May 5, 1964 A. J. MILLER 3,131,461

METHOD OF MAKING VIBRATION DAMPED TURBO MACHINERY

Filed April 20, 1961

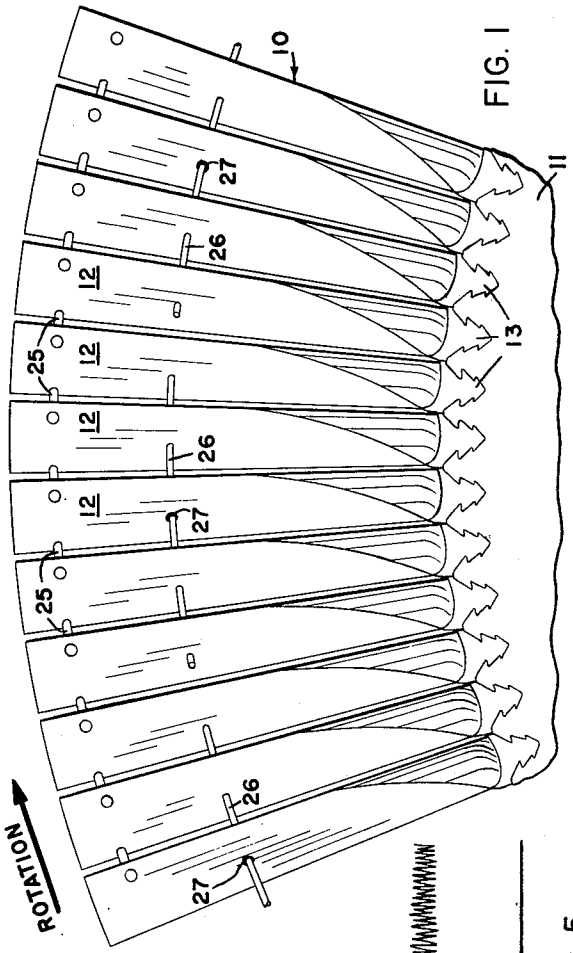


FIG. 1

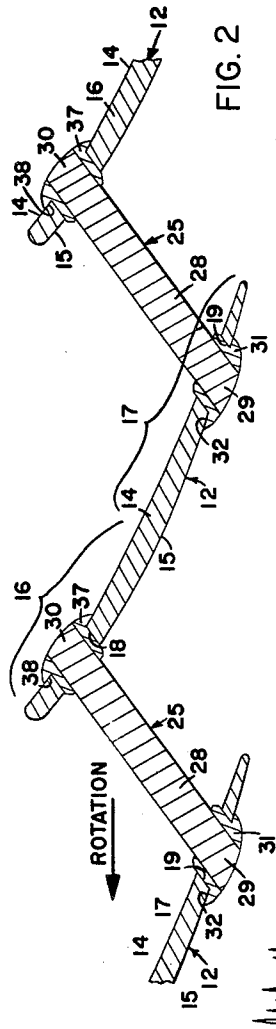


FIG. 2

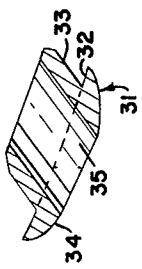


FIG. 3

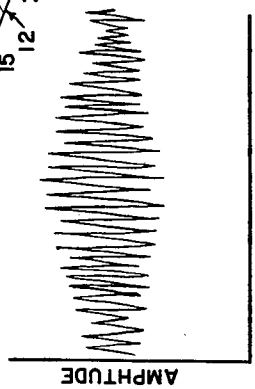


FIG. 4

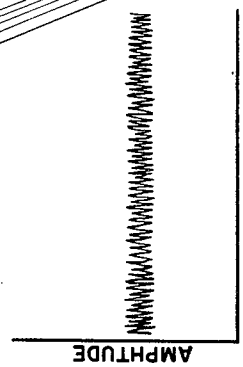


FIG. 5

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United States Patent Office 3,131,461 Patented May 5, 1964

3,131,461

METHOD OF MAKING VIBRATION DAMPED TURBO MACHINERY

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Filed Apr. 20, 1961, Ser. No. 104,282
3 Claims. (Cl. 29—156.8)

This invention relates broadly to bladed turbo machinery including steam turbines, gas turbines, axial and centrifugal flow compressors, fans and propellers. More particularly, this invention relates to an improved lashing construction for damping blade vibrations in turbo machinery and to an improved method of making a turbo machine of the vibration damped blade type.

Turbo machinery of the type contemplated by this invention, employs a plurality of radial blades which are secured to a rotor shaft. The turbo machine may be either of the type in which the energy of a fluid is transmitted to the blades for producing rotation of the shaft, such as a steam turbine, or it may be of the type in which the energy of the rotation of the shaft is transmitted to a fluid for producing movement or compression of the fluid medium such as an axial flow compressor.

Turbo machines in general are beset with a common difficulty which tends to undesirably limit the choice of design parameters. Due to the fact that the blades of a turbo machine are frequently long, thin members secured to a shaft at one end, the blades tend to vibrate during operation of the machine. Irregularities in the distribution and flow of fluids in the machine may cause the blades to vibrate excessively at either their natural frequency or at a harmonic thereof. While the blades are frequently designed so as to avoid excessive vibration at their natural frequency in normal operation of the machine, it is often difficult or impossible to avoid vibrations at a harmonic frequency particularly where the turbo machine must be used at different or varying rotational speeds as during startup or slowdown of the machine. Vibration of the blades is a frequent cause of blade failure due to bending stresses in the blades caused by vibration of the blades. When the bending stresses exceed the maximum working stress of the blade material, a crack may develop at a blade edge. As the crack enlarges under further stress, a point is soon reached where the entire blade fractures and a substantial portion of the blade is loose in the machine and free to damage the other blades of the machine. Since machines of the type described frequently rotate at a very high speed, it has been observed that in some instances a broken blade has sufficient energy to crack the outer casing of the machine and be propelled completely through it.

To avoid the difficulty described, it is common practice to damp vibration of the blades of a turbo machine at its fundamental and some of its harmonic frequencies by lashing the blades together. Prior art lashings have taken many forms, but generally they have proved unsatisfactory for a number of reasons. For example, if all of the blades of a turbo machine are lashed together by a single ring of metal secured to each of the blades and lying in a single plane, the lashing member itself will often fail due to the enlargement of the blade diameter because of centrifugal forces and because of thermal expansion of the blades. The enlargement of the blade diameter imposes a tensile or hoop stress on the lashing member which often results in its failure. A frequent alternative, therefore, is to lash only a small group of blades together with a single lashing member. While this solution reduces the hoop stress in the lashing member, it fails to completely damp vibration of the blades and it introduces a new resonant vibration frequency which corresponds to natural period of vibration of the

group of lashed blades. Also, this alternative sacrifices the desirable rigidity of constructions wherein all of the blades are lashed to their adjacent blades.

Other vibration damping schemes have been employed which utilize either partially loose lashing wires or rigid studs between the blades, but all of these schemes possess disadvantages which tend to limit their use in practical applications. For example, schemes requiring welding a lashing to the blades tend to structurally weaken the blades thereby making them more prone to failure. Furthermore, schemes which involve lashing which lies in only one plane fail to effectively damp transverse vibrations of the blades.

Moreover, the hoop stresses created by thermal and centrifugal expansion of the turbine blades are not the only cause of failure of prior art lashings. Because of the high speeds generally encountered in turbo machinery, the centrifugal forces imposed on the lashing frequently assume significant proportions and result in stresses which are directly superimposed on the hoop stresses previously described. The combination of these stresses tends to produce failure of the lashing and consequently the blades of the turbo machine are enabled to vibrate in destructive modes after failure of the lashing.

Furthermore, prior art lashing constructions have been generally confined to a single plane and, therefore, they failed to damp torsional modes of vibration which are characteristically present in turbine blades. Not only are the torsional modes of vibration a possible source of blade failure, but twisting of the blades due to centrifugal and thermal effects tends to cause the blades to depart from their proper shape and impair efficient operation of the turbo machine.

It is an object of this invention to provide an improved method of making a vibration damped turbo machine.

These and other objects of this invention are achieved in the illustrated embodiment by lashing the blades of a turbo machine about a predetermined diameter by means of hearded pins loosely inserted through apertures in the blades. A pin extends from the leading region of one blade to the trailing region of the other blade and this type of lashing is repeated about the entire fan wheel of the turbo machine. Consequently, each blade is lashed to its two adjacent blades in a rigid manner by a pin under tension and untwisting of the blades under the influence of thermal and inertial forces is restrained but high hoop stresses in the lashing are prevented.

A turbo machine in accordance with this invention may be made by forming a plurality of turbine blades each having apertures in their leading and trailing regions. Head bushings are formed having a shoulder thereon similar to the faces of the turbine blades adjacent which they are to be positioned. Lashing pins are inserted through the aperture in the leading region of one blade and through the aperture in the trailing region of the next adjacent blade. The head bushings are inserted through the respective apertures in the blades and positioned so that their shoulders conform to the faces of the blades. The head bushings are secured to the lashing pins.

The construction of a preferred embodiment of this invention will become more apparent by reference to the specification and attached drawing wherein:

FIGURE 1 is a partial front view of a turbo machine embodying this invention;

FIGURE 2 is a developed plan view of a lashing in accordance with this invention;

FIGURE 3 is a cross-sectional view of a head bushing which forms a part of the turbine lashing shown in FIGURE 2;

FIGURE 4 is a typical graph of the vibration amplitude of a conventionally lashed turbine blade; and

FIGURE 5 is a typical graph of the vibration amplitude of a turbine blade lashed in accordance with this invention.

Referring particularly to FIGURE 1, there is shown a portion or stage of the rotor member **10** of a turbo machine. It will be appreciated that the terms "turbine" and "turbo machine" as they are used throughout this specification and claims are intended to be interpreted in a broad sense and to be generic to steam and gas turbines, turbochargers, axial and centrifugal flow compressors, fans propellers and other rotating or nonrotating bladed fluid machinery, all of which may embody the principles of this invention.

A plurality of turbine blades **12** are secured to rotor shaft **11** by means of "Christmas tree" joints **13** to form a rotor stage. It will be understood that "blade" is meant to be broadly construed to include blade-like protrusions such as compressor vanes or turbine blades. As best seen in FIGURE 2, blades **12** have a front or reaction face **14** and a rear face **15**. If the turbine wheel rotates in the direction shown by the arrow in FIGURE 2, region **16** comprising the leading half of the blades may be designated as the leading region and region **17** comprising the trailing half of the blade may be designated as the trailing region. It will be noted that an aperture **18** of predetermined size and shape is formed in the leading region of each blade and an aperture **19** also of predetermined size and shape is formed in the trailing region of each blade.

Blades **12** may be formed with any desired shape which meets the structural requirements of the turbo machine. Generally, reaction face **14** is concave and rear face **15** is convex when the blades are viewed in cross section. Blades of the type described are frequently used in a low pressure stage of a steam turbine and are relatively long having a substantial amount of twist about their longitudinal axis. For convenience of illustration, the twist of blades **12** has not been shown in FIGURE 2 but can be readily perceived from an examination of FIGURE 1.

Blades **12** are mounted on shaft **11** in spaced adjacency to one another. The blades can be said to be parallel to each other as mounted on the shaft, though it will be appreciated that because of their twist and curvature they generally do not lie in single planes. As mounted on the shaft, reaction face **14** of one blade and rear face **15** of the forward adjacent blade may be said to be remote faces because they are separated from each other by the thickness of their blades and the distance between their other or adjacent faces.

In the illustrated embodiment, the blades of the turbo machine are provided with optional lashing means **26** and a primary lashing means comprising pins **25** as shown in FIGURE 1. Lashing means **26** is shown to be conventional in form and may comprise a plurality of wires each of which extends through a group of five turbine blades **12** with each lashing wire secured to the center blade of the group by a weld **27**. The primary lashing means comprising pins **25**, is positioned to substantially damp the fundamental mode of vibration of blades **12** and the secondary lashing means such as wire **26** may be positioned to damp a secondary mode of vibration of blades **12**. If desired, secondary lashing means **26** may be modified or omitted, or additional lashing means may be employed to damp other desired modes of blade vibration. If only the primary lashing means is employed it will preferably be radially positioned to damp both primary and harmonic vibration modes.

Primary lashing means **25** comprises a plurality of pins which lie in separate planes. Each pin extends from the leading region **16** of one blade **12** to the trailing region **17** of the forward adjacent blade. This type of lashing may continue around the entire circle of blades so that each blade is lashed to both of its adjacent blades. Consequently, a rigid turbo machine blade assembly is provided by this type of construction but one which is not liable to the creation of destructive hoop stresses in the lashing. Also, blade vibration in both the axial and transverse modes is effectively damped by this arrangement.

Lashing means **25** may comprise pin means having a rod **28** and a pair of head bushings **31** and **37** in the embodiment illustrated in the drawing to place the lashing means under tension when the machine is in use. Rod **28** may desirably be circular in cross section and solid in construction though other constructions and configurations may be used. It is desirable to form rod **28** and head bushings **31** and **37** from a high strength, high temperature alloy steel which is not subject to corrosion by the fluid to be passed through the turbo machine.

Rod **28** extends through aperture **18** in the leading region of one blade and aperture **19** in the trailing region of the forward adjacent blade. End **30** of rod **28** projects from the front or reaction face **14** of one blade and end **29** of the rod projects from the rear face **14** of the adjacent forward blade as shown in FIGURE 2. In other words, the ends of rod **28** project from the remote faces of adjacent turbine blades **12** of the turbo machine.

Pin **25** is provided with head bushings **31** and **37**, one of which is illustrated in FIGURE 3. Head bushing **31** has a first exterior portion **33** of a predetermined shape and size so that this portion of the head bushing will loosely slide through aperture **19** in the trailing region of its associated blade. First exterior portion **33** is desirably of substantially the same shape and size as the aperture in the trailing region of blade **12** through which it is to be inserted. Head bushing **31** has a second exterior portion **34** of larger dimension than first exterior portion **33**. Shoulder means **32** is formed between first portion **33** and second portion **34** and is of a size larger than the size of aperture **19** in the turbine blade with which the head bushing is adapted to be used so that the head bushing will not pass completely through the aperture in the blade. Shoulder **32** is formed with a shape which closely conforms to the shape of rear face **15** of the turbine blade through which the bushing is to be inserted. Head bushing **31** is also formed with an internal aperture **35** of substantially the same size and shape as the exterior configuration of end **29** of rod **28** with which the bushing is to be used so that it may be telescoped over the end of the rod. First portion **33** of head bushing **31** makes an angle with shoulder **32** corresponding to the angle which will be formed between rod **28** and rear face **15** of blade **12**. It will be appreciated that lashing or pin means **25** may take a variety of other forms. Essentially, however, pin **25** comprises a pair of head means and means joining the head means in the form described.

The second head bushing **37** may be formed in a similar manner to head bushing **31** except that the shoulder **38** will conform with reaction face **14** of its associated turbine blade. It will be understood that if both ends of rod **28** are not of the same size or shape that second head bushing **37** will be appropriately constructed so as to telescope over the other end **30** of the rod. It will also be appreciated that head bushing **37** is formed with a first region which closely corresponds to the size and shape of aperture **18** in the leading region of the blade through which it is adapted to be insterted. As can be seen in FIGURE 2, when pin **25** is completed, shoulder **38** of head bushing **37** may face shoulder **32** of head bushing **31** to restrain outward movement of adjacent blades **12**.

Head bushings **31** and **37** may be formed by any convenient process, it having been found that investment casting is readily adapted to the requirements of their manufacture. While in the illustrated embodiment two head bushings **31** and **37** are shown to be formed separately from rod **28**, it is entirely feasible to cast or otherwise form one of the head bushings integral with the end of its associated rod so that in constructing the turbine,

only one head bushing need be secured to complete pin 25.

In making a turbo machine in accordance with this invention, blades 12 are formed with apertures 18 and 19 respectively in the leading and trailing regions thereof. While it is convenient to form blades 12 together with the necessary apertures therein by forging and thereafter finishing the blades, it is not necessary that apertures 18 and 19 be formed at the same time as blades 12. Blades 12 are then assembled on rotor 11 in spaced adjacency and secured thereto usually by welding or upsetting a portion of the metal of the rotor. Rod 28, which may initially be somewhat larger than the final pin length, is inserted through aperture 18 in the leading region of one of the blades and through aperture 19 in the trailing region of the adjacent forward blade. When properly positioned, end 29 of rod 28 projects slightly from rear face 15 of the adjacent blade and end 30 projects slightly from reaction face 14 of the blade through which rod 28 is inserted. Head bushings 31 and 37 are then telescoped over the ends 29 and 30 respectively of rod 28. The head bushing are rotated, if necessary, so that the contour of their shoulders conform with the remote faces of blades 12 with which they are associated. Thereafter, the head bushings are secured to rod 28 by brazing, welding or other suitable means without, however, securing the head bushings to the blades. It is then desirable to grind off the end of the pins to match the contour of head 35 of the bushings. A jig has been found convenient for holding the pin and the bushings prior to securing them together and as an assembly aid. It will be appreciated that if one of the head bushings is integral with or secured to rod 28 previous to its insertion through the apertures in blade 12, that it is only necessary to insert rod 28 in apertures 18 and 19 so that the head of the preassembled bushing conforms with the proper face of its turbine blade and then the other head bushing may be assembled to the other end of rod 28 as previously described.

An advantage of lashing a turbo machine in accordance with this invention will be observed by a comparison of FIGURES 4 and 5. In FIGURE 4, there is shown a typical graph of the vibration amplitude in a conventionally lashed turbo machine. It will be noted that the blade under analysis, vibrates with a relatively large amplitude due to the presence of harmonic frequencies of the fundamental mode of vibration of the blade. In contrast to this, FIGURE 5 shows a typical graph of the amplitude of blade vibration in a turbo machine constructed in accordance with this invention. It will be noted that in the latter case, vibration of the blade is held to a relatively small value.

One of the reasons for the significant reduction in the amplitude of vibration in a turbo machine made in accordance with this invention, lies in the fact that each of the turbine blades may be lashed to its two adjacent blades to form a complete hoop. Such a rigid construction is not feasible with a lashing means which lies in a single plane throughout the entire circle of the blade because of the hoop stresses and centrifugal forces which would be imposed on the lashing. However, the lashing of the instant invention does not lie in a single plane and consequently, destructive hoop stresses are avoided by a slight twisting of the blades of the machine. This construction, therefore, results in a desirably rigid lashing without the inherent disadvantages exhibited by prior art constructions.

In addition, the blades of a turbo machine tend to untwist under the influence of centrigugal force and thermal expansion. With conventional type lashings which lie in a single plane, the tendency of the blades to untwist is generally not inhibited. However, with the lashing of the instant invention, since motion of both ends of the blade about the blade axis is restricted the tendency of the blades to untwist is overcome. Furthermore, since pins 25 are loose in the corresponding apertures in blades 12 through which they are inserted, the blades may assume a slightly greater twist when the turbo machine is cold or not in use. It will be seen that under these conditions, pins 25 are completely unstressed until the turbo machine is put into operation at which time the thermal and centrifugal effects on the blades are sufficient to untwist them to the point that their remote faces tightly abut the shoulders of the head bushings placing the lashing pins under tension. If the distance between the shoulders of the head bushings has been properly selected, the blades will have untwisted to an extent such that they have reached their desired position and are tight against the shoulders of the pins when the turbo machine has reached its operating speed and temperature. Further untwisting of the blades will be prevented even though the centrifugal forces or temperature rise would tend to produce this result because of the restraining action of pins 25 once the blades have reached their desired condition. The designer, therefore, may choose a blade which is relatively thin and need not appreciably thicken the base of the blade in order to prevent the undesirable untwisting which has been described.

With the construction described, wherein the lashing pins are relatively short, the number of blades used in a particular turbine may be selected to give more nearly optimum fluid flow through the turbine than was possible with prior art constructions where the distance between the blades was an undesirably limiting factor in the design of an effective lashing. The use of fewer blades also results in cost savings and in improved efficiency by reduction of frictional drag on the blades.

Another disadvantage in prior art constructions has been the necessity for heavily reinforcing the blades of a turbo machine in the region in which the lashing means is located. The relatively heavy reinforcement has added to the weight of the blade as well as forming an area of nonuniform surface on the blade which tended to disrupt fluid flow across the faces of the blades. However, with the improved construction described, it is possible to use a relatively slight reinforcement, if any, on the blade in the region of the lashing and consequently, a more uniform fluid flow is achieved.

Moreover, the improved lashing of the instant invention is effective to damp both tangental and tortional modes of vibration which further reduce the size and weight of the blades used since it has been previously necessary to compromise desired lightness for the fact of structural rigidity in order that tortional vibrations be reduced to a satisfactorily low level.

Likewise, because of the tendency of the blade to untwist under the influence of centrifugal forces imposed on it when rotating at high speed, the lashing pins are under tension in operation of the turbo machine. Consequently, tangental vibration of the blades is substantially completely eliminated and blade failure is materially reduced. Also, failure of the lashing, which has been a serious problem in prior art constructions, is substantially reduced because the pin is placed in axial tension and is not subject to fatigue failure due to bending stresses which have characterized prior lashing constructions. This latter feature is highly advantageous because it is obvious that however effective a lashing construction may be in damping the various modes of blade vibration, such a construction is rendered useless if stresses are set up in the lashing which will tend to cause the lashing to fail in service. Prior art lashings have frequently damped blade vibration at the expense of bending stresses being set up in the lashings which eventually caused the lashings and subsequently the blades to fail. In applicant's construction, however, bending stresses in the lashing pins are substantially eliminated and fatigue failure of the lashing is therefore substantially eliminated along with blade vibration to provide a reliable turbo machine construction.

Many prior art constructions have required a weld be-

tween a lashing member and the blade. The disadvantageous result of a weld in this region was twofold. First, the weld failed to be sufficiently ductile to withstand the stresses imposed on it during operation of the machine and secondly, the heat from the welding operation tended to adversely affect the mechanical strength of the blade. For example, the welding process frequently caused air hardening of a turbine blade making this region more susceptible to fracture under the flexure produced by vibration of the blades. In the present construction, no mechanical connection is made to the blades and only a simple and easily controllable brazing operation is required to be performed in the area of the blade. Consequently, change in blade characteristic due to securing of the lashing means is negligible with the instant construction.

It can be seen, therefore, that the design of turbo machinery made in accordance with this invention is less restricted by the destructive nature of stress producing vibrations than has been true of prior constructions. Consequently, the application of the instant invention results in a more efficient turbo machine which may be lower in cost and more durable and reliable in operation than previous machines.

While there has been described a preferred embodiment of this invention, it will be understood that this invention is not limited by the form shown and described, but that various modifications and embodiments thereof may be constructed within the scope of the following claims.

I claim:

1. In a method of making a vibration damped turbo machine the steps comprising:

(1) forming first and second blades each having a pair of faces;

(2) forming an aperture in a leading region of said first blade and an aperture in a trailing region of said second blade;

(3) securing said blades in spaced adjacency to each other on a rotor shaft;

(4) assembling a lashing pin extending loosely through said apertures in said first and second blades, said lashing pin being formed by:

(*a*) forming a rod portion for assembly between said apertures,

(*b*) forming a head portion on said rod portion adjacent one end thereof, said head portion being formed with a shoulder of a size greater than the size of the aperture in one of said blades and being assembled with said shoulder adjacent the face of said one of said blades most remote from the other of said blades,

(*c*) forming another head portion on said rod portion adjacent the other end thereof, said second head portion being formed with a shoulder thereon of a size greater than the size of the aperture in the other of said blades, and being assembled with said shoulder adjacent the face of said other blade most remote from said one blade, and

(*d*) said lashing pin being formed with portions extending inwardly of said shoulders of a size so that said blades may slide toward each other in frictional engagement with said lashing pin and are restrained from excessive movement away from each other by the shoulders on said lashing pin.

2. In a method of making a vibration damped turbo machine the steps comprising:

(1) forming first and second blades each having a pair of faces;

(2) forming an aperture in a leading region of said first blade and an aperture in a trailing region of said second blade;

(3) securing said blades in spaced adjacency to each other on a rotor shaft;

(4) assembling a lashing pin extending loosely through said apertures in said first and second blades, said lashing pin being formed by:

(*a*) forming a rod portion for assembly between said apertures,

(*b*) forming a head bushing, said head bushing being formed with a portion adapted to be secured to said one end of said rod portion, shoulder means thereon of a size larger than the aperture in one of said blades, and an external portion of substantially the same size as said aperture in said one blade and adapted to be loosely inserted in said aperture in said one blade,

(*c*) inserting said head bushing in said aperture in said one blade, and engaging said head bushing and said one end of said rod portion, with said shoulder means being positioned adjacent the face of said one blade which is most remote from the other of said blades,

(*d*) securing said head bushing to said rod portion only, so that said blade is free to move away from said shoulder,

(*e*) forming another head portion on said rod portion adjacent the other end thereof, said other head portion being formed with a shoulder thereon of a size greater than the size of the aperture in the other of said blades, and being assembled with said shoulder adjacent the face of said other blade most remote from said one blade, and

(*f*) said lashing pin being formed with portions extending inwardly of said shoulders of a size so that said blades may slide toward each other in frictional engagement with said lashing pin and are restrained from excessive movement away from each other by the shoulders on said lashing pin.

3. In a method of making a vibration damped turbo machine the steps comprising:

(1) forming first and second blades each having a pair of faces;

(2) forming an aperture in a leading region of said first blade and an aperture in a trailing region of said second blade;

(3) securing said blades in spaced adjacency to each other on a rotor shaft;

(4) assembling a lashing pin extending loosely through said apertures in said first and second blades, said lashing pin being formed by:

(*a*) forming a rod portion having a length greater than the spacing between said apertures in said adjacent blades, said rod portion being formed with at least one end having a size substantially smaller than the size of the aperture in one of said blades adjacent which said one end of said rod portion is adapted to be assembled,

(*b*) inserting said rod portion through said apertures in adjacent blades with said one end of said rod portion extending through said aperture in said one blade,

(*c*) forming a head bushing, said head bushing being formed with a recess therein of a shape and size adapted to receive said one end of said rod portion, shoulder means thereon adapted to conform with the face of said one blade, adjacent which said head bushing is adapted to be positioned, and an external portion of substantially the same shape and size as said aperture in said one blade and adapted to be loosely inserted in said aperture in said one blade,

(*d*) inserting said head bushing in said aperture in said one blade, telescoping said head bushing over said one end of said rod portion, and

positioning said shoulder means in abutting relation with the face of said one blade which is most remote from said other blade,

(*e*) securing said head bushing to said rod portion only, so that said blade may move away from said shoulder,

(*f*) forming another head portion on said rod portion adjacent the other end thereof, said other head portion being formed with a shoulder thereon of a size greater than the size of the aperture in the other of said blades, and being assembled with said shoulder adjacent the face of said other blade most remote from said one blade, and

(*g*) said lashing pin being formed with portions extending inwardly of said shoulders of a size so that said blades may slide toward each other

in frictional engagement with said lashing pin and are restrained from excessive movement away from each other by the shoulders on said lashing pin.

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