Aug. 7, 1962 T. FOSTER ET AL 3,048,365

ROTOR BLADE SHROUD AND VIBRATION DAMPING STRUCTURE

Filed Dec. 22, 1959 3 Sheets-Sheet 1

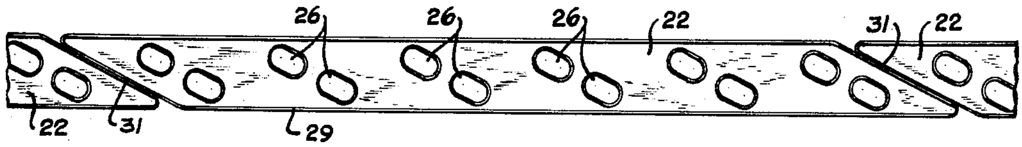

FIG. 2

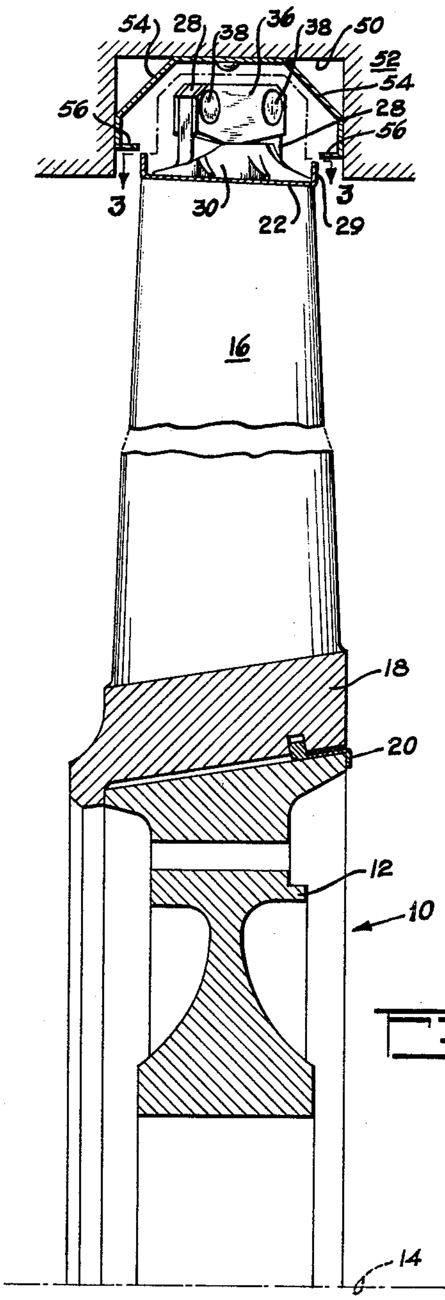

FIG. 1

INVENTORS
TOM FOSTER
RICHARD F. JAKLITSCH
HENRY B. MAYR
CHAPMAN J. WALKER

BY Victor D. Behn

ATTORNEY

ROTOR BLADE SHROUD AND VIBRATION DAMPING STRUCTURE

Filed Dec. 22, 1959 3 Sheets-Sheet 2

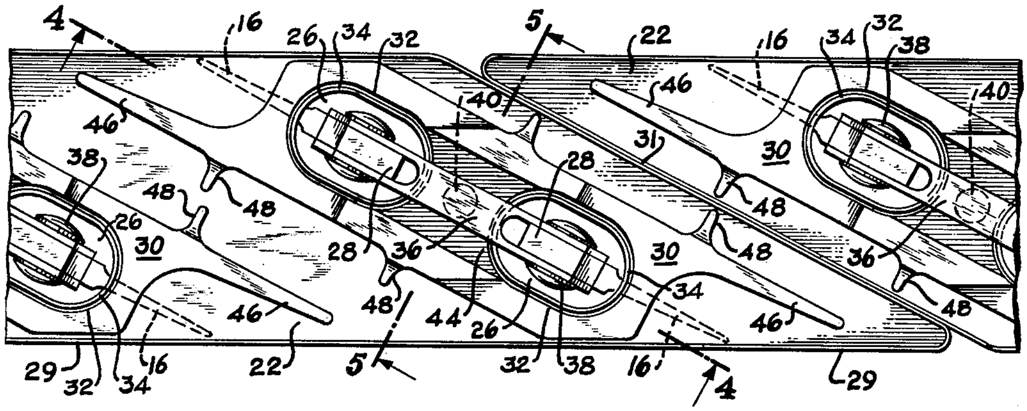

FIG-3

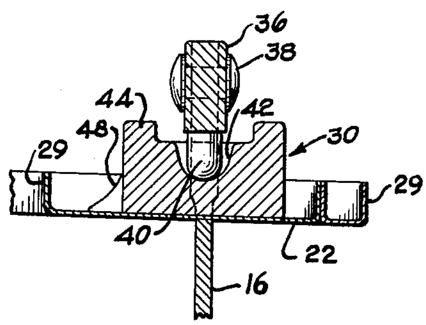

FIG-5

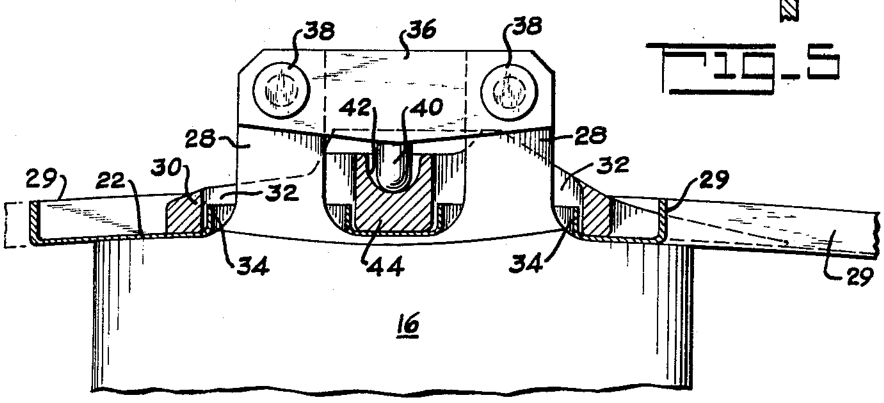

FIG-4

INVENTORS
TOM FOSTER
RICHARD F. JAKLITSCH
HENRY B. MAYR
CHAPMAN J. WALKER

BY Victor D. Behn
ATTORNEY

ROTOR BLADE SHROUD AND VIBRATION DAMPING STRUCTURE

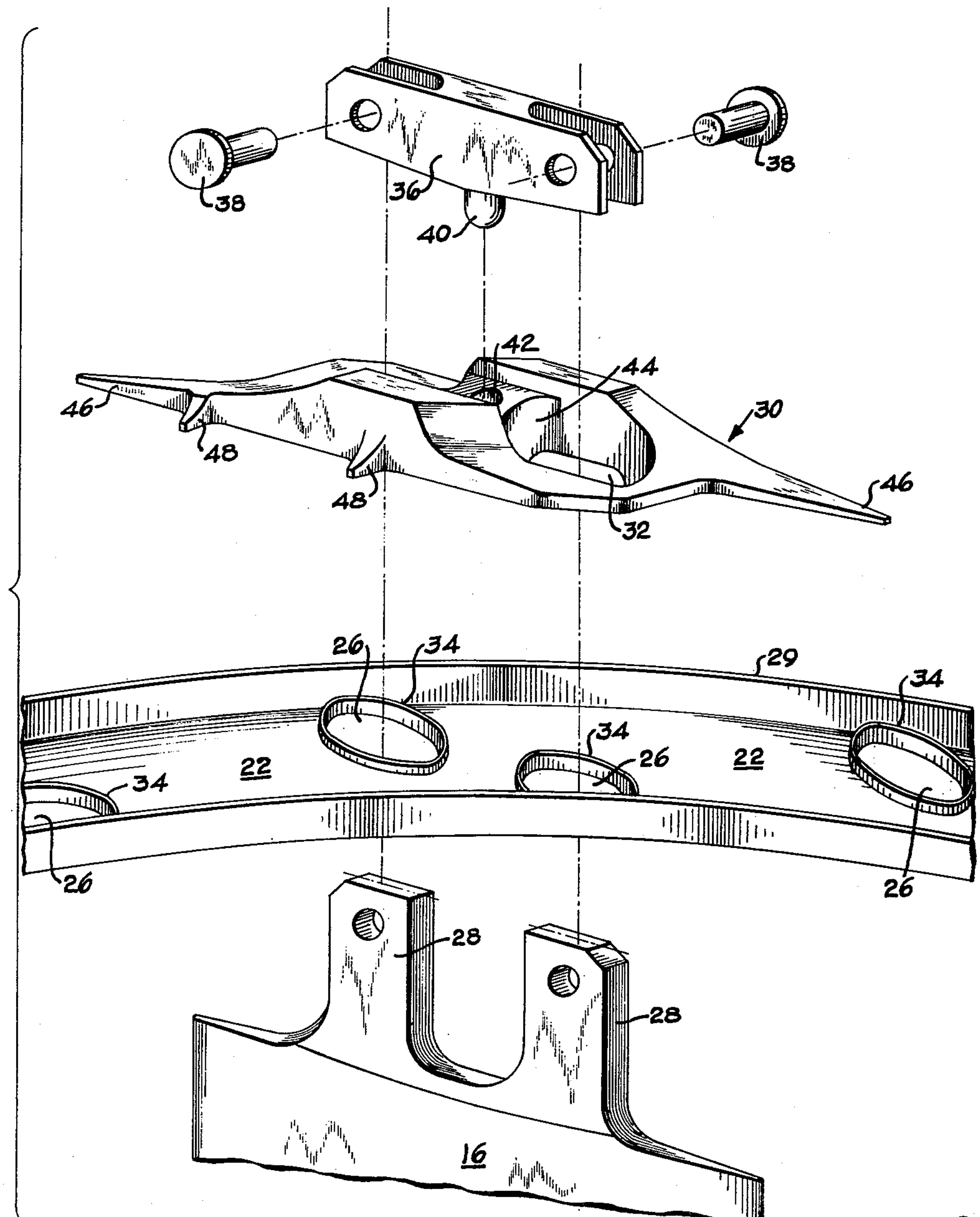

FIG. 6

INVENTORS
TOM FOSTER
RICHARD F. JAKLITSCH
HENRY B. MAYR
CHAPMAN J. WALKER

BY Victor D. Behn
ATTORNEY

United States Patent Office 3,048,365
Patented Aug. 7, 1962

3,048,365
ROTOR BLADE SHROUD AND VIBRATION DAMPING STRUCTURE

Tom Foster, Ridgewood, N.J., Richard F. Jaklitsch, Maspeth, N.Y., and Henry B. Mayr, Ridgefield Park, and Chapman J. Walker, Saddle River, N.J., assignors to Curtiss-Wright Corporation, a corporation of Delaware

Filed Dec. 22, 1959, Ser. No. 861,311
10 Claims. (Cl. 253—77)

This invention relates to rotary fluid compressors, turbines or like apparatus, such as for aircraft jet engines, and having a plurality of circumferentially-spaced blades extending outwardly from their rotors and is particularly directed to a rotor blade shroud structure having means for damping blade vibrations.

Although, as will be apparent, the invention is generally applicable to compressors, turbines and like apparatus, for convenience it will be described in connection with compressor apparatus.

The weight of fluid compressors can be materially decreased by using longer and thinner blades and by designing the compressor for operation at higher speeds. Any such weight reduction obviously is quite important in the case of air compressors for aircraft engines, as for example turbojet engines. Such long and thin high speed compressor blades, however, introduce serious blade vibration problems in bending, both fundamental and secondary modes, and in torsion whereas with the more rigid blades of the prior art only bending vibrations in the fundamental mode were important. These vibration problems are particularly serious for the longer blades of the initial rotor stages of a multi-stage axial flow compressor as compared to the shorter rotor blades of the more downstream stages.

It has been found that if the outer ends of such long and thin high speed compressor rotor blades are rigidly connected together by a shroud extending across the blade tip ends the stresses in the blades adjacent the shroud become excessive. In fact, in a particular turbojet engine compressor application, with such a rigid shroud connection across the blade tips, the stresses in the blades adjacent to the shroud were found to be as much as three times the blade stresses at their root ends.

An object of the present invention resides in the provision of a novel and simple structure connected across the tip ends of the rotor blades so as to permit relative motion of the blade tip shroud and to damp blade vibrations both in bending and torsion.

If the shroud for the rotor blades is made sufficiently strong to support itself against the centrifugal forces thereon then it will be too stiff to distribute these centrifugal forces uniformly to each blade. A further object of the invention resides in the provision of a novel flexible shroud construction such that the shroud can bend slightly under the centrifugal forces to distribute said forces substantially uniformly to the rotor blades.

In accordance with the invention the shroud is carried by and is disposed across the outer ends of the rotor blades with each blade having a radially inwardly directed surface engaging a surface on the shroud to restrain the shroud against radially outward movement, said engaging surfaces being arranged for relative frictional movement to damp blade vibrations. More specifically, the shroud consists of a plurality of flexible sheet metal elements circumferentially disposed in end-to-end relation with each shroud element having a plurality of circumferentially-spaced and relatively rigid portions, one for each blade and providing the aforementioned surface engaged by its blade with each pair of said engaging surfaces having a loose-fitting ball and socket configuration.

Other objects of the invention will become apparent upon reading the annexed detail description in connection with the drawing in which:

FIG. 1 is an axial sectional view of a compressor rotor stage embodying the invention;

FIG. 2 is a developed plan view of several of the shroud elements disposed in end-to-end relation;

FIG. 3 is an enlarged developed plan view taken along line 3—3 of FIG. 1;

FIGS. 4 and 5 are sectional views taken along lines 4—4 and 5—5 respectively of FIG. 3; and

FIG. 6 is an exploded isometric view of a blade shroud, the adjacent end of a blade and the means interconnecting said shroud and blade.

Referring now to FIGS. 2–6 along with FIG. 1, an axial flow compressor is generally indicated at **10** and includes a rotor disc **12** having an axis **14**. A plurality of circumferentially-spaced blades **16** extend radially outwardly from and are secured to the periphery of the rotor disc, for example, by a conventional fir tree type connection, at **18**. A key **20** is provided for locking the blades against axial displacement from the rotor disc.

Referring now to FIGS. 2–6 along with FIG. 1, an annular shroud construction is carried by the rotor blades across their outer or tip ends. Said shroud construction comprises a plurality of elongate and flexible shroud elements **22** disposed in end-to-end relation across the tip or outer ends of the rotor blades to form a continuous annular shroud for said blades. Each such shroud element **22** has a plurality of circumferentially-spaced pairs of openings **26** with the two openings of each pair being for a single blade and lying along a line parallel to the chordwise direction of the adjacent blade tip. Each blade **16** has two chordwise-spaced tenon portions **28** extending radially-outwardly from its outer or tip end and projecting through a pair of openings **26** in its associated shroud element.

Each shroud element **22** is of thin sheet metal construction and has an outwardly turned flange **29** running along its two circumferentially-extending edges and its two end edges. The two end edges of adjacent shroud elements abut along a line **31** FIGS. 2 and 3 which may, as illustrated, be parallel to the chordwise direction of the adjacent blade tips. An extremely light weight construction is thereby provided for the shroud elements **22** whereby said elements can bend in response to the centrifugal forces thereon during rotor rotation.

The annular shroud construction also includes a plurality of circumferentially-spaced cradle elements **30** which are disposed along the radially-outer side of shroud element **22**. There is one such cradle element **30** for each blade **16** and each cradle element **30** has a relatively rigid construction compared to that of the shroud elements **22**. Each cradle element **30** has a pair of openings **32** which are alined with a pair of openings **26** in the shroud element so that the tenons **28** of a blade also project through the cradle openings **32**. Hence, the cradle elements **30** can be assembled in position on their respective shroud elements **22** after each shroud element has been placed in position over its blades **16**. Each shroud element **22** has outwardly-turned flanges **34** formed about its openings **26** thereby helping to locate the cradle elements **30** in position on the shroud elements.

A bridge element **36** is connected across the ends of the projecting blade tenons **28** as by rivets **38**. Each bridge element **36** has a radially-inwardly projecting portion or pin **40** having a semi-spherical end which extends into a recess or socket **42** formed in a relatively heavy web **44** of the associated cradle **30**, said web **44** separating the holes **32** in said cradle As is apparent from the drawing, the axis of the pin and socket connection **40**, **42** between each blade **16** and a shroud element **22** substantially coincides with the longitudinal axis of the blade. The bottom of each cradle socket **42** is also approximately semi-spherical but of somewhat larger radius than that of the end of the pin **40**. Thus the pin **40** and socket **42** in effect provide a loose ball and socket fit therebetween to permit sliding motion of the ball end of the pin **40** in its socket **42**.

During rotation of the rotor **10** each shroud element **22** and its cradle elements **30** are urged radially outwardly against the blade pins **40** by the centrifugal forces on said elements. In this way the shroud elements **22** are floatingly held in position by the centrifugal forces thereon urging said shroud elements outwardly against the blade pins **40**. Vibration of the blade **16** in torsion results in frictional sliding motion between the blade pin **40** and the bottom of the shroud cradle socket **42** engaged by the pin. Bending vibration of a blade resulting in changes in the angle between the blade tip and associated shroud element **22**, such as when a node exists at the blade tip, results in angular motion of the axis of its pin **40** relative to the associated socket **42** to produce frictional sliding between said pin and socket. This frictional sliding between the small diameter pin **40** of each blade and its shroud socket **42** has been found to be sufficient to damp such torsional and bending blade vibrations. Only a small frictional effort is necessary for such damping. For example, in a particular turbojet engine having first stage compressor blades with a length of approximately eleven inches sufficient frictional damping was obtained with each pin **40** and socket **42** having a contact area of only about 0.09 inch radius under load. This small contact area results from deflection of the engaging socket and pin surfaces under load and is obtained by providing the socket **42** with a somewhat larger radius than that of the spherical end of the pin **40**. If the frictional area of contact or moment arm of the frictional forces is large then the frictionally contacting blade and shroud surfaces will substantially lock together and result in excessive blade vibration stresses. Bending vibrations of a blade **16** producing lateral motion of the blade tip also results in limited sliding between the blade pin **40** and shroud socket **42** and in addition such lateral vibratory motion of a blade tip is further damped as a result of all the blade tip ends extending through a single shroud element **22** in effect being tied together against substantial relative lateral motions by the ball and socket connection **40**—**42** between said blades and the shroud element.

As is conventional in such rotor blades each blade chord at its tip end is twisted relative to the blade chord at its root end. Because of the flexibility of each blade the magnitude of this twist changes somewhat with changes in the centrifugal force on the blade. The holes **26** and **32** through which the tenons **28** of each blade **16** extend are of such size as to provide clearance between said tenons and the walls of said holes in all positions of twist of the blade. It should also be noted that the blade tip ends stretch radially and therefore increase their circumferential spacing in response to the centrifugal forces thereon. However, with the shroud made up of a plurality of individual end-to-end elements **22** which merely abut each other no circumferential stresses are developed in the shroud elements **22** and therefore the circumferential spacing of the shroud element holes **26** does not increase in response to the centrifugal forces. Therefore, the holes **26** in the shroud elements and the holes **32** in the cradles **30** must also be of sufficient size to accommodate the increased spacing of the blade outer ends resulting from blade stretching. This factor together with the problem of assembly of the shroud elements **22** over the blades limits the lengths of the shroud elements. As illustrated, each shroud element has a length such that it extends over six blades **16**. In an actual compressor design this shroud length was such as to subtend an angle of about 40° from the rotor axis. Obviously, however, the invention is not limited to this precise number of blades per shroud element or to this arcuate length of each shroud element. The shroud elements **22** should not be so long, however, that the aforementioned blade stretching requires excessively large clearance between the blade tenons **28** and the walls of the holes **26** nor should it be so long as to make assembly difficult. However, each shroud element preferably should be long enough to extend over a sufficient number of blades **16** such that it is not likely that all these blades will have similar lateral vibrations of their blade tip ends at any one time.

The recess **42** in each shroud cradle element **30** is of sufficient depth so that the bottom of the recess is disposed radially inwardly of the center of mass of the cradle element whereby the forces imposed on said cradle element by the pin **40** will not tend to overturn said cradle element.

The area of contact between each shroud element **22** and each of its cradle elements **30** is sufficiently large so that during normal operating speeds of the rotor the contact pressure of said shroud element against its cradle elements is sufficient substantially to lock them frictionally together against relative motion. Accordingly, each shroud element **22** and its cradle elements **30** could be made as an integral or a one-piece structure. From a fabrication standpoint, however, it is simpler to separately form the shroud and cradle elements as illustrated. Also if, as illustrated, the cradle elements **30** are separate members which merely have frictional contact with the shroud elements then as the blades stretch in response to centrifugal forces thereon slight blade vibrations will permit slight shifting of each cradle element **30** relative to its shroud element **22** to keep its socket **42** alined with the associated blade pin **40**. The separate fabrication of the cradle elements is also important because the cradle elements can then properly position themselves relative to their respective blades nothwithstanding the substantial manufacturing tolerances required for the long thin blade herein contemplated thereby avoiding stresses which would otherwise be induced in the blades if the cradle elements were not so properly positioned.

Each shroud element **22** is made of thin lightweight sheet metal, such as aluminum, so that each element is capable of flexing in the region between its cradle elements **30**. This flexibility of the shroud insures substantially uniform centrifugal loading of the blades **16** through their pins **40** by their associated shroud elements **22** and cradles **30** notwithstanding dimensional differences from one blade to another resulting for example, from manufacturing tolerances.

In order to help support the thin sheet metal wall of each shroud element **22** against the centrifugal forces thereon during rotor rotation, each cradle **30** may, as illustrated, have a plurality of finger-like extensions **46** and **48**. These extensions **46** and **48** in effect divide the area of the thin sheet metal sections of each shroud element **22** between its cradles **30** into a plurality of smaller sections or panels thereby reducing the blending stresses in the shroud resulting from said centrifugal forces. It is apparent from FIG. 3 that the general outline of each cradle **30** with its extensions **46** and **48** is a parallelogram which is disposed so that the blade chord of the outer end of the blade associated with said cradle **30** substantially coincides with a line parallel to and disposed midway between the long sides of said parallelogram.

As illustrated in FIG. 1, each shroud element **22** and its supporting blade structure is received within an annular groove **50** formed in the inner wall of the stator housing **52** surrounding the rotor **10**. An annular baffle member **54** supported on the stator housing **52** within the groove **50** has its two annular edges **56** disposed so as to closely overlie the outwardly-turned marginal flanges **29** along the two circumferentially extending edges of each shroud element **22** thereby reducing leakage flow around the outside of the shroud elements **22**.

In the embodiment described the pin **40** on each blade bridge element **36** and the socket **42** on the associated shroud cradle **30** provide a loose-fitting ball and socket connection therebetween. Obviously, however, in lieu of such a ball and socket connection the relative positions of each pin **40** and associated socket **42** could be reversed or even each such bridge element **36** and cradle **30** could both be provided with a socket with a double ended link being received in said sockets for transmitting the centrifugal loads.

While we have described our invention in detail in its present preferred embodiment it will be obvious to those skilled in the art after understanding our invention that various changes and modifications may be made therein without departing from the spirit or scope thereof. We aim in the appended claims to cover all such modifications.

We claim as our invention:

1. A bladed rotor structure for compressors, turbines or like fluid apparatus; said rotor structure comprising a rotor member; a plurality of circumferentially-spaced blades secured to said rotor member and extending radially outwardly therefrom for co-action with the apparatus fluid; and an annular shroud comprising a plurality of arcuate shroud elements disposed in end-to-end relation across and carried by the outer ends of said blades to form the outer boundary of the flow path for said fluid, each of said blades having a portion secured thereto with a radially-inwardly facing surface and each said shroud element having portions with radially-outwardly facing surfaces engageable with the inwardly facing blade portion surfaces of a group of blades to restrain said shroud element against radially outward movement in response to centrifugal forces thereon during rotor member rotation and to connect the outer ends of said group of blades together to damp blade vibrations of the type causing lateral vibratory motion of the blade outer ends, said radially inwardly facing surface on each blade portion and the radially outwardly surface on the shroud element engaged thereby having a loose-fitting ball and socket configuration such that said surfaces are arranged for relative frictional movement in response to torsional vibrations of a blade to damp said torsional vibrations and in response to bending vibrations of a blade which produce angular motion between the blade outer end and the associated shroud element to damp such bending vibrations.

2. A rotor structure as recited in claim 1 in which the axis of said ball and socket configuration of said blade portion and shroud portion engaging surfaces being adjacent and substantially parallel to the longitudinal axis of the blade.

3. A bladed rotor structure for compressors, turbines or like fluid apparatus; said rotor structure comprising a rotor member; a plurality of circumferentially-spaced blades secured to said rotor member and extending radially outwardly therefrom for co-action with the apparatus fluid; and an annular shroud comprising a plurality of arcuate shroud elements disposed in end-to-end relation across and carried by the outer ends of said blades to form the outer boundary of the flow path for said fluid, each of said blades having a portion secured thereto with a radially-inwardly facing surface and each said shroud element having portions with radially-outwardly facing surfaces engageable with the inwardly facing blade portion surfaces of a group of blades to restrain said shroud element against radially outward movement in response to centrifugal forces thereon during rotor member rotation and to connect the outer ends of said group of blades together to damp blade vibrations of the type causing lateral vibratory motion of the blade outer ends. said facing surfaces being arranged for relative frictional movement in response to torsional vibrations of a blade to damp said torsional vibrations and in response to bending vibrations of a blade which produce angular motion between the blade outer end and the associated shroud element to damp such bending vibrations, each said shroud element being flexible and having a plurality of circumferentially-spaced and relatively-rigid portions, there being one such rigid shroud portion for each blade with each such rigid portion having the radially-outwardly facing shroud surface which is engaged by the aforementioned radially-inwardly-facing blade portion surface.

4. A rotor construction as recited in claim 3 in which each blade has a pair of tenons extending radially outwardly from its tip end and projecting through openings in its shroud element and in its associated shroud rigid portion and each blade has a member connected across the outer ends of its said pair of tenons with said member having a radially-inwardly projecting portion disposed between its associated pair of tenons and with the end surface of said portion being the aforementioned radially-inwardly-facing blade portion surface.

5. A rotor construction as recited in claim 4 in which each said inwardly projecting blade portion has a rounded end and each said shroud rigid portion has a recess with a rounded bottom surface engaged by said rounded end of its associated blade, the radius of the bottom surface of each said recess being larger than that of the rounded end engaged thereby.

6. A bladed rotor structure for compressors, turbines or like fluid apparatus; said rotor structure comprising a rotor member; a plurality of circumferentially-spaced blades secured to said rotor member and extending radially outwardly therefrom for co-action with the apparatus fluid; and an annular shroud comprising a plurality of arcuate shroud elements disposed in end-to-end relation across and carried by the outer ends of said blades to form the outer boundary of the flow path for said fluid, each of said blades having a portion secured thereto with a radially-inwardly facing surface and each said shroud element having portions with radially-outwardly facing surfaces engageable with the inwardly facing blade portion surfaces of a group of blades to restrain said shroud element against radially outward movement in response to centrifugal forces thereon during rotor member rotation and to connect the outer ends of said group of blades together to damp blade vibrations of the type causing lateral vibratory motion of the blade outer ends, said facing surfaces being arranged for relative frictional movement in response to torsional vibrations of a blade to damp said torsional vibrations and in response to bending vibrations of a blade which produce angular motion between the blade outer end and the associated shroud element to damp such bending vibrations, each said shroud element having a flexible sheet metal construction and having a plurality of individual relatively-rigid members disposed on its radially-outer side in frictional contact therewith and circumferentially-spaced therealong, there being one such rigid member for each blade with each such rigid member having said aforementioned radially-outwardly-facing shroud surface which is engaged by an aforementioned radially-inwardly-facing blade portion surface.

7. A rotor structure as recited in claim 6 in which each blade has a pair of chordwise-spaced tenons extending radially outwardly from its tip end and projecting through a pair of openings in its shroud element and in its associated rigid member and each blade has a member connected across the outer ends of its said pair of tenons with said member having a radially-inwarldy projecting pin disposed between its associated pair of tenons and with the end surface of said pin being the aforementioned radially-inwardly-facing blade portion surface.

8. A rotor structure as recited in claim 7 in which each said blade pin has a rounded end and each said rigid mem-

ber has a recess with a rounded bottom surface engaged by the rounded end of its associated blade pin, the radius of the bottom surface of each said recess being larger than that of the rounded pin end engaged thereby.

9. A rotor construction as recited in claim 8 in which the bottom of the recess in each said rigid member is disposed radially inwardly of the center of mass of said rigid member.

10. A bladed rotor structure for compressors, turbines, or like fluid apparatus; said rotor structure comprising a rotor member; a plurality of circumferentially-spaced blades secured to said rotor member and extending radially outwardly therefrom for co-action with the apparatus fluid; and an annular shroud comprising a plurality of arcuate shroud elements disposed in end-to-end relation across and carried by the outer ends of said blades to form the outer boundary of the flow path for said fluid, each of said blades having a pair of tenon portions extending radially outwardly through openings in its associated shroud element and also having a member connected across the outer ends of said pair of tenons and having a portion projecting radially inwardly between said tenons to provide a radially-inwardly facing surface and each said shroud element having portions with radially-outwardly facing surfaces engageable with the inwardly facing blade portion surfaces of a group of blades to restrain said shroud element against radially outward movement in response to centrifugal forces thereon during rotor member rotation and to connect the outer ends of said group of blades together to damp blade vibrations of the type causing lateral vibratory motion of the blade outer ends, said facing surfaces being arranged for relative frictional movement in response to torsional vibrations of a blade to damp said torsional vibrations and in response to bending vibrations of a blade which produce angular motion between the blade outer end and the associated shroud element to damp such bending vibrations.

References Cited in the file of this patent

UNITED STATES PATENTS

1,371,328	Schneider	Mar. 15, 1921
1,378,464	Junggren	May 17, 1921
1,639,247	Zoelly et al.	Aug. 16, 1927
1,998,951	Downer	Apr. 23, 1935
2,315,655	Redding	Apr. 6, 1943
2,658,719	Johanson	Nov. 10, 1953
2,963,272	Welsh	Dec. 6, 1960
2,970,808	Coppa	Feb. 7, 1961

FOREIGN PATENTS

375,169	Great Britain	June 23, 1932
377,101	Great Britain	July 21, 1932