Aug. 2, 1955 D. F. WARNER 2,714,499

BLADING FOR TURBOMACHINES

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Fig. 1.

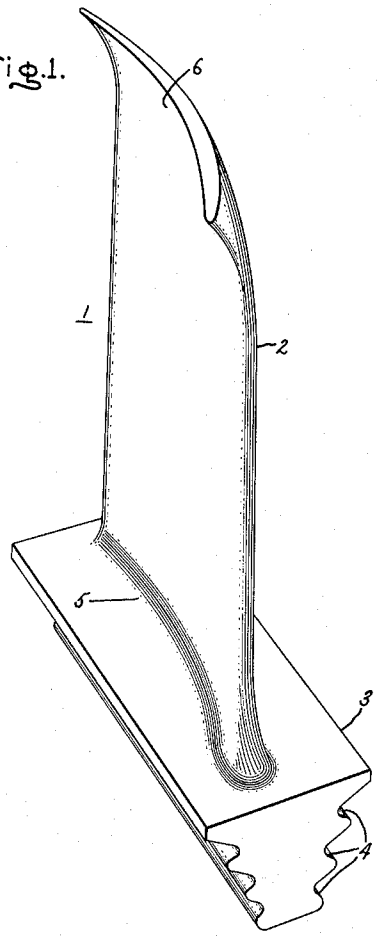


Fig. 2.

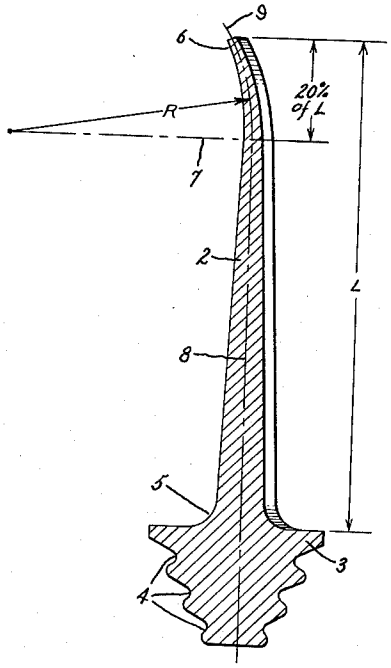
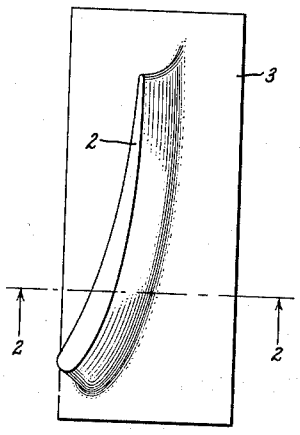


Fig. 3.



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BLADING FOR TURBOMACHINES

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5 Claims. (Cl. 253—77)

This invention relates to turbomachines and more particularly to an improved blade structure for the rotating stages of such machines.

It has been observed that during the operation of turbomachines, cracks frequently occur in the rotating blades and in many instances complete blade failure occurs. In many instances, these cracks are failures of the type which has become known in the art as "fatigue cracks" or "fatigue failures." These terms refer to a condition which results from operation of the rotating blades in the presence of extraneous disturbing forces which tend to set up and excite a vibration of the blade structure. Such vibrations may be of many different modes and are usually quite complex and difficult to analyze. However, it may be said in general that these disturbing or exciting forces cause the blade to vibrate more or less violently with respect to the rotor to which the blade is secured. It is known that the blade structure vibrates in such a way as to set up nodes or stationary portions with other portions of the blade structure remote from such nodes in more or less violent vibratory motion. The flexing action of the blade structure of the vibratory portion with respect to the node portions subjects certain portions of the blade to more or less continuous stress reversals until the blade material either fails or cracks as a result of such action.

In addition to the vibration problem, there also exists a serious problem, particularly in gas turbines which utilize high temperature gases as motive fluid, which results from non-uniform temperature or temperature stratification of the motive fluid along the length of the blade. A temperature stratification of the motive fluid supplied to a turbine will result in unequal thermal expansions at various sections of the blade and these unequal thermal expansions may result in thermal stresses of sufficient magnitude to cause serious deformation and, in some instances, even failures of certain portions of the blade structure.

Accordingly, it is an object of this invention to provide an improved turbomachine blade structure for obviating the above-mentioned difficulties.

It is also an object of the invention to provide an improved blade structure wherein the adverse effects of local vibration modes are minimized in certain portions of the blade.

Another object of the invention is to provide an improved blade structure having increased stiffness for resisting vibratory exciting forces.

Another object is to provide an improved turbomachine blade structure wherein stresses resulting from temperature stratification of the fluid flowing past the blades are minimized.

Other objects and advantages of the invention will be apparent from the following description taken in connection with the accompanying drawings in which Fig. 1 is a perspective view of a turbomachine blade in accordance with the invention; Fig. 2 is a sectional view of the arrangement shown in Fig. 3 and looking in the direction

of the arrows 2—2; and Fig. 3 is a plan view of the blade structure shown in Fig. 1.

Referring now to Fig. 1, the turbine blade is indicated generally at 1, having a blade portion 2 and a base portion 3. As illustrated in the drawing, base portion 3 is provided with dovetail surfaces 4 to provide means for securing the blade to the rotor (not shown) of a turbomachine. Those skilled in the art will recognize that other types of dovetails may be employed, or, if desired, the base portion 3 may be of a type suitable for welding to the rotor of a turbomachine.

In a conventional blade structure, the surfaces of the blade portion are defined by the envelope of a plurality of air foil sections which may be considered to be stacked one on top of another. The various air foil sections may differ, thus producing a blade of tapering thickness and the various sections may be rotated with respect to other sections so as to produce a twisted blade structure. Generally speaking, it is desirable to stack and orient the various air foil sections in such a way that the centroid of each section coincides with a common rectilinear axis, which axis is arranged to coincide or to substantially coincide with a radial line through the axis of rotation of the turbomachine rotor. The air foil section which coincides with the top surface of the base portion is usually referred to as the root section 5; the air foil section at the opposite extremity of the blade portion is referred to as the tip section 6; and the projected distance between said root and tip sections along said rectilinear axis is usually referred to as the length or height of the blade.

In accordance with the present invention, the blade portion 2 is constructed in the conventional manner just described between the root section 5 and an intermediate section located between the root section 5 and the tip section 6. For reasons which will appear presently, this intermediate section will be referred to as a tangent section 7, and it is spaced from the tip section by an amount which is of the order of 20 percent of the length L of the blade. It will be apparent to those skilled in the art and from the foregoing description that the blade surfaces between the root section 5 and the tangent section 7 comprise both curvilinear and rectilinear elements.

Referring now to Fig. 2, the above-mentioned common rectilinear axis will now be referred to as the centroidal axis 8 for reasons of clarity. In accordance with the invention and for reasons which will appear presently, the several air foil sections lying between the tip section 6 and the tangent section 7 are stacked one on top of another, but each section is displaced relative to an adjacent section so that the locus of centroids of the various sections between tangent section 7 and tip section 6 is a curved line having a radius R of the order of 50 percent of the blade length. As will be apparent from the drawings, the curved locus 9 is made tangent with axis 8, and axis 8 and locus 9 comprise the centroidal axis of the improved blade structure. Thus it will be seen that all surfaces of the blade lying between the tip section 6 and tangent section 7 have curvilinear elements in all directions.

During operation, each element of the rotating blade will be subjected to high centrifugal forces due to the high rotational speed of the rotor of a turbomachine. As previously noted, the rectilinear portion of the centroidal axis 8 is coincident with a radial line through the axis of rotation. Therefore, each element of blade 2 merely tends to move radially upward along the rectilinear portion of axis 8 or parallel thereto, toward tangent section 7. This is true only with respect to those elements lying between root section 5 and tangent section 7.

Still referring to Fig. 2 and to portions of the blade lying between tip section 6 and tangent section 7, all elements of the blade likewise tend to move outward under

the action of the high centrifugal forces. However, since all elements of the blade in this region are displaced from a radial line which passes through the center of rotation, the centrifugal forces will tend to straighten the curvature of the blade in this region, i. e., the centrifugal forces produce bending of this portion of the blade so that curved locus 9 tends to approach a straight line coincident with axis 8. This bending action under the influence of high centrifugal forces causes the blade to become very stiff and highly resistant to any exciting vibratory forces in a direction normal to centroidal axis 8, since such exciting forces are of a relatively low order of magnitude as compared to the high order of magnitude of the centrifugal forces.

In addition to providing improved resistance to vibratory forces with resulting increased blade life, the invention also minimizes thermal stresses resulting from nonuniformity of temperature of the motive fluid. Particularly in gas turbines, it has been observed that the operating temperature of the motive fluid and consequently of the turbine blade varies along the length of the turbine blade. It has also been observed that in such gas turbines, the maximum blade temperature occurs near the center of the blade, i. e., near a location midway between the root section 5 and the tip section 6. The blade temperature at the root and tip sections may be as much as 200 deg. F. cooler than the temperature at the center of the blade. When such a condition exists, very high stresses are set up in the blade as a result of unequal thermal expansion. These stresses often result in permanent deformation of the blade structure, and in some cases, even cause failure. In accordance with the invention wherein curvilinear elements are provided in all directions, in the blade region lying between the tip section 6 and tangent section 7, the blade is therefore curved in the same general direction as the temperature gradient, thus allowing elastic deformation of the blade without permanent deformation or failure thereof.

It will be obvious to those skilled in the art that the location of the tangent section 7 with respect to the root section 5 is not limited to the precise dimensional configuration previously mentioned. The actual spacing of the tangent section with respect to the root section will be dependent on the precise nature of the problem to be solved, i. e., upon the relative strength of the vibratory excited forces and upon the blade thickness and a given section. Generally speaking, however, operating experience has shown that many so-called cracks and failures of the fatigue type which occur in blading for turbomachines will often occur in the outer tip region which comprises about 20 percent of the blade length.

Thus, it will be seen that the invention provides an improved blade structure which is highly resistant to vibratory exciting forces, and wherein the effect of such forces as well as those arising due to unequal thermal expansions is minimized, thus resulting in improved blade life. In addition, the differences in the improved blade structure as compared to conventional blading present no additional manufacturing difficulties beyond those normally incident to the manufacture of conventional blading.

While a particular embodiment of the invention has been illustrated and described, it will be obvious that various changes and modifications may be made without departing from the invention, and it is intended to cover in the appended claims all such changes and modifications that come within the true spirit and scope of the invention.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A turbomachine blade having spaced root and tip sections and an intermediate section spaced from the roof section by an amount of the order of 80 percent of the spacing between the root and tip sections and having leading and trailing edge portions, and all surfaces of the blade having curvilinear elements in all directions between the intermediate section and the tip section and between the leading and trailing edge portions.

2. A turbomachine blade having spaced root and tip sections and an intermediate section, the surface of the blade between the root section and the intermediate section being defined by the envelope of a plurality of sections of airfoil shape with all of said sections substantially aligned along a rectilinear centroidal axis, and the surface of the blade between the intermediate section and the tip section being defined by the envelope of a second plurality of sections of airfoil shape displaced from said rectilinear axis by different amounts so that the locus of the centroids of the second plurality of sections is curvilinear having a radius of curvature of said locus of the order of magnitude of 50 percent of the spacing between the root and the tip sections, said locus also being tangent to the rectilinear centroidal axis at said intermediate section, whereby all surfaces of the blade between the intermediate section and the tip section and between the leading and trailing edge portions have curvilinear elements in all directions.

3. A turbomachine blade having spaced root and tip sections and an intermediate section spaced from the root section by an amount of the order of 80 percent of the spacing between the root and tip sections, the surface of the blade between the root section and the intermediate section being defined by the envelope of a plurality of sections of airfoil shape and all substantially aligned along a rectilinear centroidal axis, and the surface of the blade between the intermediate section and the tip section being defined by the envelope of a second plurality of sections of airfoil shape and aligned along a curvilinear centroidal axis, the curvilinear and rectilinear centroidal axes being tangent at the intermediate section.

4. A turbomachine blade in accordance with claim 3 wherein the centroidal axis of the second plurality of sections is a curve having a radius of the order of magnitude of 50 percent of the spacing between the root and tip sections.

5. A turbomachine blade having spaced root and tip sections and an intermediate section, the surface of the blade between the root section and the intermediate section being defined by the envelope of a plurality of sections of airfoil shape and all substantially aligned along a rectilinear centroidal axis, and the surface of the blade between the intermediate section and the tip section being defined by the envelope of a second plurality of sections of airfoil shape and aligned along a curvilinear centroidal axis having a radius of the order of magnitude of 50 percent of the spacing between the root and tip sections, the curvilinear and rectilinear centroidal axes being tangent at the intermediate section.

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