximating the pitch circle of the associated turbine wheel.

It is a further principal object of this invention to provide a nozzle plate construction having a nozzle formed therein, by inexpensive and simple machine operations, which has a circular throat and an elongated outlet hole with an expanding outlet section therebetween, said outlet hole being of substantially uniform width for the major portion of its length, said expanding outlet section being defined by a plurality of conical surfaces each generated by rotating a line about an axis, said axes intersecting at the center of said throat and intersecting the medial line of said outlet hole at spaced points, the cross-section of each of said conical surfaces at said outlet points of intersection being of equal diameter.

The further objects, features and advantages of the invention will be apparent from the following detailed description of a present preferred embodiment of the invention, taken with the accompanying drawings, in which:

Fig. 1 is a fragmentary view of a nozzle plate and turbine wheel showing a nozzle in accordance with this invention;

Fig. 2 is a section generally along the line 2—2 of Fig. 1 and showing the novel nozzle in operational relation with the turbine blades, the latter shown developed on their pitch circle;

Fig. 3 is a diagrammatic view comparing the outlet hole of the nozzle of the invention with the outlet hole configuration of a squared and arcuate nozzle for the turbine shown; and

Fig. 4 is a cross-section taken on line 4—4 of Fig. 2.

The novel nozzle plate of the invention is of general application but, for the purposes of this disclosure, it will be described in connection with a fluid turbine provided with a circular series of blades radially extending from the periphery of a turbine wheel. Furthermore, to more clearly bring out certain novel features of the invention, the turbine chosen is a comparatively high speed turbine having a small blade pitch circle. Only the elements of the turbine necessary for a proper understanding of the invention have been shown.

The comparatively small, high-speed fluid turbine includes a wheel 11 mounted for rotation in a conventional manner, not shown. The blades 12 extend radially from the periphery of the wheel 11 and are united to

3

the wheel 11 in any preferred manner. The blades 12 are equally spaced apart to provide the circular series of interblade passages 13 for the motive fluid. The motive fluid inlet space 14 into which the motive fluid, steam, high temperature gas, etc., is conducted in any preferred manner has the end thereof adjacent the turbine wheel 11 closed by the nozzle plate or diaphragm 15 which is positioned adjacent the wheel 11. The nozzle 16, suitably oriented relative to the blades 12 and the passages 13, is formed in the plate 15. The nozzle 16 includes a circular entrance hole 17, an entrance section 18, a throat 19, an outlet section 20 and an outlet hole 21. A recess 22 is bored or otherwise formed in the plate 15 to communicate the inlet hole 17 with the motive fluid inlet space 14.

The entrance section 18 is of circular cross-section throughout its length and its cross-sectional area diminishes in the direction of the throat 19 in such manner that a suitable throat approach is provided to the motive fluid therethrough. The throat 19 is circular and as shown is defined by the juncture of the sections 18 and 20. However, if the required results indicate it, it may be in the form of a short cylindrical section. The outlet section 20, as shown in Fig. 2, comprises the nozzle outlet section terminating at the line 4—4, shown as normally disposed to the central nozzle axis, and the triangular nozzle extension section between said line 4—4 and the outlet hole 21. The contour of the nozzle outlet section at line 4—4 of Fig. 2 is shown in Fig. 4; it is to be noted that said contour is the contour in a plane at right angles to the plane of the paper and including the line 4—4. The outlet section 20 expands from the throat 19 in the direction of the outlet hole 21 at a rate to give the required expansion ratio while maintaining stream line flow of the motive fluid. The outlet section 20 is defined by a plurality of intersecting conical surfaces. The surface defining the short side of the outlet section 20 is generated about the axis C, that defining the long side about the axis A, and that defining the connecting central portions about the axis B. The axes A, B and C are angularly disposed relative to each other, they intersect at the center of the circular throat and they intersect the projection of the pitch circle D on the outlet face of the nozzle plate 15 at spaced points, said projection will be referred to as the pitch circle D hereinafter.

The relative angular spacing of the axes A, B and C, as well as their spacing along the pitch circle D, depends on the configuration of the outlet hole 21, as will be explained. Generally speaking, the greater the diameter of the pitch circle D the smaller the angles between the axes and the smaller the number of axes required and, conversely, the smaller the diameter of the pitch circle D the larger the angles between the axes and the larger the number of axes required. As few as two axes may be employed with large pitch circles; with pitch circles that are quite small, as many as five or six axes may be employed. In any case, the grouped axes are so disposed that the central line of the group coincides with the central axis of the nozzle. In the example shown, the axis B coincides with the central axis of the nozzle 16 and is, thus, disposed at the nozzle angle relative to the outlet face of the nozzle plate 15.

In arriving at the desired configuration of the outlet hole 21 it is necessary first to determine the nozzle angle and the area ratio, i. e., the area of the cross-section at line 4—4/the area of the throat, in the usual way from the characteristics of the motive fluid that is to be used, the turbine operating conditions and requirements and the imposed design limitations. With these data and the already determined nozzle angle and area ratio, the ideal nozzle with squared and arcuate outlet is designed for the particular turbine application. The designed ideal nozzle will give the optimum throat area, outlet area and nozzle length along the central axis for the nozzle 16. In order that the nozzle 16 approach the designed ideal nozzle in nozzle efficiency and driving fluid losses, the outlet hole

4

21 must approach the outlet hole of said designed ideal nozzle in area and configuration, also the width, or height, of the outlet hole 21 must equal or approach the width or height of the outlet hole of said designed ideal nozzle over as much of the length of the hole 21 as is possible; also, the intersection points of the axes A, B, and C with the pitch circle must be such that the jet issuing from the outlet hole 21 is substantially tangent to the pitch circle D for the maximum portion of its extent so that losses due to overshooting of the blade passages and to scavenging and eddying of the fluid medium during filling and emptying of said passages may be kept to a minimum.

That these desiderata be obtained, the outlet hole 25 of said designed ideal nozzle is drawn, as in Fig. 3, with its central axis tangent to the pitch circle D. In the example chosen, said central axis intersects the pitch circle D at the point B. This is not always so as said point of intersection can come close to and on either side of the point B. It is evident from Figs. 2 and 3 that the width of the outlet hole 21 will be of maximum uniformity and most closely approach that of the outlet hole 25 of said designed ideal nozzle when the diameters of the cross-section circles of each of the cones generated about the axes A, B and C in respective planes each normal to the respective cone axis and passing through the intersection point of the respective cone axis and the pitch circle D, are equal to each other and to the width of the outlet hole 25. These normal planes will respectively include the cone circle diameter lines, that of the cone generated about the axis A is in the plane Y intersecting the axis A at the outlet hole 21, that of the cone generated about the axis B is in the plane Y intersecting the axis B at the outlet hole 21 and that of the cone generated about the axis C is in the plane Y intersecting the axis C at the outlet hole 21, Fig. 2. The diameters are shown as the lines X intersecting the respective cone axis and the pitch circle D in Fig. 3.

Therefore, on the premise of equal diameters in said normal planes and for a given position of the center of the throat relative to the pitch circle D, the cone angle of any possible conical surface about an axis through any point on the pitch circle D and through the center of the throat of said designed ideal nozzle is determined as is the ellipse of the intersection of such conical surface with the face of the plate 15. Substantial equality of the composite outlet area in both cases and approximation of the configuration is obtained by selecting a suitable spacing of the axes on the pitch circle D.

It is next determined from the results desired and from experience at what point on pitch circle D the nozzle jet will be tangent to said pitch circle. While said tangent point will generally be one of the axis intersections it may be a point on said circle D between a pair of axis intersections. When circle D is of small diameter and it is desired to reduce overshooting of the blades to a minimum the axis intersection nearest the long nozzle side end of the outlet hole is usually established as the tangent point. Thus from this point a tangent line is drawn and the center of the throat located on it since the length of the nozzle along the divergence axis was previously determined. Lines are then drawn connecting each of the other axis intersections to the locus of the throat center on said tangent line. From this the other axis lengths and angles become available, the contour of the composite outlet hole 21 is corrected correspondingly and the angles of the reamers required for the conical surfaces are determined.

In forming the nozzle 16 the pitch circle D is first scribed on the outlet face of the plate 15 and the points A, B and C marked thereon at the desired locus of the outlet hole 21. With a boring tool, such as a drill, centered on point B and axially aligned with axis B, a hole of a diameter equal to the diameter of the throat 19 is cut in the nozzle plate 15 from the outlet face thereof to the locus of the bore 22. The bore 22 is then formed as by one or more milling operations. A tool driving

5

spindle is then passed into the cut hole with its axis aligned with the hole axis (axis B). A suitable cutter is mounted at the end of the spindle and the inlet section 18 formed with the stream line contour as shown. The spindle is then removed, and a reamer of the angle determined for axis B is mounted axially of said cut hole. The cut hole is then reamed from the throat 19 to the outlet face of the plate 15, the reamer being of sufficient initial diameter and sufficiently longer than axis B to assure this. The reamed hole is then preferably filled with a suitable metal plug. A hole is then cut by the same drill, as used before, to cut a hole centered on axis A and extending from the outlet face of the plate 15 through the throat 19. This hole is then reamed from the throat 19 to the outlet face of said plate by a reamer of the angle determined for axis A. Again, with the same boring tool a hole centered on axis C is cut from said outlet face through the throat 19. This hole is also reamed from the throat 19 to said outlet face, by a reamer similar to those already used but of the angle determined for axis C. This completes the nozzle forming operation although when the spacing of the points A, B and C, Fig. 1, is comparatively large it may sometimes be desirable to grind the ridges at the intersections of the conical surfaces.

The nozzle 16 as described is made entirely by simple machine operations each of which only involves the cutting of a surface of revolution with a rotating cutting tool. Furthermore, the whole of the nozzle outlet section 16 is made by simple, readily available rotary tools of constant pitch.

I claim:

1. A nozzle plate for use in turbines having a pitch circle of relatively small diameter, said nozzle plate having a nozzle passageway formed therein and including a discharge face, said nozzle passageway including a restricted throat, an elongated outlet hole in said discharge face, and a discharge section connecting said throat with said outlet hole and expanding from said throat to said outlet hole, said discharge section defined by a plurality of intersecting surfaces of revolution each generated by rotating a line about an axis, said axes intersecting the longitudinal medial line of said outlet hole at points spaced apart along said medial line and passing through said throat and intersecting therein.

2. A nozzle plate for use in turbines having a pitch circle of relatively small diameter, said nozzle plate having a nozzle passageway formed therein and including a discharge face, said nozzle passageway including a circular throat, an elongated outlet hole in said discharge face, and a discharge section connecting said throat with said outlet hole, said discharge section defined by a plurality of intersecting surfaces of revolution each generated by rotating a line about a respective axis, all of said axes passing through and intersecting at the center of said throat, said axis intersecting the longitudinal medial line of said outlet hole at points spaced apart along said medial line.

3. A nozzle plate for use in turbines having a pitch circle of relatively small diameter, said nozzle plate having a nozzle passageway formed therein and including an inlet face and an outlet face, said nozzle passageway comprising a restricted circular throat, an inlet hole opening at said inlet face, an inlet section connecting said inlet hole to said throat, an enlarged elongated outlet hole in said outlet face, and a discharge section connecting said throat to said outlet hole, said inlet section defined by at least one surface of revolution, said outlet hole changing direction along its length and its medial line formed of angularly disposed sections, said discharge section defined by a plurality of intersecting surfaces of revolution each generated by rotating a line about a respective axis, all of the axes within said nozzle passageway from the inlet hole to the outlet hole there-

6

of, said axes intersecting each other at the center of said circular throat and intersecting said medial line at spaced points thereon.

4. A nozzle plate for use in turbines having a pitch circle of relatively small diameter, said nozzle plate having a nozzle passageway formed therein and including an inlet face and an outlet face, said nozzle passageway comprising an inlet hole opening at said inlet face, a restricted circular throat, an inlet section connecting said inlet hole to said throat, an enlarged elongated outlet hole in said outlet face, and a discharge section connecting said throat to said enlarged elongated outlet hole, said discharge section defined by a plurality of intersecting conical surfaces, each of said conical surfaces generated about a respective axis, said axes intersecting each other in said throat and each intersecting the projection of said pitch circle at said outlet hole.

5. A nozzle plate as defined in claim 4, in which said axes are so grouped and relatively disposed that a line passing through the middle of the axes group from said throat to said outlet hole is disposed at the nozzle angle relative to said plate outlet face.

6. A nozzle plate as defined in claim 4, in which one of said axes is tangent to the projection of said pitch circle.

7. A nozzle plate for use in turbines having a pitch circle of relatively small diameter, said nozzle plate having a nozzle passageway formed therein and including an outlet face, said nozzle passageway including a restricted circular throat, an enlarged elongated outlet hole in said outlet face, and an expanding discharge section connecting said throat to said outlet hole, said discharge section defined by a plurality of intersecting conical surfaces each generated about a respective axis, said axes intersecting each other at said throat and intersecting the projection of said pitch circle at said outlet hole at spaced points, the respective radii of generation of said conical surfaces being equal in respective planes normal to the respective axis at the respective pitch circle intersection point.

8. A nozzle plate for use in turbines having a pitch circle of relatively small diameter, said nozzle plate having a nozzle passageway formed therein and including an outlet face, said nozzle passageway including a restricted circular throat, an enlarged elongated outlet hole in said outlet face, and an expanding discharge section connecting said throat to said outlet hole, said discharge section defined by a plurality of intersecting conical surfaces each generated about a respective axis, said axes grouped about the nozzle axis as a central line for said axes group and intersecting each other at the center of said throat and the projection of said pitch circle on the outlet hole at spaced points, said axes and pitch circle projection intersections being spaced from each other to give said outlet hole substantially the same area and substantially the same height for the major portion of its length as the outlet hole of the corresponding ideal nozzle, the respective radii of generation of said conical surfaces being equal in respective planes normal to the respective axis at the respective axis and pitch circle projection intersection point.

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