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ROTOR BLADE FOR HIGH TEMPERATURE TURBINES

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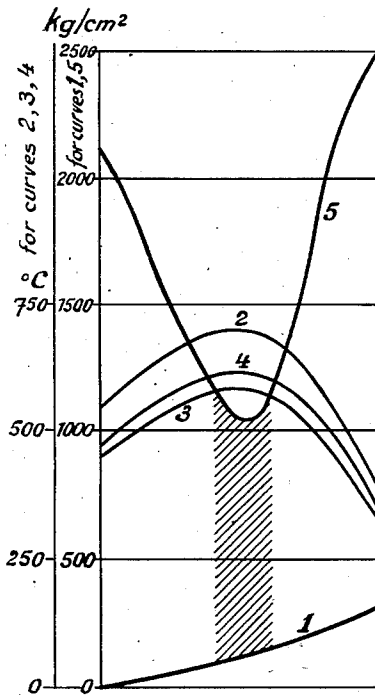


Fig. 7

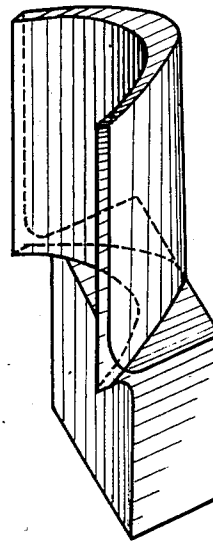


Fig. 2

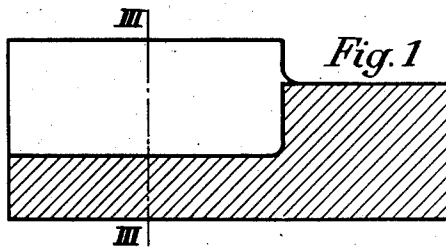


Fig. 1

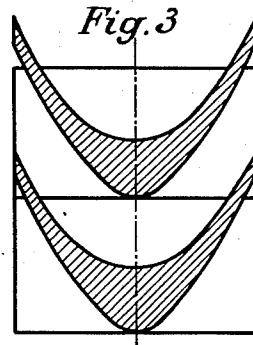


Fig. 3

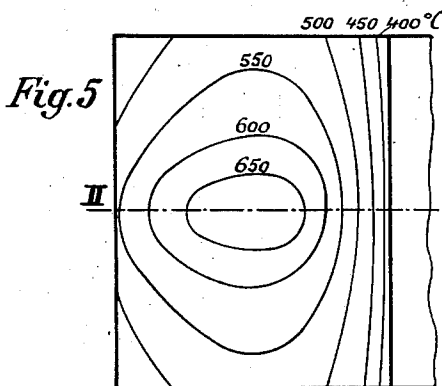


Fig. 5

Fig. 4

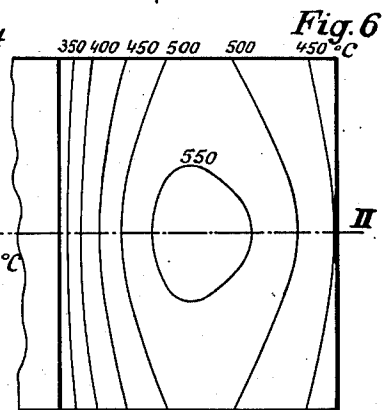


Fig. 6

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ROTOR BLADE FOR HIGH-TEMPERATURE TURBINES

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The present invention relates to turbines operated by a driving medium of high temperature, such as explosion turbines, and has for one of its objects to provide blades for the rotors of such turbines which are of such form and construction as to be capable of being impinged for an indefinite period of time by jets of a driving medium of a temperature above the red heat of iron (about 550° C.), and particularly by jets of explosion gases of high temperature, without failure or interruption of the normal operation of the turbine.

The following description will be directed primarily to the embodiment of the invention in an explosion turbine, but it will be recognized that the invention is applicable also to other types of turbines driven by fluids of very high temperature, i. e. at or above the red heat of iron.

I have found, as a result of extensive research and investigation, that because of the reversal in direction of the gas stream in the pocket or trough of the blade, the gases undergo a compression which is accompanied by an increase in the temperature of such gases. Thus I have found that if the temperature of the gas stream as it enters the rotor blade channel is, for example, 800° C., such temperature rises to 920° C. in the middle of the blade pocket and falls to 800° C. as it leaves the blade channel after the compression impact has become equalized. This phenomenon, investigation has shown, appears in the rotor blade channel uniformly from the bottom to the top of the blade. On the other hand, the portion of the gas stream which flows through the blade channel along the rear face of a blade is subjected to no compression impact and consequently suffers no rise in temperature.

Combustion gases, as is known, transmit heat to the blades both by conduction and by radiation as they stream through the rotor blade channel, the degree of such heat transmission depending upon the temperature of the gases at any given point and also upon the temperature of the blades themselves at different points of their surface. The heat so absorbed by each blade becomes distrib-

uted through the body thereof and is in part re-radiated to the surrounding atmosphere at the top and at the sides of the blade or is withdrawn by conduction as a result of ventilation. A further portion of the absorbed heat is conducted through the foot of the blade into the rotor annulus or the blade carrying sectors. After an explosion turbine has been in operation for about 30 minutes a state of equilibrium is reached in which the amount of heat delivered by the combustion gas stream to the blades is equal to the heat lost by the blade to its surrounding atmosphere and to the rotor body. After this condition of equilibrium is reached, definite and constant temperatures exist in the different parts of the blade. If now the points of equal temperature in such blade are connected by lines (isotherms), there will be obtained a clear picture of the actual temperatures which the individual portions of the blade reach.

This picture, I have found, is far different from that which could be based on prior views on the conditions existing in the blades, which views would lead experts in the art, following the customary lines of thought, to the conclusion that the different zones or portions of the blades assume a uniform temperature during the operation of the turbine. The present invention is based upon the peculiar and novel discovery which I have made following extensive research to the effect that the temperature distribution over the surface of the blade and throughout the interior thereof is a quite definite one but an extremely nonuniform one.

This temperature distribution and the variation in the permissible load corresponding thereto, I have made the basis for a new construction of the blades of explosion turbines, which construction is fundamentally different from that of the blades employed in known continuous current turbines operated by steam. I have thus departed from the teachings of the prior art which gave no hint that the blades of an explosion turbine must be differently constructed from those of a continuous current turbine. According to the prior art, satisfactory flow conditions in

the blade channel and adequate strength against bending forces and against centrifugal force controlled exclusively the form of the blade. In accordance with the present invention the form of a blade for very high temperature work, such as an explosion turbine blade, is made to depend on and to meet certain other factors which heretofore have not been known or recognized.

My novel form of blade is essentially different from the explosion turbine blades of the prior art and under the same conditions, such as equal operating safety, similar blade material, similar combustion gas temperature, pressure and velocity, the same number of jets per unit of time, the same number of combustion chambers, the same rotor diameter, and the same rotor speed, a considerable increase in the radial length of the blades and consequently a considerable increase in the capacity of the machine (which is an important advantage from the standpoint of the initial cost of a turbine plant), is made possible as compared with known blades; or, with the same radial length of blade, my invention makes possible an increase in the combustion gas temperature and consequently an increase in the thermal efficiency. The discovery that I have made and upon which the present invention is based has disclosed the peculiar and surprising fact that definite temperature zones are created within the body of the explosion turbine blade. The zone of highest temperature is located island-like in approximately the middle of the blade, while the zones of decreasing temperature lie toward the blade periphery. The temperature conditions upon the rear surface of the blade differ essentially from the temperatures which prevail upon the trough of concave surface of the blade; the temperature in the body of the blade shows a quite definite transition from the temperatures at such trough or concave surface of the blade to that upon the rear surface thereof.

Considering now the load on the blade under these conditions, there are to be distinguished the stresses arising from centrifugal force and the bending stresses caused by the pressure of the combustion gas stream. If the sums of both of these stresses are represented in a coordinate system as ordinates while the height of the blade is represented as abscissæ, there is obtained a line which begins at the zero point of the coordinate system (which corresponds to the top edge of the blade) and extends upwardly. If now there is introduced into the same coordinate system the temperature gradation along a medial longitudinal line on the concave surface of the blade and the temperature gradation along a similar line on the rear surface of the blade, there are obtained two curves which are concave to the abscissæ axis and

whose crown is approximately in the middle of the effective blade height. By integration over the whole blade cross-section there can be obtained a curve lying between the two just mentioned curves and indicating the average temperature in each separate blade cross-section. This average temperature line is most important for the calculation of the resistance or strength of the blade.

As the clearance for turbine blades are very small, the creeping strength is the most determining factor in building materials for blades which are exposed to high temperatures, and this property must receive the closest attention in the study of rotor blades. By creeping strength is meant the maximum load which can be continuously applied at a certain temperature for an indefinite period without causing a permanent distension of the material, at least not beyond a fixed safe maximum. If now in the coordinate system mentioned above there is introduced the creeping strength curve corresponding to the average temperature of the blade made of any suitable material, it will be found that this curve is convex to the abscissæ axis and that its crown lies along the same abscissæ as that in which is located the crown of the average temperature curve. The distance between this creeping strength curve and the curve representing the sum of the loads due to centrifugal force and the pressure of the gas stream, is then a measure of the strength of the blade against creeping.

In blades as heretofore constructed in which considerations of bending and centrifugal stresses were controlling and which were designed for use in continuous current turbines, the creeping strength curve, when the blades were subjected to the investigation outlined above, was extremely close to the curve representing the load due to centrifugal force and gas pressure; the reserve strength of known blades against creeping would consequently be found to be insufficient. If, therefore, a blade of this kind whose form and dimensions were calculated for use with steam in a continuous current turbine and which would be entirely satisfactory in such a turbine, were employed upon the rotor of an explosion turbine, in which, it will be remembered, jets of high temperature, high pressure gases impinge intermittently against the blades, such blades would after a short time begin to creep and give rise to serious disadvantages and dangers during operation.

Hitherto, the problem connected with the manufacture of a turbine blade for use with driving fluids of high temperature has usually been solved by employing more highly heat-proof structural materials for the blades. The present invention solves such problem, which assumes more serious proportions in

explosion turbines than in steam turbines, in an entirely different and novel manner.

According to the present invention, a blade for explosion turbines is so constructed that the blade will resist the tendency to creep over indefinite periods of time. To accomplish this object I widen the blade beyond the width prescribed by the flow conditions and the centrifugal and pressure load upon the blade, so that the middle portion of the blade, whose strength is small as compared with the mechanical load thereon because of its high average temperature in operation, is reinforced by the sides of the blade; such sides, as the blade is increased in width, reach lower temperatures than the middle portion of the blade and consequently possess greater strength against the mechanical load thereon than such middle portion. The present invention thus embodies my discovery that because of the unavoidably high temperatures which exist in the middle portion of the blade, the difference between the creeping strength and the actual load resulting from centrifugal force and gas pressure is so small in known blades that no sufficient reserve strength remains. My discovery that the temperatures in the body of the blade decrease in zone fashion with increasing width of blade makes it possible, when the blade is made sufficiently wide, to create so much reserve strength between the theoretical creeping strength and the actual load that the blade sides reinforce the middle portion of the blade in the manner of a reinforcing framework, while the reserve strength in the middle portion suffices to hold the highly strained middle portion within this framework formed by the less strained blade sides. I am thus able to use materials for work at a temperature for which they have hitherto been regarded as unsafe.

In the accompanying drawing there are illustrated the temperature and load conditions in, and the strength of, the blades discussed hereinabove. In said drawing Fig. 1 represents a central longitudinal section through an explosion turbine blade built in accordance with the present invention; Fig. 2 is a perspective view of such blade; Fig. 3 is a section along the line 3—3 of Fig. 1; Fig. 4 represents a development of the blade section shown in Fig. 3, the concave wall of the blade appearing as the vertical straight line at the right-hand end of Fig. 4; Fig. 5 similarly represents a plan view of the concave face of the blade developed as in Fig. 4; Fig. 6 is a development of the rear face of the blade; and Fig. 7 is a diagram showing the physical properties of a blade constructed according to the present invention.

In Figs. 4, 5 and 6 are shown the isotherms which represent the temperatures at various points on and in the blade when the condition of equilibrium mentioned above has been

reached. These isotherms represent the conditions in a blade constructed as shown in Figs. 1 to 3 and impinged by intermittent jets of explosion gases of approximately 800° C. These isotherms show the peculiar and novel fact that during the operation of an explosion turbine clearly distinguishable and definable temperature zones are created in the body of the rotor blades. This fact, as I have indicated above, is quite contrary to the general impression in the art, based very probably upon experience with continuous steam turbines, that rotor blades generally have substantially the same temperature throughout their active portion. The zone of highest temperature exists island-like in the middle of the blade, while toward the edges of the blades lie zones of constantly decreasing temperature. The temperature conditions existing on the concave or trough surface of the blade are different from those upon the rear surface of the blade, while in the body of the blade there is a definite gradation from the temperatures at the concave surface to those at the convex or rear surface of the blade.

If we now calculate the actual load on such a blade resulting from centrifugal force and the bending force due to gas stream pressure and represent the sum of these values in the coordinate system in which the abscissæ represent the height of the blade measured from the top to the bottom thereof, while the ordinates represent such sum, there is obtained the curve 1 shown in Fig. 7. If now we plot the temperatures on the surface of the blade trough or pocket and on the rear surface of the blade along the median line II—II of Figs. 4, 5 and 6, against the blade height, there are obtained the curves 2 and 3 respectively (Fig. 7). By integration over the whole blade cross-section there is obtained the curve 4 which represents the average temperature in the central longitudinal section of the blade. This curve 4 is controlling in the calculation of the strength of the blade. Since, as stated above, the creeping strength is the most important property of machine parts employed in high temperature work, with small clearances, primary consideration must be given this property in the present case. The curve 5 in Fig. 7 is based on curve 4 for a definite blade material, such as, for example, an alloy containing 10% iron, 65% nickel, 15% chromium, and 7% molybdenum.

The blade according to Figs. 1-3 may therefore be loaded up to the amounts indicated by curve 5; actually its load is represented by the curve 1. At about the middle of the radial length of the blade the curves 1 and 5 are closest to each other. From this it will be clear that the smallest degree of safety is therefore to be found not at the foot of the blade, as was to be expected from prior art considerations, but at the horizontal sec-

tion taken at about the middle of the blade height. The problem of the present invention was therefore to make sufficiently great the distance between the curves 1 and 5, which distance is a measure of the reserve strength of the blade. The solution of this problem according to the invention is based upon my discovery that the weakest portion of the blade is not the bottom but the middle part thereof, as is illustrated by curve 5; the reserve strength at this middle portion of the blade can be increased only to a very slight extent by known measures, and the means for increasing such reserve strength are not proportionate to the result. The present invention embodies, however, the further discovery that I have made to the effect that the sides of the blades, contrary to the hotter middle section, take on lower temperatures with increasing width and that finally the blade can be given a width at which the sides of the blade reach temperatures which lie considerably below that at which the creeping strength is exceeded. The blade shown in Figs. 1 to 3 has been given a width of this degree as can be seen from Figs. 5 and 6. The widened sides of the blades, being cooler, act as a reinforcing and carrying framework for the inner island-like highly strained blade portion, the latter being hung in such framework as in a skeleton frame. The average values of the temperature which the blade assumes in operation are thus reduced so that by such expedient an indirect cooling of the blade is obtained. By widening the blade the moment of resistance also is increased so that curve 1 of Fig. 7 lies lower than does the corresponding curve of a blade constructed according to the prior art. To such widening of the blade, therefore, is to be attributed the increase in the distance between the lowest point of the curve 5 and the curve 1. If no increase in operating safety by increase of the reserve strength of my new blade is sought, then gases at higher temperatures may be employed with no loss in the degree of safety of operation, so that the operation of the explosion turbine can be improved and its economy increased. If the temperature conditions remain the same, then the radial length of the blade can be increased, so that the capacity of the blades is increased.

I claim:

1. A blade for the rotor of a turbine driven by a fluid of a temperature above the red heat of iron, the width of such blade being substantially greater than that demanded by the flow conditions and by the load due to centrifugal force and to the pressure of the fluid stream, said blade being capable of continuous operation for indefinite periods with the middle portion thereof at a temperature above red heat, said middle portion,

whose resistance to creeping, because of the high average temperature which it assumes during operation, is small under the mechanical load thereon, being reinforced by the sides of the blade which with increasing width of the blade take on lower temperatures than such middle portion and consequently possess a greater strength as against the mechanical load thereon than does said middle portion.

2. A blade for the rotor of a turbine driven by a fluid of a temperature above the red heat of iron, the width of said blade being such that when the blade is in operation at rated or above rated capacity and the center of the blade assumes a temperature above red heat, zones of sufficient extent of lower temperature than the center of the blade exist at the sides thereof and reinforce such center and prevent creeping of the blade, the width of the blade being greater than that demanded by the flow conditions and by the load due to centrifugal force and to the pressure of the gas stream.

3. A blade for the rotor of a turbine driven by a fluid of a temperature above the red heat of iron, said blade capable of continuous operation for indefinite periods with the middle portion thereof at a temperature above red heat, the width of the blade being such that when the blade is in operation at rated or above rated capacity, sufficiently wide zones of lower temperature will surround the hotter central portion of the blade to reinforce the same and prevent creeping of the blade.

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