Feb. 7, 1961 A. P. COPPA 2,970,808

BIMETALLIC SHROUD STRUCTURE FOR ROTOR BLADES

Filed Oct. 30, 1957

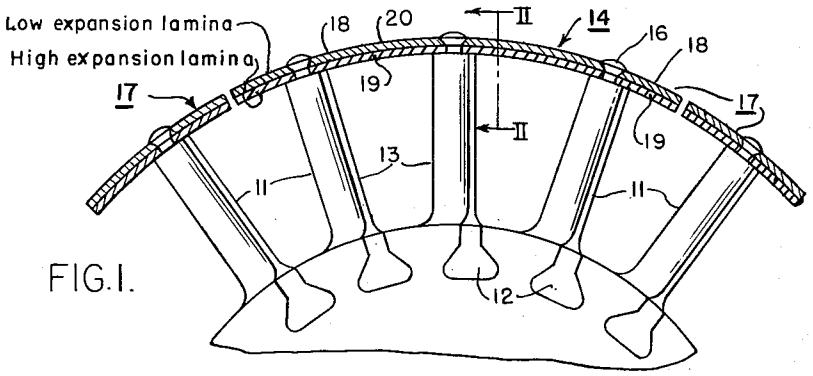


FIG. 1.

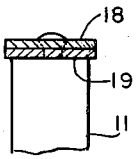


FIG. 2.

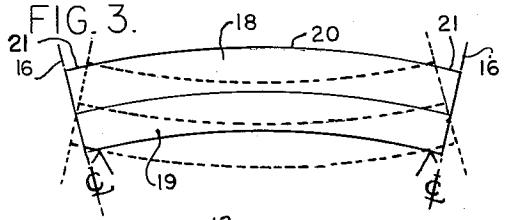


FIG. 3.

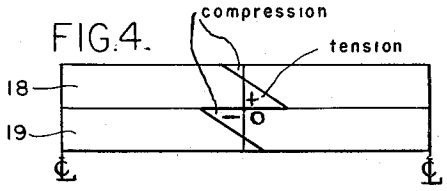


FIG. 4.

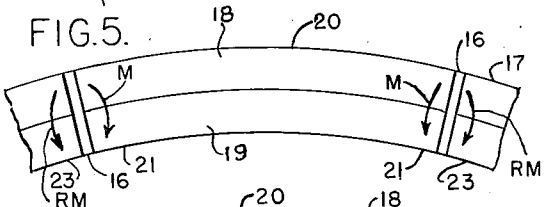


FIG. 5.

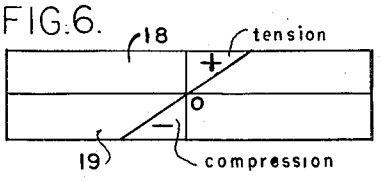


FIG. 6.

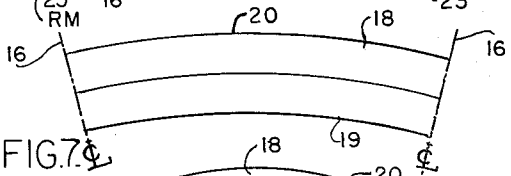


FIG. 7.

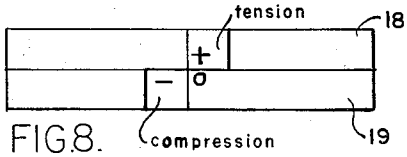


FIG. 8.

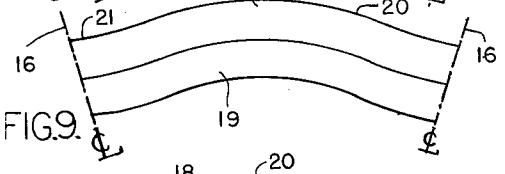


FIG. 9.

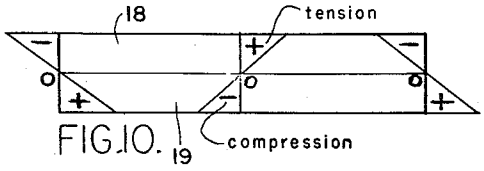


FIG. 10.

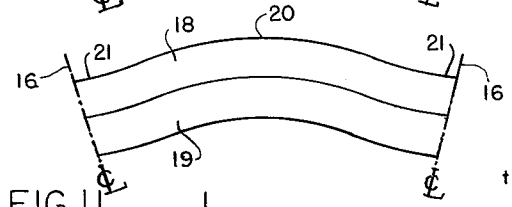


FIG. 11.

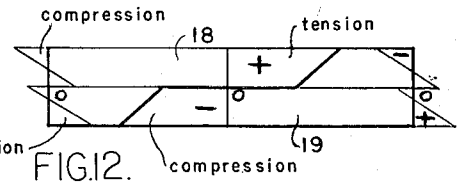


FIG. 12.

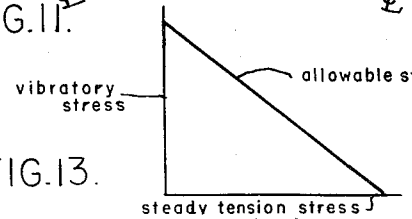


FIG. 13.

INVENTOR
ANTHONY P. COPPA

BY Peter J. Patane
ATTORNEY

United States Patent Office 2,970,808 Patented Feb. 7, 1961

2,970,808

BIMETALLIC SHROUD STRUCTURE FOR ROTOR BLADES

Anthony P. Coppa, Havertown, Pa., assignor to Westinghouse Electric Corporation, East Pittsburgh, Pa., a corporation of Pennsylvania

Filed Oct. 30, 1957, Ser. No. 693,294

5 Claims. (Cl. 253—77)

This invention relates to elastic fluid axial flow apparatus, more particularly to the shrouds for the blades utilized in such apparatus, and has for an object to provide improved apparatus of this kind.

In turbines having blades operating at high speeds and which utilize steam at a high pressure and high temperature, it has been found that thick shrouds are required in order to maintain a satisfactory stress level therein. This invention provides shrouds of reduced thickness while maintaining a given stress level.

Where the shrouds are secured to the blades by tenons, as is well known in the art, the places of maximum vibratory stress are at the tenon portions, that is, the portions of the shroud adjacent the tenons. For given operating conditions, the total stresses in the shroud, caused by the vibration of the blades, the centrifugal force, the steam pressure, and the shroud thermal expansion, cannot exceed a fixed value depending upon the shroud material. In other words, if the shroud material and the operating conditions are maintatined constant, when the stresses due to centrifugal force, steam pressure and shroud thermal expansion are reduced, the allowable vibratory stresses may be increased. This invention provides a shroud which will safely withstand a higher vibratory stress.

One embodiment of the present invention provides, in a steam turbine, a shroud which is secured by tenons to vane portions of a plurality of rotating blades. The shroud comprises two laminae joined to each other. The radially inner lamina has a rate of thermal expansion which is high relative to the radially outer lamina. During normal operation, stresses due to thermal expansion of the bimetallic shroud arise at the tenon portions of the shroud which tend to balance the bending stresses produced in these portions of the shroud by the centrifugal force and the steam pressure. More specifically, the tendency of the radially inner lamina (which is constructed of high expansion material) to expand, gives rise to compression forces within the inner lamina which balance a portion of the tension forces produced within such inner lamina at the tenon portion of the shroud by the bending thereof, due to centrifugal and steam forces.

The foregoing and other objects are effected by the invention as will be apparent from the following description and claims taken in connection with the accompanying drawings, forming a part of this application, in which:

Fig. 1 is a fragmentary side view, partly in section, of several blades mounted on a rotor and incorporating a shroud which is constructed in accordance with the present invention;

Fig. 2 is a sectional view taken along the line II—II of Fig. 1, looking in the direction indicated by the arrows;

Figs. 3, 5, 7, 9 and 11 diagrammatically represent a portion of the shroud under various conditions;

Figs. 4, 6, 8, 10 and 12 diagrammatically illustrate

various stresses for the conditions illustrated by Figs. 3, 5, 7, 9 and 11; and

Fig. 13 graphically illustrates a relationship between steady stresses and allowable vibratory stresses for a given material.

Referring to the drawing in detail and in particular to Figs. 1 and 2, there is illustrated a typical turbine rotor carrying an annular row of blades 11, of conventional form, constituting one stage of a multi-stage axial flow steam turbine.

The blades 11 are attached to the rotor by means of side entry root portions 12, secured in suitable grooves in the rotor, and include vane portions 13 extending radially outwardly with respect to the longitudinal axis of rotation of the rotor. An annular shroud 14 is secured to the blades 11 by means of tenons 16 integral with the vanes 13. The shroud 14 is divided into a plurality of arcuate segments or strips 17, with a gap between adjacent segments 17, and each segment is secured to a plurality of blades.

The shroud 14 comprises a radially outward element or lamina 18, of one material, which is bonded or joined to a radially inward element or lamina 19, of a different material from the lamina 18.

The radially outward lamina 18 is constructed of a material having a low rate of thermal expansion relative to the radially inner lamina 19, the latter being constructed of a material having a high rate of thermal expansion. Furthermore, the shroud is constructed so that one-half of its radial thickness comprises the high expansion material, the inner lamina 19, and one-half the low expansion material, the outward lamina 18.

The lamina 18 may be constructed from a material such as titanium, twelve percent chrome steel, Invar, or other similar materials. The lamina 19 may be constructed from a material such as eighteen percent chrome and eight percent nickel steel, high expansion steel, or other similar materials. As is well known, titanium, twelve percent chrome steel, and Invar have a rate of thermal expansion which is low relative to eighteen percent chrome and eight percent nickel steel, and high expansion steel.

The shroud is attached to the blades in such a manner that the longitudinal centerlines of the laminae 18 and 19 are circular and have a common center, or, in other words, the laminae 18 and 19 are disposed in a coaxial relation about the longitudinal axis of the turbine. The transverse centerlines (normal to the longitudinal centerlines) of the laminae 18 and 19 are parallel to each other and to the longitudinal axis of the rotor and the laminae have an axial width as illustrated in Fig. 2.

The laminae 18 and 19 are bonded or joined to each other so that they are in intimate and contiguous relation. The bonding agent utilized is a nickel base braze because it will increase the temperature difference between the laminae 18 and 19, since it has a rate of thermal conductivity lower than a copper base braze. The lamina 19 is closest to the steam flowing through the blades and the benefits to be derived from the present invention, as hereinafter described, are increased by interposing this thermal barrier between the laminae 18 and 19.

Figs. 3 through 11 illustrate an analysis of the stresses which will arise in the shroud when constructed in accordance with the present invention. Figs. 3, 5, 7, 9 and 11 illustrate a shroud portion 20 between two adjacent tenons 16 (indicated by the center-lines), having tenon portions 21. Figs. 4, 6, 8, 10 and 12 illustrate graphically the stresses in the shroud portion 20 corresponding to Figs. 3, 5, 7, 9 and 11, respectively. The stresses are illustrated relative to each other, rather than in absolute values, and the relative stresses along the radial

lines are indicated by the horizontal distances from the points of origin, indicated at O.

The shroud portion 20 which is illustrated in Fig. 3 in solid lines has the same curvature as a similar portion of the shroud illustrated in Fig. 1. However, in this instance the shroud portion 20 is hypothetically assumed to be simply supported at the tenon portions 21. If the temperature of the shroud portion 20 is now increased, it being free to expand and contract, the shroud portion 20 will bow downwardly, as shown in Fig. 3 by the dotted lines, because the high expansion lamina 19, which is on the lower side, expands at a faster rate than the low expansion lamina 18, which is on the upper side, causing the lower portions of the lamina 18 to be stretched by the upper portions of the lamina 19 and the upper portions of the lamina 19 to be compressed by the lower portions of the lamina 18. The resulting bowing produces stresses in the laminae, constant from one tenon portion to the other, which are primarily tension stresses in the lamina 18 and primarily compression stresses in the lamina 19. The relative values of these stresses, hereinafter referred to as thermal stresses, are represented graphically by the triangles of Fig. 4. Referring to the shroud and the triangles from the top to the bottom, portions of the lamina 18 are first stressed in compression (−), then in tension (+), followed by subsequent portions of the lamina 19 in compression (−), and in tension (+), respectively.

The analysis is continued in Figs. 5 and 6 by considering the shroud 20 as a part of the larger segment 17, illustrated in Fig. 1, and secured between two tenons 16 (indicated diagrammatically). On opposite sides of the tenons 16 are tenon portions 21 and adjacent tenon portions 23. When stationary and at normal room temperature, the shroud portion 20, assembled to an annular row of blades 11, is under the influence of no force which would cause it to deform from its normal curvature and to be stressed. Subsequently, the temperature of the shroud is increased and the shroud portion 20 attempts to expand and deform in a manner similar to that described in the previous paragraph.

The deformation considered in connection with Figs. 3 and 4 does not occur because the tenons 16 and the adjacent tenon portions 23 restrain the rotation of the tenon portions 21. That is, the tenons 16 and the adjacent tenon portions 23 are made strong enough to restrain the rotation of the tenon portions 21 which would occur if the shroud portion 20 were simply supported as in the situation illustrated in Figs. 3 and 4, but since the shroud is divided into segments with gaps between adjacent segments 17, the shroud portions are free to expand circumferentially. The expansion forces within the shroud portion 20 produce moments M which tend to deflect the shroud portion 20 as illustrated by the dotted lines in Fig. 3 and to rotate the tenon portions 21, the right-hand tenon portion counterclockwise and the left-hand tenon portion clockwise, against the restraint of the tenons 16 and adjacent tenon portions 23. This restraint prevents rotation, but circumferential expansion is permitted by the gaps between adjacent segments 17. The restraint is indicated by the reaction moments RM. The effect on the shroud portion 20 can be best visualized by considering the reaction moments RM as tending to deform the shroud so that the lower surface thereof would be concave and the upper surface convex. The foregoing moments produce stresses in the shroud, as illustrated by Fig. 6. The stresses in the lamina 18 are entirely tension stresses, and the stresses in the lamina 19 are entirely compression stresses. In a longitudinal direction, the stresses are of the same magnitude from one tenon portion to the other, but from top to bottom the stresses vary, as illusrtated. The stresses illustrated in Fig. 6 are hereinafter referred to as restraining stresses.

Figs. 7 and 8 continue the analysis by illustrating the effect on the shroud portion 20 of the thermal stresses, Figs. 3 and 4, and the restraining stresses, Figs. 5 and 6.

The shroud portion retains its normal curvature so that the upper surface is convex and the lower concave, producing tension stresses in the lamina 18 and compression stresses in the lamina 19. An algebraic summation, illustrated in Fig. 8 by the rectangles, of the stresses illustrated in Fig. 4 and Fig. 6 shows that the stresses in the laminae 18 and 19 are contant along radial planes, as well as from one tenon portion to the other. The lamina 18 is stressed only in tension and the lamina 19 is stressed only in compression. These stresses are hereinafter referred to as the shroud thermal stresses due to the bimetallic construction.

The analysis is further continued by illustrating in Figs. 9 and 10 the deformation and bending stresses in the shroud portion 20, during normal operation, due to the centrifugal force and the steam pressure. These forces cause the middle portion of the shroud portion 20 to bow outwardly and the middle portion of the shroud is deformed so that the upper surface is convex and the lower concave. The tenon portions of the shroud are deformed so that the upper surfaces are concave and the lower convex. The foregoing produces compression stresses at the upper surfaces of the tenon portions 21 and the lower surfaces of the middle portion and tension stresses at the lower surfaces of the tenon portion 21 and the upper surfaces of the middle portion. In this instance, the stresses at the middle of the shroud portion 20 are different from those at the tenon portions thereof.

The last step in the analysis is to consider the effect, upon the deformation and bending stresses which occur in any shroud due to centrifugal force and steam pressure, of the stresses due to the fact that the shroud constructed in accordance with this invention is a bimetal. This requires that Figs. 7 and 9 be compared with Figs. 8 and 10. It will be noted that an algebraic summation of the deformations illustrated in Figs. 7 and 9 results in the shroud deformation illustrated in Fig. 11 being the same for a bimetallic shroud as it is for an ordinary shroud, since the bimetallic effect produces no new deformation, as illustrated by Fig. 7. A summation, illustrated in Fig. 12, of the stresses indicated by Figs. 8 and 10 shows that the stresses vary from the middle portion to the tenon portions 21 of the shroud and that the stresses at the middle portion have increased but those at the tenon portion have decreased from those illustrated in Fig. 8. Thee stresses produced by the fact that the shroud is a bimetal balance, at the tenon portions, a part of the bending stresses produced during normal operation by the centrifugal force and steam pressure. More specifically, the tendency of the radially inner lamina 19 (which is constructed of high expansion material) to expand, gives rise to the compression forces within the inner lamina which are illustrated in Fig. 8. These compression forces balance a portion of the tension forces produced within the inner lamina 19 at the tenon portion 21 of the shroud portion 20 by the bending thereof, due to centrifugal and steam forces, illustrated in Fig. 10. Hereinafter the tension stresses at the tenon portions 21 of the shroud 20, illustrated in Fig. 12, due to the combined effect of the centrifugal force, the steam pressure and the bimetallic construction, will be referred to as steady tension stresses.

For a complete analysis of the stresses to which a shroud portion is subjected there must be added, to the steady tension stresses illustrated in Fig. 12, the stresses due to vibration of the blade and shroud. Hence, the total stress in a shroud is the sum of the vibration stress and the steady tension stress. This total stress cannot exceed a certain limit for certain operating conditions and a given material. For purposes of illustration, the foregoing is shown in Fig. 13, wherein the ordinates represent the vibration stress and the abscissa represent the steady tension stress for a given material. From the foregoing, it follows that the steady tension stress may be equal to the total stress if the vibration stress is zero

and vice versa. The oblique line, in Fig. 13, indicates this relationship and also shows that if the steady tension stresses are reduced, the shroud may safely withstand higher vibration stress, provided the size of the shroud is maintained the same as heretofore. If it is not desired to increase the allowable vibration stress in the shroud, then the shroud may be reduced in size, for given operating conditions, if constructed in accordance with this invention in contrast to the prior construction.

As is well known, the vibration stresses in the shroud are at a maximum at the tenon portions of the shroud. The present invention finds particular application where the combined vibration and steady tension stresses at the middle portion of the shroud are not near the allowable limit, but where the combined vibration and steady tension stresses at the tenon portions of the shroud are at or near the limit allowable. Hence, where the increase in steady tension stress at the middle portion of the shroud can be safely withstood (because of the usually lower vibration stress at this portion of the shroud), the decrease in steady tension stress at the tenon portion of the shroud allows the shroud to assume a larger vibration stress and still be within the allowable combined limit of steady tension and vibration stresses.

While the invention has been shown in but one form, it will be obvious to those skilled in the art that it is not so limited, but is susceptible of various changes and modifications without departing from the spirit thereof.

What is claimed is:

1. In elastic fluid utilizing apparatus, a rotor having an annular row of blades, a shroud structure secured to said blades, said shroud structure including a plurality of segments disposed in spaced relation with each other, each of said segments comprising a first lamina and a second lamina having a high rate of thermal expansion relative to said first lamina and secured thereto, said first lamina being of substantially the same width as and disposed radially outwardly of said second lamina.

2. In elastic fluid utilizing apparatus, a rotor having an annular row of blades, a tenon provided on each of said blades, a shroud structure associated with said blades and secured to said blades by said tenons, said shroud structure comprising a plurality of segments disposed in spaced relation with each other, each of said segments including a first lamina and a second lamina, said first lamina being contiguously bonded to said second lamina and said first lamina having a rate of thermal expansion which is lower than that of said second lamina, and said first lamina being of substantially the same width as and disposed radially outwardly of said second lamina.

3. In elastic fluid utilizing apparatus, a rotor having an annular row of blades, a tenon provided on each of

said blades, a shroud structure associated with said blades and secured to said blades by a portion of said tenons, said shroud structure comprising a plurality of mutually spaced segments, each of said segments including a first lamina and a second lamina, said first lamina being contiguously attached to said second lamina, said second lamina having a high rate of thermal expansion relative to said first lamina and being disposed radially inwardly of said first lamina, said first and second laminae being of substantially similar cross section.

4. In elastic fluid utilizing apparatus, an annular row of blades, a rotor upon which said blades are mounted, each of said blades having a tenon, a plurality of arcuate bimetallic strips disposed in mutually spaced relation and secured to a portion of said blades by said tenons, each of said strips comprising a first lamina and a second lamina having a high rate of thermal expansion relative to said first lamina, said first and second laminae being of substantially equal cross section, said first lamina being disposed radially outwardly of said second lamina, and said first lamina being disposed coaxial with said second lamina and rigidly bonded thereto.

5. In elastic fluid utilizing apparatus, a rotor, an annular row of blades having an end mounted on said rotor and a free end, a tenon provided at the free end of each of said blades, a shroud structure comprising a plurality of mutually spaced arcuate bimetallic segments having openings aligned with said tenons, said tenons extending through said openings and securing said segments to said blades, said segments comprising a first lamina constructed of one material and a second lamina constructed of another material, the materials being so chosen that the laminae have different rates of thermal expansion, said laminae being secured to said blades so that the lamina having the higher rate of thermal expansion is placed radially inwardly of the lamina having the lower rate of thermal expansion and said laminae being disposed in coaxial relation with each other, said first and second laminae being substantially coextensive and being contiguously bonded to each other.

References Cited in the file of this patent

UNITED STATES PATENTS

2,258,773	Kroon	Oct. 14, 1941
2,315,655	Redding	Apr. 6, 1943
2,336,859	Gooch	Dec. 14, 1943

FOREIGN PATENTS

13,881	Great Britain	July 5, 1905
228,250	Germany	Nov. 10, 1910
260,448	Great Britain	Nov. 4, 1926
377,101	Great Britain	July 21, 1932