Nov. 4, 1924. 1,514,293

F. LAWACZECK

RUNNER FOR ROTARY ENGINES

Filed Aug. 24, 1921 2 Sheets-Sheet 1

Fig.1.

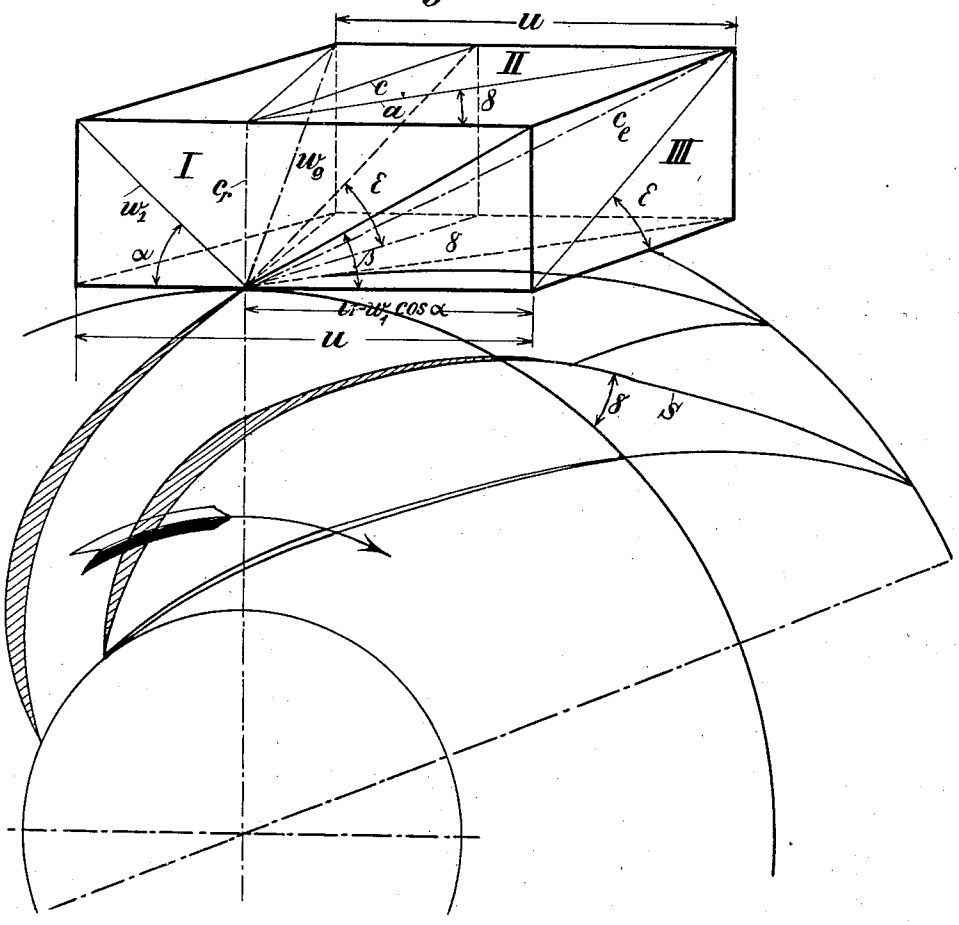
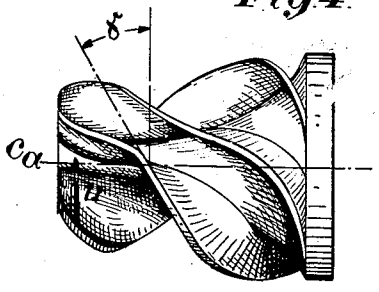



Fig.4.




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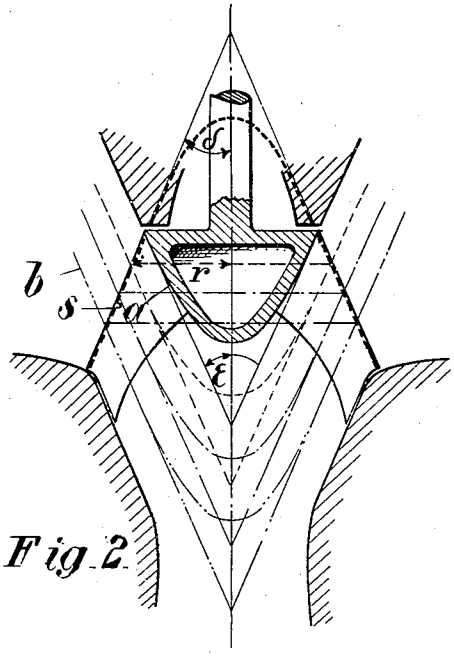



Fig. 2.

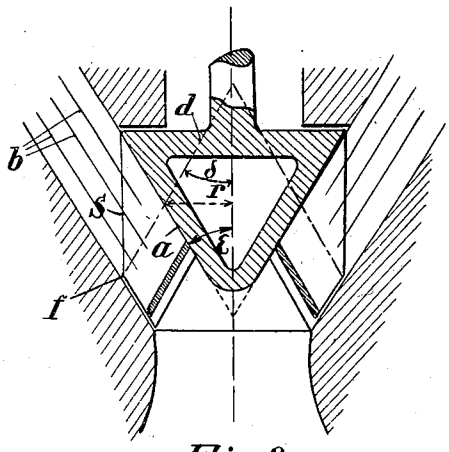
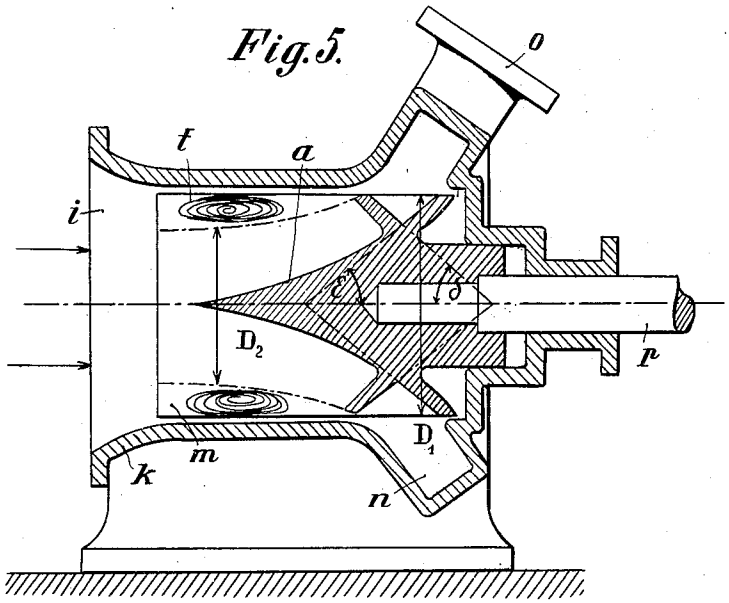



Fig. 3.

Fig. 5.




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# UNITED STATES PATENT OFFICE.

FRANZ LAWACZECK, OF POCKING, GERMANY.

## RUNNER FOR ROTARY ENGINES.

Application filed August 24, 1921. Serial No. 494,892.

(GRANTED UNDER THE PROVISIONS OF THE ACT OF MARCH 3, 1921, 41 STAT. L., 1313.)

*To all whom it may concern:*

Be it known that I, FRANZ LAWACZECK, a citizen of Germany, residing at Pocking, Upper-Bavaria, Germany, have invented certain new and useful Improvements in Runners for Rotary Engines (for which I have filed applications in Germany, September 2, 1915, and September 10, 1920; France, July 5, 1920, Pat. No. 518,915), of which the following is a specification.

My invention relates to turbines, pumps and other rotary engines and more particularly to the construction of the runners of such engines, its particular object being to lay down the rules for designing the blades and other parts of the runner in such a manner as to obtain the highest possible efficiency. In the following the application of my invention to water turbines and pumps is more particularly described; however, my invention is not by any means limited to these types of engines.

In a great number of turbines the velocity of the water in-flowing through the runner has neither an exclusively axial nor an exclusively radial direction, but the direction of the flow is intermediate between the radial and axial directions. Often this direction of flow is altered from a radial or nearly radial direction to an axial direction, for instance in the Francis turbine.

In designing the blades of turbines, heretofore not sufficient attention was paid to the fact that the inflowing water has not an exclusively radial direction but also an axial component of flow. If, however, the blade is designed at the admission and merely in accordance with the direction of flow which extends in the plane of rotation so that the water, as far as the amount and direction of the radial component is considered, will flow in without shocks, there must be losses owing to the shocks as soon as the direction of the inflowing water has also an axial component.

According to my invention the blades are designed in such a manner that at every point of the blade the three angles by which the direction and configuration of the blade are determined, and which are located in three planes preferably extending at right angles to one another, are made interdependent.

In the drawings affixed to this specification and forming part thereof several runners embodying my invention are illustrated diagrammatically by way of example. In the drawings—

Fig. 1 is a perspective radial section of part of a turbine runner,

Figs. 2 and 3 are axial sections of blades of two turbine runners having somewhat different configuration,

Figs. 4 and 5 are an elevation and an axial section, respectively, of a pump runner.

Referring to the drawings in Fig. 1 $w_e$ is the absolute admission velocity of the water, the line representing the amount and direction of such velocity. In order to ascertain the rules by which the design of the rotating blade is determined, this absolute admission velocity is geometrically combined with the circumferential velocity $u$ of the runner, the result being the relative admission velocity $c_e$. The direction of this velocity $c_e$ can be resolved by projection onto three planes at right angles to one another into three different directions whose angles formed with the axes of projection, that is with the lines of intersection of two of the three planes, are then determined.

In the drawings, the following three planes of projection have been chosen:

The plane I nearest to the spectator and which appears vertical in Fig. 1, coincides with the plane of rotation and consequently is a radial plane. The projection of the relative velocity $c_e$ onto plane I forms with the circumferential velocity $u$ extending in plane I an angle $\beta$.

The second plane of projection II which in the present case extends at right angles to plane I, is parallel to the plane extending tangentially to the admission cylinder. It contains therefore the circumferential velocity $u$ as well as the axial direction extending at right angles to $u$. The projection of the relative velocity $c_e$ into this plane forms with the circumferential velocity $u$ an angle $\gamma$. The third plane of projection III extends at right angles to the planes I and II and in parallel to the axial plane passing through the admission point under consideration. The projection of the relative velocity $c_e$ into this plane forms with the axial direction an angle $\varepsilon$.

According to my invention, now, the blades are designed in such a manner, that the three angles $\beta$, $\gamma$, and $\varepsilon$ are dependent upon and definitely related to one another

at every point of the blade. The best conditions for a water admission free of shocks exist when the relation between the three angles is expressed by the equation:

$$tg\epsilon = \frac{tg\beta}{tg\gamma}$$

If the three angles are thus related to one another, the admission edge $s$ of the blade which encloses with the circumferential velocity $u$ at every point the angle $\gamma$, is a curve or a straight line, which, in contradistinction to the blades of turbines and pumps hitherto designed, is not directed axially, but is more or less inclined to the axis, the inclination of the admission edge $s$ being the greater, i. e. the angle $\gamma$ the smaller, the greater the circumferential velocity $u$ of the runner and the smaller the axial component of admission of the water.

An entrance of the water into the runner which is free of shocks will result if the direction of the blades coincides with the direction of that relative entrance velocity $c_e$ (Fig. 1), which combines with the circumferential velocity $u$ into the absolute velocity in space $w_e$ of the entering water. This direction of the blade of every point which corresponds with the relative velocity $c_e$ is predetermined by the three angles beta, gamma, and epsilon in three planes extending at right angles to each other, viz, the radial plane I, the tangential plane II and the axial plane III (Fig. 1). If the blade presents at the point under consideration the angles shown by way of example in Fig. 1, then an entrance free of shocks will ensue if the water has the absolute velocity of entrance $w_e$ and the runners rotate at a speed $u$.

From Fig. 1 there results now

$$tg\ \text{beta} = \frac{c_r}{u - w_1 \cdot \cos\ \text{alpha}};\quad tg\ \text{gamma} = \frac{c_a}{u - w_1 \cdot \cos\ \text{alpha}};\quad tg\ \text{epsilon} = \frac{c_r}{c_a};$$

Therefore, the expression:

$$\frac{tg\ \text{beta}}{tg\ \text{gamma}} = \frac{c_r}{(u - w_1 \cdot \cos\ \text{alpha})} \cdot \frac{(u - w_1 \cdot \cos\ \text{alpha})}{c_a} = \frac{c_r}{c_a}$$

is equal to $tg$ epsilon, provided that the condition of the shockless entrance of the water is completely fulfilled.

I am aware that it is old to dispose the admission edge of runner blades slightly inclined. This was done, however, merely in order to obtain a form of blade which is easier to manufacture without unduly straining the metal, the degree of inclination being a matter of free choice and not being placed in definite relation to the direction and velocity of the admission of the water. Besides, the inclination of such blade edges as heretofore designed, differ very little from the normal axial position and have, in no case, the predetermined relation to the inclination of the stream lines as required by my invention.

If the admission end of the blade is designed at every point according to the above equation, the shape of the blade toward the discharge end may be optional, attention being of course paid to as steady and shockless a flow of water in the runner as possible. Blades fulfilling the conditions of my invention are particularly simple to manufacture if designed as helical surfaces.

The use of helical surfaces is old, particularly in rotary pumps, but the surfaces heretofore used are not adapted for obtaining a correct relation, such as defined above, between the three angles of the flow of water, nor for correctly shaping the blade ends at the low pressure end of the runner, or in other words, considering the example of a turbine which I have been discussing, selecting the admission according to the mathematical relation above defined while at the same time designing the end of the blade at the discharge of the runner in such manner that as far as possible, the total energy of the water is utilized and above all reducing as far as possible the circumferential component of the water discharged to zero.

In order to obtain a correct relation of both ends of the blade, I avail myself of the expedient to select the inclination of the generatrix of the helical surface in a definite manner which is adapted to the described conditions of operation and flow and therefore also to the conditions of admission above explained. In helical pumps or turbines as heretofore designed the generatrix, i. e. the line intersecting the axis of rotation which by simultaneously advancing and rotating generates the helical surface, always was inclined relatively to its axis of rotation ad libitum and without consideration to the conditions of flow or operation of the helical pump or turbine. As a rule, the inclination of the generatrix relatively to the axis of rotation was 90°.

According to my invention the helical surfaces are designed and the generatrix and its inclination are selected as follows:

If, for example, the wall $a$ of the runner (Fig. 3) which also forms the boss, is formed in section as a cone having the vertex angle $2\varepsilon$ and the admission edges $s$ of the blades

are arranged on a cylindrical surface, the stream lines $b$, at any rate in the vicinity of the admission edges $s$ may be considered as straight lines which extend in parallel to the border line $a$. This also applies to the point of admission $f$ of the blade which is farthest from the border line $a$ of the boss.

The angle $\varepsilon$ is therefore constant along the admission edge. As also the radial admission velocity $c_r$ (Fig. 1) is constant along this edge, neither $t_g\beta$ and with it the angle $\beta$ itself, nor the angle $\gamma$ are altered along the admission edge. If, therefore, the surface of the blade is helical, this surface must have a constant inclination at the admission end. This condition is fufilled and an admission free of shocks is secured if the generatrix of this helical surface is inclined at the angle $\delta$ which is symmetrical and equal to angle $\varepsilon$ in relation to the plane of rotation or the radius $r$, respectively, at the admission point in question. The border line $a$ of the boss, the generatrix $d$ of the helical surface and the axis of rotation consequently form an isosceles triangle with the radius $r$ bisecting the perpendicular extending from the apex down to the base line of this triangle.

This condition also applies if the boss instead of being conical has a different shape, such as a paraboloid as illustrated in Fig. 2, with the difference, however, that the stream lines $b$ will become parabolas and the generatrix $e$ of the helical surface will also be a parabola which is symmetrical to the stream line parabola in the sense indicated above.

If to consider a still more general case, there are stream lines the directions of which along the admission edge on the common cylinder differ, generatrices of the helical blade surfaces must have the corresponding symmetrical angular positions, at the points of the admission edge, that is, they must be in such a position that the angles $\delta$ and $\varepsilon$ are equal and symmetrical to the radius $r$ of the point in question.

By aid of the values which determine the amount and direction of the flow of water the inclination of the generatrix can be ascertained as follows:

In the following equations which are derived as an example of a Francis turbine, H is the head, $g$ the acceleration of gravity, $\varphi_1$ and $\varphi_2$ are experience values, $u$ (Fig. 1) is the circumferential velocity at the point in question, $c_a$ and $c_r$ are the axial and the radial velocity, respectively, of the water in the runner.

The well known equation of working

$$H=\frac{uw\cos\alpha}{g}$$

for a definite case gives the value

$$w\cos\alpha=\frac{gH}{u}.$$

From the diagram for the admission it follows that

$$t_g\beta=\frac{c_r}{u-w\cos\alpha}=\frac{1}{g}\frac{c_r u}{\frac{u^2}{g}-H}$$

which must be realized for the blade if it is to do the work desired. As not all stream lines are parallel, as there is further contraction, etc., we must provide for an allowance according to experiences, so that

$$t_g\beta=\frac{1}{g}\frac{c_r H}{\frac{u^2}{g}-H}\frac{1}{\varphi 1}$$

The jet which enters the runner at the angle $\beta$ relatively to the blade on being discharged from the runner should, if possible, have an absolute axial movement. This is the condition for the equation of working given above

$$H=\frac{uw\cos\alpha}{g}.$$

Consequently the blade should have an angle $\gamma$ (Figs. 1 and 4) so that

$$t_g\gamma=\frac{c_a}{u}$$

where $u$ is the circumferential velocity of the point in question of the blade. Considering the contraction at this point it will be necessary to so select $t_g\gamma$ that

$$t_g\gamma=\frac{c_a}{u}\frac{1}{\varphi 2}.$$

As the circumferential velocity $u$ varies with the radius, the angle $\gamma$ will steadily be reduced the further the points considered are distant from the axis of the runner.

If the values derived above for $t_g\beta$, that is for the direction of the blade in the radial plane, and for $t_g\gamma$, that is the direction of the blade in a tangential plane to the cylinder shall be obtained at every point of the blade, these two angles must have the mutual relation given above, viz.:

$$t_g\epsilon=\frac{t_g\beta}{t_g\gamma}.$$

Considering, that, if the blades form helical surfaces, these surfaces will satisfy the above equation if $t_g\epsilon=t_g\delta$ (that is, equal to the tangent of the generatrix) we have the following equation:

$$tg\epsilon=tg\delta=\frac{tg\beta}{tg\gamma}=\frac{1}{g}\frac{c_r u}{\frac{u^2}{g}-H}\frac{1}{\varphi_1}\frac{u}{c_a}\varphi_2=\frac{1}{\varphi}\frac{\frac{c_r}{c_a}}{\frac{1-g-H}{u^2}}$$

To these conditions corresponds also the runner of the rotary pump illustrated in Figs. 4 and 5.

The water here enters through the suc-

tion nozzle $i$ into the casing $k$ and is conveyed to the discharge chamber $n$ of the pump by means of the helical blades $m$ of the runner, the generatrix of which is inclined at an angle $\delta$. From the chamber $n$ the water is discharged through the discharge pipe $o$. Rotation is imparted to the runner by a shaft $p$. The blades $m$ forming perfect helical surfaces which are arranged about the slightly conical boss $a$ of the runner are best seen in Fig. 4.

The specific number of revolutions of the runner is a maximum if the discharge diameter is equal to the admission diameter. A particle of water which flows along the outside circumferential cylinder has in this case within the runner only an axial velocity but no radial component. Consequently, this portion of the water cannot exchange work with the runner but will form vortices as indicated at $t$ in Fig. 5. As this vortex zone decreases the free passage, it is preferable to avoid the formation of vortices by suitably shaping the profile as indicated by dotted lines in Fig. 5. The vortex will completely disappear if the diameters $D_1$ and $d_5$ differ to such an extent that their circumferential velocities are related as follows:

$$\frac{u_1^2 - u_2^2}{2g} = H.$$

In this case, the body of liquid revolving between $D_1$ and $D_2$ exerts such a centrifugal pressure that the gap pressure is balanced thereby.

I claim:

1. A blade for runners designed to work in a flowing medium, said blade being formed substantially so that for all points where the medium enters the runner, not only the angle beta formed by the tangent to the blade surface which extends in the direction of flow relative to the blade, when this tangent is projected into the radial plane, with the tangent to the circle of rotation, but also the angles gamma, formed by the tangent first mentioned when it is projected into a plane extending tangentially to the cylindrical circumference of the perspective point, with the tangent to the circle of rotation, and epsilon formed by the first mentioned tangent when it is projected into the axial plane, with the line which extends in this plane in parallel to the shaft axis, vary in proportion to the value and direction of the absolute entrance velocity $w_e$ of the flowing medium.

2. A blade for runners designed to work in a flowing medium, said blade being formed substantially so that the following three angles, viz the angle beta formed by the tangent to the blade surface which extends in the direction of flow relative to the blade, when this tangent is projected into the radial plane, with the tangent to the circle of rotation, the angle gamma formed by the tangent first mentioned, when it is projected into a plane extending tangentially to the cylindrical circumference of the respective point, with the tangent to the circle of rotation, and the angle epsilon formed by the first mentioned tangent, when it is projected into the axial plane, with the line which extends in this plane in parallel to the shaft axis, are interdependent according to the equation

$$tg\ \text{epsilon} = \frac{tg\ \text{beta}}{tg\ \text{gamma}}.$$

3. A blade for runners designed to work in a flowing medium, said blade being formed substantially so that the following three angles, viz the angle beta formed by the tangent to the blade surface which extends in the direction of flow relative to the blade, when this tangent is projected into the radial plane, with the tangent to the circle of rotation, the angle gamma formed by the tangent first mentioned, when it is projected into a plane extending tangentially to the cylindrical circumference of the respective point, with the tangent to the circle of rotation, and the angle epsilon formed by the first mentioned tangent, when it is projected into the axial plane, with the line which extends in this plane in parallel to the shaft axis, are interdependent according to the equation

$$tg\ \text{epsilon} = \frac{tg\ \text{beta}}{tg\ \text{gamma}},$$

while the angle of inclination delta between the generatrix of the blade surface and the axis is equal to the angle epsilon.

4. A blade for runners designed to work in a flowing medium, said blade being formed substantially so that the following three angles, viz the angle beta formed by the tangent to the blade surface which extends in the direction of flow relative to the blade, when this tangent is projected into the radial plane, with the tangent to the circle of rotation, the angle gamma formed by the tangent first mentioned, when it is projected into a plane extending tangentially to the cylindrical circumference of the respective point, with the tangent to the circle of rotation, and the angle epsilon formed by the first mentioned tangent, when it is projected into the axial plane, with the line which extends in this plane in parallel to the shaft axis, are interdependent according to the equation

$$tg\ \text{epsilon} = \frac{tg\ \text{beta}}{tg\ \text{gamma}},$$

the generatrix of the blade surface extending symmetrically to the tangent on the current line in every point so that the radius of the respective point of the blade forms

the height extending from the apex down to the base line of the isosceles triangle which comprises the base angles epsilon and delta.

5. A blade for runners designed to work in a flowing medium, said blade being formed substantially so that the following three angles, viz the angle beta formed by the tangent to the blade surface which extends in the direction of flow relative to the blade, when this tangent is projected into the radial plane, with the tangent to the circle of rotation, the angle gamma formed by the tangent first mentioned, when it is projected into a plane extending tangentially to the cylindrical circumference of the respective point, with the tangent to the circle of rotation, and the angle epsilon formed by the first mentioned tangent, when it is projected into the axial plane, with the line which extends in this plane in parallel to the shaft axis, are interdependent according to the equation

$$tg\ \text{epsilon} = \frac{tg\ \text{beta}}{tg\ \text{gamma}}$$

and the angle of inclination of the generatrix of the helical surface at every point of the blade results from the equation

$$tg\ \text{delta} = \frac{1}{g} \cdot \frac{c_r u}{\frac{u^2}{g} - H} \frac{1}{\text{phi}_1} \frac{u}{c_a} \cdot \text{phi}_2 = \frac{1}{\text{phi}} \frac{\frac{c_r}{c_a}}{1 - \frac{g \cdot H}{u^2}}$$

6. A blade for runners designed to work in a flowing medium, said blade being formed substantially so that the following three angles, viz the angle beta formed by the tangent to the blade surface which extends in the direction of flow relative to the blade, when this tangent is projected into the radial plane, with the tangent to the circle of rotation, the angle gamma formed by the tangent first mentioned, when it is projected into a plane extending tangentially to the cylindrical circumference of the respective point, with the tangent to the circle of rotation, and the angle epsilon formed by the first mentioned tangent, when it is projected into the axial plane with the line which extends in this plane in parallel to the shaft axis, are interdependent according to the equation

$$tg\ \text{epsilon} = \frac{tg\ \text{beta}}{tg\ \text{gamma}},$$

the boss having a paraboloidal configuration and the generatrix of the helical surface being a parabola disposed at all points symmetrically to the parabolas formed by the said boss and by the stream lines lying in the axial plane.

7. A blade for runners designed to work in a flowing medium, said blade being formed substantially so that the following three angles, viz the angle beta formed by the tangent to the blade surface which extends in the direction of flow relative to the blade, when this tangent is projected into the radial plane, with the tangent to the circle of rotation, the angle gamma formed by the tangent first mentioned, when it is projected into a plane extending tangentially to the cylindrical circumference of the respective point, with the tangent to the circle of rotation, and the angle epsilon formed by the first mentioned tangent, when it is projected into the axial plane, with the line which extends in this plane in parallel to the shaft axis, are interdependent according to the equation

$$tg\ \text{epsilon} = \frac{tg\ \text{beta}}{tg\ \text{gamma}},$$

the diameter of the runner with a radial component of velocity being at least so much greater than the discharge section with axial flow that the equation

$$\frac{u_1^2 - u_2^2}{2g} = H$$

is valid.

In testimony whereof I affix my signature.

FRANZ LAWACZECK.