Nov. 24, 1953 T. N. HULL, JR 2,660,401

TURBINE BUCKET

Filed Aug. 7, 1951

Fig.1.

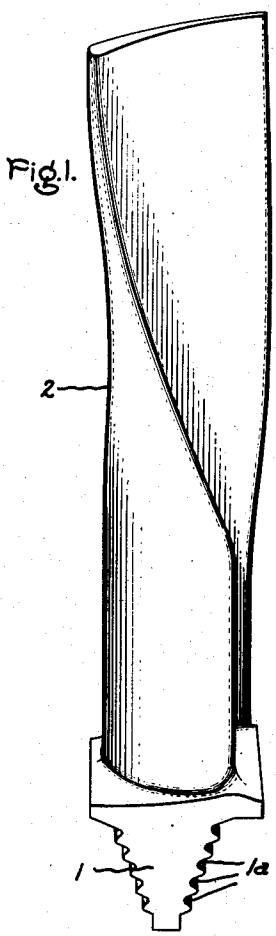


Fig.2.

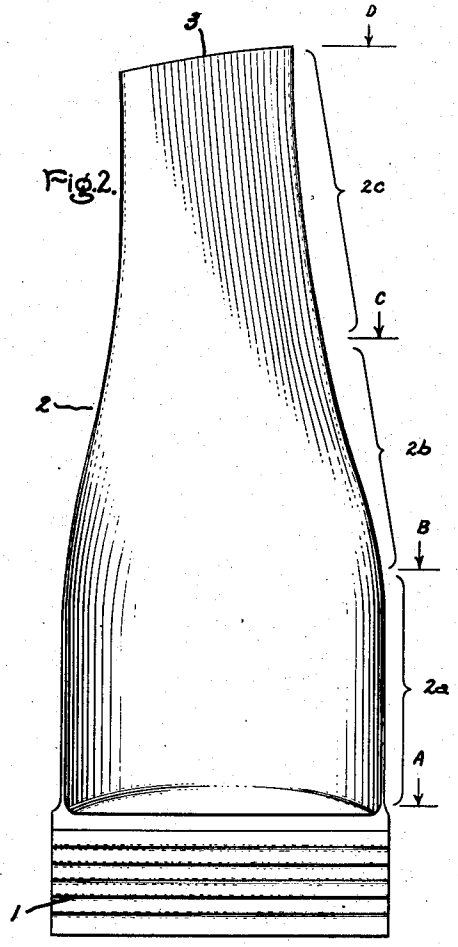


Fig.4.

Fig.5.

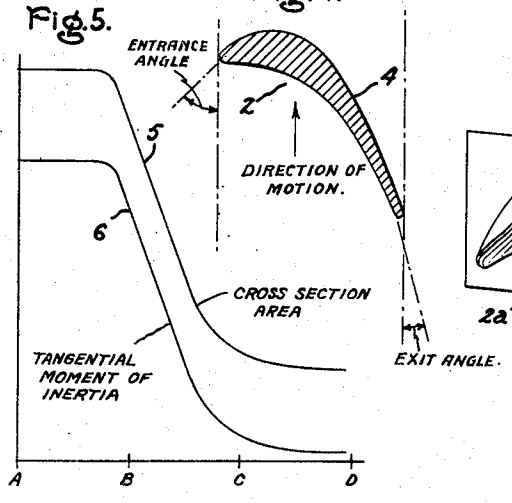
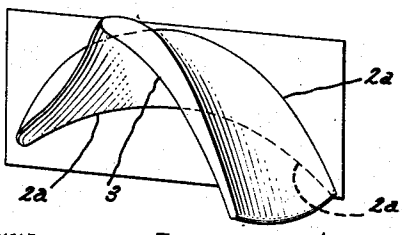


Fig.3.



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TURBINE BUCKET

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3 Claims. (Cl. 253—77)

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This invention relates to turbomachine blades or "buckets," particularly to a turbine bucket for service in high temperature gas turbine power-plants.

In recent years, in connection with the development of practicable gas turbine power-plants, there have been developed numerous modifications of the so-called "vortex type" of blade, characterized by a blade shape that is warped or twisted from root to tip in order to obtain various desired aerodynamic characteristics. In order to reduce the stresses in the blade due to centrifugal force, it has been customary to taper the blade from root to tip so that it has a continuously decreasing cross-section area. Likewise, the transition in cross-section shape, and the change in entrance and exit angles, has been gradual from root to tip. This uniform transition along the length of the blade has been dictated by the aerodynamic considerations involved in designing blades according to the various vortex design theories.

As the capacity of gas turbine power-plants has progressively increased, it has been necessary to rapidly increase the length of the compressor and turbine blades, with the result that serious troubles have been encountered with fatigue failures of the comparatively long slender blades. These problems have resulted partly from the use of "shroudless" buckets, as contrasted with earlier steam turbine rotor structures in which a continuous shroud band of some sort is secured to the bucket tips. Such shrouds have an important influence in reducing tangential vibration of the buckets, which type of vibration appears to have a most serious effect in producing fatigue failures. With a shroudless bucket, fixed more or less rigidly at its base and completely free to vibrate at its tip, it is extremely difficult to so design a gas turbine power-plant that the blades will not, at some speed or other, experience excessive resonant vibration due to discontinuities in the motive fluid stream. These discontinuities may be caused by the fact that the motive fluid is produced by six or more separate "combustors" spaced circumferentially around the axis of the power-plant, or by the partitions in the turbine nozzle ring or struts extending across the flow path.

These fatigue failures of turbine buckets have been an important source of difficulty in placing in regular commercial operation the first large gas turbine power-plants. It has become increasingly necessary to find a satisfactory and simple solution for this problem in order to make

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possible large scale commercial exploitation of this type of prime mover.

Accordingly, the object of this invention is to provide an improved turbine bucket having a novel configuration especially designed to eliminate fatigue failures in the blade root or dovetail due to the long, slender, shroudless bucket having a natural frequency so low as to become resonant under the influence of discontinuities in the motive fluid flow.

While improvement in the bucket vibration characteristics could be effected merely by substantially increasing the axial width of the bucket, that expedient would proportionately increase the axial thickness and the weight of the turbine rotor. Accordingly, it is a further object to effect this improvement in bucket fatigue strength without increasing the axial thickness of the bucket-wheels.

Other objects and advantages will become apparent from the following description, taken in connection with the accompanying drawings, in which Fig. 1 is a front perspective view of a turbine blade incorporating invention, Fig. 2 is a side view of the same blade, Fig. 3 is an end view looking at the tip of the blade, Fig. 4 is a sectional view illustrating the shape of an intermediate portion of the blade at the plane identified C in Fig. 2, and Fig. 5 is a graphical representation of certain design characteristics of the blade.

Generally, the invention is practiced by dividing the effective length of the blade into three portions, a root portion having a cross-section of substantial thickness and being shaped generally as an "impulse" type of blade, a tip portion having a very thin cross-section of airfoil shape and constituting a "reaction" type of blade, and an intermediate portion which sharply transitions from the impulse blade shape at the root to the reaction type of blade shape at the tip.

Referring now more particularly to Fig. 1, the blade comprises a conventional base portion 1 provided with dovetail grooves 1*a*, or any of the many well-known equivalent means for fastening the base to the rim of the bucket-wheel. The precise type of fastening is not material to an understanding of the present invention; and it will be appreciated that the novel blade shape which constitutes the present invention is applicable to shroudless buckets or blades wherever the length of the blade is such that vibration problems, with resulting risk of fatigue failures, are encountered.

As shown in Figs. 1 and 2, the blade 2 is di-

vided radially into three portions of distinctive shape. These three portions are defined between the planes identified A, B, C, D in Fig. 2. The root portion immediately adjacent the bucket base 1 extends from the plane A to the plane B. This portion is identified 2*a* and is characterized by the cross section shape shown at 2*a* in Fig. 3. It will be immediately apparent to those skilled in the turbine art that this blade shape is essentially that of the well-known "impulse" type of turbine, having a section of very substantial thickness, the maximum thickness occurring approximately at the midpoint of the axial width of the blade. This type of blade is roughly crescent-shaped; and, because of the cross-section shape and the substantial thickness, it has excellent resistance to vibration in a tangential direction. The precise shape of this portion of the blade is of course determined in accordance with the well-known design principles governing the impulse type of blade, as used for many years past in steam turbines. For instance, the entrance angle may be on the order of 29° and the exit angle may be on the order of 28°.

Attention is particularly directed to the fact that both the cross section shape of the blade and the cross section area are exactly, or very nearly exactly, constant from the section A adjacent the base 1 throughout approximately the root third of the blade, that is, extending outward to the plane B in Fig. 2. In other words, the outline identified 2*a* in Fig. 3 represents the shape of the blade at both planes A and B in Fig. 2.

The outer third of the blade is identified 2*c* in Fig. 2, and has a thin airfoil-shaped cross-section indicated at 3 in Fig. 3. It will immediately be apparent that this tip section is of very much smaller cross-section area than the root section 2*a*, also that the maximum thickness, in accordance with the well-known aerodynamic design of airfoil sections, occurs substantially forward of the middle of the chord; and the entrance angle has increased very substantially and the discharge angle has decreased so that the outer third of the blade has the characteristic warped shape of blades designed in accordance with the above-mentioned vortex theories. Specifically, the entrance angle at the tip may be on the order of 80°, and the exit angle may be about 23°.

The middle third of the blade, identified 2*b* in Fig. 2, transitions very rapidly, yet smoothly and continuously, from the impulse type root section to the thin airfoil type tip section. To indicate the rapidity of this change in shape, reference may be had to Fig. 4, which represents the cross-section shape of the blade at the plane identified C in Fig. 2. It will be apparent that this section is still of comparatively great thickness, but that the shape has changed to that of an airfoil with the point of maximum thickness at about one-third the chord of the airfoil from the leading edge. The entrance angle is about 45 degrees and the exit angle about 25 degrees.

The manner in which the blade shape transitions from the impulse shape at the root, as shown at 2*a* in Fig. 3, to the airfoil section 4 at section C, may be seen from a comparison of the outlines of the blade as shown in Figs. 1 and 2. It will be seen that this transition in shape takes place with great rapidity in the intermediate blade portion 2*b*.

The corresponding change in cross-section area as a function of radius is illustrated graphically in Fig. 5. Here the abscissa represents the radial length of the blade, with the stations A, B, C, D marked as in Fig. 2. The curve identified 5 represents the change in cross-section area from root to tip. It will be seen that the area is exactly, or very nearly exactly, constant throughout the root portion 2*a* (from plane A to plane B). The cross-section area is also substantially constant, but at a very much lower value, throughout the tip portion 2*c* (from plane C to plane D). And it changes with great rapidity in the intermediate blade portion 2*b* (from plane B to plane C). More specifically, it may be noted that the cross-section area in the tip portion is on the order of only about 20 to 30 per cent of the root area between plane A and plane B. Generally, it may be stated that the cross-section area of the tip portion is not more than about one-third that of the root portion.

It is also interesting to note the corresponding change in value of the tangential moment of inertia of the cross-section area, which design characteristic has the most important effect on the resistance of the blade to vibration in a tangential direction. This characteristic is represented by the curve labeled 6 in Fig. 5. It will be apparent that the tangential moment of inertia of the blade section follows generally the shape of the cross section area curve, the moment of inertia at the tip being only on the order of a few per cent of the moment of inertia of the root section 2*a*. More specifically, it may be stated that the tangential moment of inertia of the blade section throughout the tip portion 2*c* is not more than about one-tenth the moment of inertia at the root portion 2*a*.

As described above, the root portion 2*a* is substantially an impulse type blade, while the tip portion 2*c* is essentially a reaction type blade, while the transition portion 2*b* changes very rapidly from an impulse type section to substantially a reaction blade. Actually, it is not necessary that the root portion 2*a* be a "100% impulse" section all the way from section A to section B. The blade section will be of substantially pure impulse type at the section A; but the cross-section shape may change slightly with radius so that at section B, the shape is suitable for perhaps 10 per cent reaction. Thus, the root portion 2*a* is for all practical purposes an "impulse type" blade section.

As contrasted with the prior art blade shapes having a gradual continuous transition in both shape and cross-section area from root to tip, the invention provides a blade which has been found to have unusual resistance to vibration in a tangential direction relative to the bucket wheel to which it is secured. Whereas blades of the same general size and capacity designed according to previous gas turbine practice had a fatigue life of only on the order of a few hundred thousand cycles, corresponding to a few hundred hours of normal operation, tests of sample blades made in accordance with the invention have indicated the life will be many years.

This improvement in fatigue resistance is achieved by the invention without increase in the axial thickness of the bucket-wheels and, therefore, with substantially no change in the total weight of the rotor. There may be some slight increase in the rotor weight, due to the fact that the root section of the blades is somewhat thicker than the prior art designs. The invention is also advantageous in that it permits greater bucket length, for a given weight of rotor

and length of service life, so that the motive fluid flow path area can be increased to decrease the velocity of the fluid leaving the turbine and, therefore, reduce the "leaving loss" represented by the velocity energy remaining in the motive fluid. Thus, an improvement in aerodynamic efficiency can be obtained without increasing the weight of the rotor, and with much better life "expectancy" than with prior art blade shapes.

Stated another way, the advantage of the design is apparent from the fact that it has permitted a 40 per cent reduction in bucket width (corresponding generally to a 40 per cent reduction in bucket-wheel weight) over that which would be required for the same fatigue resistance in a bucket not using the invention. This design also improves the bucket's resistance to vibration in the axial direction.

Thus, it will be seen that the invention provides a novel turbine blade shape which effects important improvements in resistance to fatigue failure, at substantially no cost in increased rotor weight, and with an improvement in aerodynamic efficiency.

While only one blade shape of this novel type has been described specifically, it will be apparent to those skilled in the art that many small changes may be made without departing from the invention, and it is intended to cover by the appended claims all such modifications as fall within the true spirit and scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. An integral turbomachine blade having the effective length thereof subdivided into root, intermediate, and tip portions, the root portion comprising substantially one-third of the blade length and having a substantially constant crescent-shaped section substantially that of an impulse type blade, the tip portion comprising substantially the outer third of the blade length and having a substantially constant airfoil-shaped section substantially that of a reaction type blade, the intermediate blade portion rapidly transitioning smoothly and continuously from the impulse-shaped root to the reaction-shaped tip, the cross-section area of the root portion being on the order of three times the cross-section area of the tip portion whereby the high moment of inertia of the root section resists vibration of the blade.

2. An integral turbo-machine blade having the effective length thereof divided into root, intermediate, and tip portions, the root portion comprising substantially one-third of the blade length and having a shape substantially that of an impulse type blade, the cross-section shape and area of said root portion being substantially constant throughout the radial length thereof,

the tip portion comprising substantially the outer third of the blade length and having a substantially constant cross-section shape substantially that of a reaction type blade, the intermediate blade portion rapidly transitioning smoothly and continuously from the impulse-shaped root portion to the reaction-shaped tip portion, the cross-section area of the tip portion being substantially constant along the radial length thereof and being not more than about one-third the cross-section area of the root portion, while the cross-section area of the intermediate portion decreases rapidly from the root portion to the tip portion, whereby the tangential moment of inertia of the cross-section area is high and substantially constant throughout the root portion, while the tip portion is of substantially smaller section and tangential moment of inertia.

3. In an integral turbomachine blade having the effective length thereof divided into root, intermediate, and tip portions, the root portion comprising substantially one-third of the blade length and having a crescent shape substantially that of an impulse type blade, the cross-section shape and area of said root portion being substantially constant throughout the radial length thereof with an entrance angle on the order of 30° and an exit angle on the order of 30°, the tip portion comprising substantially the outer third of the blade length and having substantially constant airfoil-shaped cross-section substantially that of a reaction type blade with an entrance angle on the order of 80° and an exit angle in the neighborhood of 20°, the intermediate blade portion rapidly transitioning smoothly and continuously from the impulse-shaped root portion to the reaction-shaped tip portion, the cross-section area of the tip portion being on the order of one-third as large as that of the root portion while the cross-section area of the intermediate blade portion decreases rapidly from the root portion to the tip portion, whereby the tangential moment of inertia of the cross-section area is high and substantially constant throughout the root portion while the tip portion is of substantially smaller section and moment of inertia.

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