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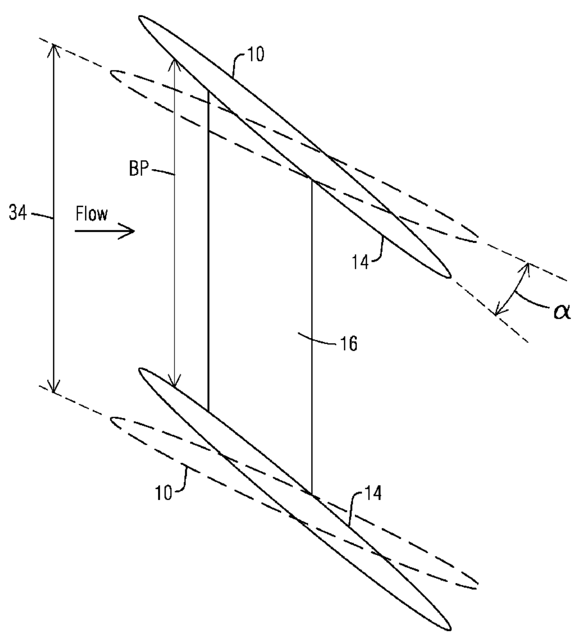
(54) Title: PRELOADED SNUBBER ASSEMBLY FOR TURBINE BLADES

FIG. 4



(57) Abstract: A preloaded snubber assembly for turbine blades includes a plurality of turbine blade airfoils (10) including a trailing edge and a leading edge joined by a pressure side and a suction side to provide an outer surface (14) extending in a radial direction (R) to a tip. At least one snubber locator support (20) is integrally formed onto the outer surface (14) of each turbine blade airfoil (10). The at least one snubber locator support (20) includes a slot opening (22). A snubber (16) is in contact with the slot opening of the at least one snubber locator support (20), each snubber (16) includes a first end (42), a second end (44), a leading edge (26), a trailing edge (28), an inside diameter side (32), an outside diameter side (30), a snubber length (46), and a snubber width (48). For attachment between the blades the snubbers are elastically bent and removably inserted and positioned into the slot openings.

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PRELOADED SNUBBER ASSEMBLY FOR TURBINE BLADES

BACKGROUND

1. Field

[0001] The present invention relates to gas turbine engines, and more specifically to a preloaded snubber for a turbine blade.

2. Description of the Related Art

[0002] In an industrial gas turbine engine, hot compressed gas is produced. The hot gas flow is passed through a turbine and expands to produce mechanical work used to drive an electric generator for power production. The turbine generally includes multiple stages of stator vanes and rotor blades to convert the energy from the hot gas flow into mechanical energy that drives the rotor shaft of the engine. Turbine inlet temperature is limited to the material properties and cooling capabilities of the turbine parts. This is especially important for upstream stage turbine vanes and blades since these airfoils are exposed to the hottest gas flow in the system.

[0003] A combustion system receives air from a compressor and raises it to a high energy level by mixing in fuel and burning the mixture, after which products of the combustor are expanded through the turbine.

[0004] Since the turbine vanes and blades are exposed to the hot gas flow discharged from combustors within the combustion system, cooling methods are sometimes used to obtain a useful design life cycle for the turbine blade or vane. Blade and vane cooling is typically accomplished by extracting a portion of the compressed air from the compressor and directing it to the turbine section, thereby bypassing the combustors. After introduction into the turbine section, this cooling air flows through passages formed in the airfoil portions of the blades and vanes.

[0005] Gas turbines are becoming larger, more efficient, and more robust. Large blades and vanes are being produced, especially in the hot section of the engine system. Of particular challenge is the last stage blade. Traditionally the last stage blade has been solid, tip shrouded and uncooled. This configuration has limitations as the blades require more robustness as the gas path diameters increase and the gas path temperatures increase.

[0006] In order to allow for increasing the gas path diameter, turbine blades may be hollow, cooled, curve root attached blades with integral part span snubbers as seen in Figures 1 through 3. Figures 2 and 3 show multiple blades and snubbers in a conventional configuration. There is an extensive amount of time and effort involved with making sure the snubbers are properly aligned and within a certain distance in order to make eventual contact once the turbine blades are moving at a certain speed. The turbine snubbers are also used for the purpose of damping blade mechanical vibrations, particularly for blades having high aspect ratio. An edge from each snubber is a contact surface for the next snubber once the turbine blades are moving at a specific rotational speed.

[0007] The snubber creates an assembly challenge due to the potential interference between the attachment engagement and snubber contact surface engagement as can be seen in Figures 2 and 3. The assembly cannot be completed without specialized tooling and processes. The existing snubber systems are all axisymmetric forming a constant radius, segmented support ring for the large blades. The damping design criteria for bearing angle and contact pressure are often difficult to achieve. The snubber also presents a performance challenge due to the increased aerodynamic blockage as well as its effect on the exhaust diffuser behavior. Assembly issues in regards to the snubbers and the eventual connections are difficult, especially since contact is not made until the turbine blades have started to move at a certain rotational speed.

[0008] In current assemblies, the snubbers will connect with each other once the turbine is up and running at a particular rotational speed. The blade untwists as a function of rotational speed. The airfoil will also have radial growth at increased rotational speeds. Once the blades have sufficiently untwisted, the snubbers come into contact through their contact surfaces once that particular rotational speed is met as shown in Figure 2. The contact surface, or bearing surface, on each snubber connects once a certain rotational speed is reached. There is typically no initial contact of the snubbers at zero and low speeds as is shown in Figure 3.

[0009] Aeromechanical systems for snubbers and tip shrouds consider the vibratory mode shape to define the bearing angle and contact pressure to achieve the required level of mechanical constraint and damping. Additionally, these systems try to achieve minimum weight to reduce the stress on the blade. There has been no significant reduction in the snubber aerodynamic penalty because of the mechanical requirements for blade support and part life.

SUMMARY

[0010] In one aspect of the present invention, a preloaded snubber assembly for turbine blades comprises: a turbine blade airfoil comprising a trailing edge and a leading edge joined by a pressure side and a suction side to provide an outer surface extending in a radial direction to a tip; at least one snubber locator support integrally formed onto the outer surface of each turbine blade airfoil, wherein the at least one snubber locator support comprises a slot opening; and a plurality of snubbers, each comprising a first end and a second end joined by a leading edge and a trailing edge, an inside diameter side, an outside diameter side, a snubber length, and a snubber width, wherein at least one of the first end and the second end of the snubber is in contact with the slot opening of the at least one snubber locator support matching the cross-section of the snubber.

[0011] In another aspect of the present invention, a method for attaching snubbers to a rotor assembly comprises: providing a plurality of turbine blades with a blade passage in between each blade, wherein the plurality of turbine blades each comprise an airfoil, a trailing edge and a leading edge joined by a pressure side and a suction side to provide an outer surface extending in a radial direction to a tip, wherein at least one snubber locator support is integrally formed onto the outer surface of each turbine blade airfoil, wherein the at least one snubber locator support comprises a slot opening, installing the plurality of turbine blades in a cold, untwisted condition, elastically bending a plurality of snubbers, each snubber comprising a first end and a second end joined by a trailing edge and a leading edge, an inside diameter side, an outside diameter side, a snubber length, and a snubber width, removably inserting the plurality of snubbers between each turbine blade, each snubber removably positioned into each of the slot openings of the at least one snubber locator support of each turbine blade, wherein the slot opening of the at least one snubber locator support is constructed to provide a contact surface for the at least one first end and second end of each snubber for operational blade movement.

[0012] These and other features, aspects and advantages of the present invention will become better understood with reference to the following drawings, description and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The invention is shown in more detail by help of figures. The figures show preferred configurations and do not limit the scope of the invention.

[0014] FIG 1 is a perspective view of a prior art blade with snubber.

[0015] FIG 2 is a radial view of an assembled large turbine blade with curved root and integral part span snubber of the prior art.

[0016] FIG 3 is a perspective view of a prior art snubber and airfoil section.

[0017] FIG 4 is a perspective view of hot and cold blade positions of an exemplary embodiment of the present invention.

[0018] FIG 5 is a perspective view of a cold blade positioned along a preloaded snubber in an exemplary embodiment of the present invention.

[0019] FIG 6 is a cross sectional view of a snubber of an exemplary embodiment of the present invention taken along line A-A of Figure 5.

[0020] FIG 7 is a cross sectional view of the snubber of an exemplary embodiment of the present invention, taken along line B-B of Figure 5.

[0021] FIG 8 is a radial view of an exemplary embodiment of the present invention in a cold blade position.

[0022] FIG 9 is a cross sectional view of the snubber and blade of an exemplary embodiment of the present invention, taken along line C-C of Figure 8.

[0023] FIG 10 is a cross sectional view of the snubber and blade of an exemplary embodiment of the present invention, taken along line D-D of Figure 8.

[0024] FIG 11 is a perspective view of a snubber with connections of an exemplary embodiment of the present invention.

[0025] FIG 12 is a perspective radial view of a snubber and blade of an exemplary embodiment of the present invention.

[0026] FIG 13 are cross sectional views of the snubber of an exemplary embodiment of the present invention, taken along line E-E of Figure 12.

[0027] FIG 14 are cross sectional views of the snubber of an exemplary embodiment of the present invention, taken along line F-F of Figure 12.

[0028] FIG 15 is a cross sectional view of the snubber and blade of an exemplary embodiment of the present invention.

DETAILED DESCRIPTION

[0029] In the following detailed description of the preferred embodiment, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration, and not by way of limitation, a specific embodiment in which the invention may be practiced. It is to be understood that other embodiments may be utilized and that changes may be made without departing from the spirit and scope of the present invention.

[0030] Broadly, an embodiment of the present invention provides a preloaded snubber assembly for turbine blades that includes a plurality of turbine blade airfoil including a trailing edge and a leading edge joined by a pressure side and a suction side to provide an outer surface extending in a radial direction to a tip. At least one snubber locator support is integrally formed onto the outer surface of each turbine blade airfoil. The at least one snubber locator support includes a slot opening. A snubber is in contact with the slot opening of the at least one snubber locator support, each snubber including a first end, a second end, a leading edge, a trailing edge, an inside diameter (ID) side, an outside diameter (OD) side, a snubber length, and a snubber width.

[0031] A gas turbine engine may comprise a compressor section, a combustor and a turbine section. The compressor section compresses ambient air. The combustor combines the compressed air with a fuel and ignites the mixture creating combustion products comprising hot gases that form a working fluid. The working fluid travels to the turbine section. Within the turbine section are circumferential rows of vanes and blades, the blades being coupled to a rotor. Each pair of rows of vanes and blades forms a stage in the turbine section. The turbine section comprises a fixed turbine casing, which houses the vanes, blades and rotor. A blade of a gas turbine receives high temperature gases from a combustion system in order to produce mechanical work of a shaft rotation.

[0032] Damping is an important benefit that a snubber may provide for a turbine blade. The damping occurs when there is direct contact between adjacent blades and snubbers. An aspect of the level of damping is a contact surface. The contact surface is the area of contact between each component. Another phenomena that occurs once the blades are at a certain rotational speed, is that there is radial growth of the airfoil as well as an untwisting at operating conditions.

[0033] Improved damping may occur with a snubber that is not physically attached to the blades, but is preloaded in place and maintains a constant contact with between snubber and blades. The blade/snubber assembly, aerodynamics, and performance, as will be discussed in detail below, may be able to provide a bridge between blades through loading while the blades are in an untwisted cold blade position.

[0034] As is shown in Figures 4 through 15, a turbine blade 10 may have an airfoil and may include at least one snubber locator support 20 formed along an outer surface

14 of the blade airfoil. The at least one snubber locator support 20 may include a slot opening 22. The turbine blade 10 may be referred to as the airfoil, or turbine blade airfoil. The turbine blade airfoil may include a trailing edge and a leading edge joined by a pressure side and a suction side to provide the outer surface 14 extending in a radial direction to a tip. The blade airfoil may be one of a plurality of blade airfoils in a row. The blade 10 may have a curved root 18 such as is shown in Figure 1.

[0035] Each turbine blade 10 may have a cold and a hot running position. Figure 4 shows these two types of blade positions in an exaggerated form for the benefit of explanation. The solid blade form is the blade in a hot position, while the dashed blade is the blade in a cold position. An angle is formed between the two positions. A snubber 16 may be a separate part that may be removably inserted between adjacent blades in an assembled wheel, with the wheel having a plurality of blades 10. The snubber 16 may removably connect to the at least one snubber locator support 20 on each blade 10. In Figure 4 the snubber is shown in parallelogram type geometry, however, the snubber may have various shapes and sizes based on the application. The hot snubber does not fit cold blade passages 34.

[0036] The at least one snubber locator support 20 may be integrally formed along the outer surface 14 of the blade airfoil. In certain embodiments, the at least one snubber locator support 20 may be positioned along the airfoil at a distance that may equate to a snubber span radius of a conventional snubber blade assembly at a zero speed. The at least one snubber locator support 20 may provide the areas of contact and constraint between the plurality of airfoils 10 and a plurality of snubbers 16. The at least one snubber locator support 20 may have one of several different shapes in order to fit an application as shown in Figures 4-15. The size and shape of each snubber locator support 20 may be determined by mechanical and aerodynamic requirements such as the size of the snubber 16, the contact surface for damping, and the airfoil radial growth and untwist at operating conditions.

[0037] The shape of the snubber 16 may also vary depending on mechanical and aerodynamic requirements. Figures 13-14 show different embodiments of the snubber 16. The snubber 16 may have a substantially rectangular shape, a convex shape, a concave shape, or the like.

[0038] The plurality of blades 10 may be placed and installed on the wheel. The wheel may include a rotating disc. The disc may include a plurality of elongated channels provided therein and spaced along a disc periphery. Each of the blades 10 may be installed in each of the elongated channels on the disc. The plurality of blades 10 may define a passage 34, having a passage length and a passage width between each blade 10. The snubber 16 may be supported at the airfoils with snubber locator support 20 in the passage 34. It may be possible to reduce the aerodynamic blockage of the conventional snubber with a thinner snubber 16. The snubber 16 may have a thinner mid section such as is shown in Figure 14. The snubber 16 may have a variable width or thickness in the passage 34 along a circumferential direction.

[0039] Each snubber 16 may include a first end 42, a second end 44, a trailing edge 28, a leading edge 26, a snubber chord-wise width 48, and a snubber length 46. Figures 4-15 illustrates how the snubber 16 may be in contact with the snubber locator support 20, and therefore the blade 10. The snubber length 46 and snubber chord-wise width 48 are within the passage width and passage length as defined by the space between the blades 10.

[0040] In certain embodiments, the snubber 16 may include a side that includes at least one spherical fitting connection 24 such as shown in Figures 9 and 11. The at least one spherical fitting connection 24 may prevent chord-wise sliding of the snubber. Each spherical fitting connection 24 may fit into a spherical joint on the airfoil slot opening 22. The spherical joint on the one side may prevent axial motion. The at least one spherical fitting connection 24 may be centrally located along one edge, the least one spherical fitting connection 24 may be on each end of an edge listed as several non-limiting examples. Figure 9 shows the assembly while the blade is in a twisted hot blade configuration. The contact surface may be sized to support the snubber load and to provide a required contact area for damping.

[0041] The snubber 16 may be removably connected to the snubber locator support 20 in multiple embodiments. The snubber locator support 20 and slot opening 22 may be created by locally adding material to the airfoil in an aerodynamic shape and then machining the straight circular section slot as presented in Figures 8-10. The circular cross-section of both the slot opening and the snubber end allows the snubber to rotate without binding as the circumferential distance between the blades changes. In certain embodiments, the slot opening 22 may have a round, smooth contact surface. The snubber may include a rounded cross-section end that may match the slot opening along the snubber locator support 20 on the blade 10. In certain embodiments, the slot opening may include a straight contact line along the blade side. One side of the slot opening may provide both radial and chord-wise constraint with the opposite side providing only a radial constraint. The one side of the snubber may maintain tight chord-wise control, the other side may slide in a chord-wise direction. Each snubber 16 may be installed onto the snubber locator support 20 after all blades 10 may be installed on the wheel. Each snubber 16 may be removably connected to the airfoils by the snubber locator support 20. The blade 10 may be allowed to be free to untwist and grow radially without any restriction, or binding, from the snubber 16.

[0042] The preloaded snubber 16 may be arched while being installed in order to maintain a control between the blades 10. The snubber may stay in position and once the blades are in a hot position, at a different angle, the snubber may be secure with the ability to decrease the arch in the snubber and still maintain contact with the snubber locator support 20 along the blade 10.

[0043] For installation, the preloaded snubber may have to be arched about the axis 38 that is parallel to the blade sections as shown in Figures 5-7. A cold assembly may require that the blade 10 be untwisted by an angle (α) prior to installing the preloaded snubber 16. This elastic bending of the preloaded snubber prior to insertion may allow for the snubber to maintain the angular position at the blade interface. This deflection allows for easy installation as well as positive contact with the slot openings when the bending load is removed and the preloaded snubber 16 partially straightens to fill the blade passage (34). The blades 10 prevent the snubber from straightening completely. The snubber may also have a side that may slide in a chord-wise direction.

[0044] The installed cold snubber 16 may contact the untwisted cold blade 10 at two load locations 40 as shown in Figure 5. These loads or forces need to be large enough to manage the blade and maintain contact in the pre-untwisted position. The snubber 16 has to be sufficiently stiff to hold the cold blade in this position. As the blade spins up to speed, the load will change with the snubber centrifugal load and the load would change from point loads to a more even distribution along the area of contact. The load distribution may be dependent on the total amount of untwist during operation. The preloaded snubber 16 maintains a slight concave “up” position, as is shown in Figure 7, even after the assembly bending load is released. This shape may allow the snubber to maintain a preload against the blades 10 as the blades 10 grow radially from the thermal mechanical loads.

[0045] The method of removable connection may prevent the snubber 16 from sliding off of the support at least one snubber locator support 20 during operation. The method may not restrict the airfoil motion in untwisting or radial growth. There are no special fitting requirements between the snubbers 16 of adjacent blades 10. Instead, the snubbers 16 may simply be installed between the blades 10 along the snubber attachment platforms 20.

[0046] The snubbers 16 may have a superior aerodynamic shape compared to snubbers that are integral with the blades 10. Integral snubbers, by their nature, must have a large interface with the contacting snubber in the adjacent blade 10 and that causes aerodynamic losses. As mentioned above, the snubber thickness may be reduced and be provided with a very thin profile. A thinner midsection profile may also reduce aerodynamic blockage.

[0047] In certain embodiments, the leading edge 26 and trailing edge 28 of the snubber 16 may have various shapes such as is shown in Figure 12. In certain embodiments, the snubber 16 may have an airfoil-like cross section such as shown in Figure 13, in order to produce radially inward directed lift to partially off-set the centrifugal load of the snubber 16. This potential load reduction may be used to improve the blade life, the blade performance via reduced thickness or with a reduced cooling flow.

[0048] In certain embodiments, the blade 10 may include an air flow cooling circuit. The snubber 16 may be cooled by providing cooling air flow 12 from the blade 10 through the snubber locator support 20 to the snubber 16 as presented in Figure 15 with the blade in an untwisted cold blade position. In certain embodiments, the cooling flow may have to jump a gap between the snubber locator support 20 and the snubber 16. Even though the snubber 16 is not a part of the blade 10, the snubber 16 may still be able to receive cooling air flow 12 across the snubber 16 to decrease temperatures. Cooling air flow 12 may run through the airfoil and flow through a cooling cavity 36 with access to the snubber 16 as is shown in Figure 15. The snubber cooling system may be configured to meet design requirements. Additional features may be added to meet the required configuration such as drilled holes, cavities, a trailing edge ejection, a pressure side ejection and the like.

[0049] In all embodiments, blade 10 to blade 10 contact is maintained for all operating speeds. There is no need for special tools in order to properly set and assemble the plurality of snubbers 16 in place for proper contact. The plurality of blades 10 may be placed in the wheel, and each snubber 16 may be placed into each snubber locator support 20. Once each snubber 16 is placed into each snubber locator support 20, there is blade 10 to blade 10 contact. The blade 10 to blade 10 contact may be maintained at all operating speeds, including no speed and at high speeds. Therefore, damping may be available at all operating speeds.

[0050] Since the snubber 16 is removable, the snubber 16 may be easily replaced. In certain embodiments, a one interval uncooled part may be placed in position along the snubber locator support 20 for temporary placement. Additional cooling flow savings may also be produced with this one interval part. The preloaded snubber may provide similar untwist constraint, frequency, and mode shape control as integral snubbers.

[0051] A thinner snubber 16 than conventionally used may be used and therefore provide improved aerodynamic performance. The thickness necessary in a conventional snubber 16 for contact surface may not be necessary when the snubber 16 may be removably connected to the snubber locator support 20, since the snubber locator support 20/snubber 16 connection provides the contact surface. The portion of the snubber 16 that is in between the blades 10 may be as thin as possible for the application. The thickness may also be variable for various possibilities such as shown in Figures 13 and 14.

[0052] Servicing of the blades 10 and snubbers 16 may improve with the ability to change out the removably connected snubbers 16. Differently shaped snubbers 16 may be placed in service to update or improve performance of the turbine. Instead of having to replace a full blade 10, the snubber 16 alone may be removed and replaced. The easy replacement of snubbers 16 may allow for reduced part life designs that may not require active cooling.

[0053] Aeromechanical tuning may be provided for the blades 10 with adjustments to the snubbers 16, or replacement of the snubbers 16 with ease. If problems occur while in service, an individual snubber 16 may be replaced with a different snubber 16 with more damping and or improved shape per the specific application.

[0054] As mentioned above, the size and shape of each snubber locator support 20 and snubber 16 may be determined by mechanical and aerodynamic requirements. The size of the snubber 16 used in a turbine application may be changed since the snubber 16 may be removed. The contact surface for damping may be reduced due to the change in configuration from the conventional integral snubber. The amount of airfoil radial growth and untwist during operating conditions may change the requirements for the size and shape of the snubber locator support 20 and snubber 16.

[0055] Optimization may occur with proper testing of the turbine. Mistuning may be used to reduce blade vibration responses. A removably connected snubber 16 may provide multiple methods to mistune the vibratory response of the blades 10. There may be two or more snubber 16 configurations distributed in the blade passages 34 in order to interfere with coupled blade-to-blade vibration as seen in the formation of a nodal diameter pattern. Each snubber 16 in the turbine blade assembly may be of a different shape. Different snubbers 16 may also change blade natural frequencies. Some of the snubbers 16 may be removed that may eliminate the formation of a coherent nodal diameter pattern.

[0056] Blade-to-blade contact is maintained for all operating speeds with embodiments of the assembly. Since blade-to-blade contact is maintained for all operating speeds, damping is available at all operating speeds. Blade frequencies and mode shapes can be tuned.

[0057] While specific embodiments have been described in detail, those with ordinary skill in the art will appreciate that various modifications and alternative to those details could be developed in light of the overall teachings of the disclosure. Accordingly, the particular arrangements disclosed are meant to be illustrative only and not limiting as to the scope of the invention, which is to be given the full breadth of the appended claims, and any and all equivalents thereof.

CLAIMS

What is claimed is:

1. A preloaded snubber assembly for turbine blades comprising:

a plurality of turbine blade airfoils (10) each comprising a trailing edge and a leading edge joined by a pressure side and a suction side to provide an outer surface (14) extending in a radial direction (R) to a tip;

at least one snubber locator support (20) integrally formed onto the outer surface (14) of each turbine blade airfoil (10), wherein the at least one snubber locator support (20) comprises a slot opening (22); and

a plurality of snubbers (16) each comprising a first end (42), a second end (44) joined by a leading edge (26) and a trailing edge (28), an inside diameter side (32), an outside diameter side (30), a snubber length (46), and a snubber width (48),

wherein at least one of the first end (42) and the second end (44) of each snubber (16) is in contact with the slot opening (22) of the at least one snubber locator support (20) matching the cross-section of the snubber (16).

2. The preloaded snubber assembly according to claim 1, wherein at least one of the first end (42) and second end (44) of the snubber (16) further comprises at least one spherical joint connection (24) along a chordal direction.

3. The preloaded snubber assembly according to any of claims 1-2, wherein the snubber width and thickness is variable in the passage along a circumferential direction.

4. The preloaded snubber assembly according to any of claims 1-3, wherein the snubber cross-section is variable in the passage along a tangential direction.

5. The preloaded snubber assembly according to any of claims 1-4, wherein the slot opening (22) comprises a circular cross-section.

6. The preloaded snubber assembly according to any of claims 1-5, wherein the slot opening (22) comprises a straight contact line along the outer surface of the blade.

7. The preloaded snubber assembly according to any of claims 1-6, further comprising an air flow cooling circuit within the turbine blade airfoil (10), wherein a cooling cavity (36) in the air flow cooling circuit extends out from the turbine blade airfoil (10) to the snubber (16).

8. The preloaded snubber assembly according to claim 7, wherein a pathway for cooling flow 12 is made from the cooling cavity (36), through the snubber locator support (20), and into the snubber (16).

9. A method for attaching snubbers to a rotor assembly comprising:

providing a plurality of turbine blades (10) with a blade passage (34) in between each blade (10),

wherein the plurality of turbine blades (10) each comprise an airfoil, a trailing edge and a leading edge joined by a pressure side and a suction side to provide an outer surface (14) extending in a radial direction (R) to a tip,

wherein at least one snubber locator support (20) is integrally formed onto the outer surface (14) of each turbine blade airfoil (10), wherein the at least one snubber locator support (20) comprises a slot opening (22),

installing the plurality of turbine blades (10) in a cold, untwisted condition;

elastically bending a plurality of snubbers (16), each snubber (16) comprising a first end (42), a second end (44) joined by a leading edge (26) and a trailing edge (28), an inside diameter side (32), an outside diameter side (30), a snubber length (46), and a snubber width (48);

removably inserting the plurality of snubbers (16) between each turbine blade (10), each snubber (16) removably positioned into each of the slot openings (22) of the at least one snubber locator support (20) of each turbine blade (10),

wherein the slot opening (22) of the at least one snubber locator support (20) is constructed to provide a contact surface for the at least one first end (42) and second end (44) of each snubber (16) for operational blade movement.

FIG. 1
PRIOR ART

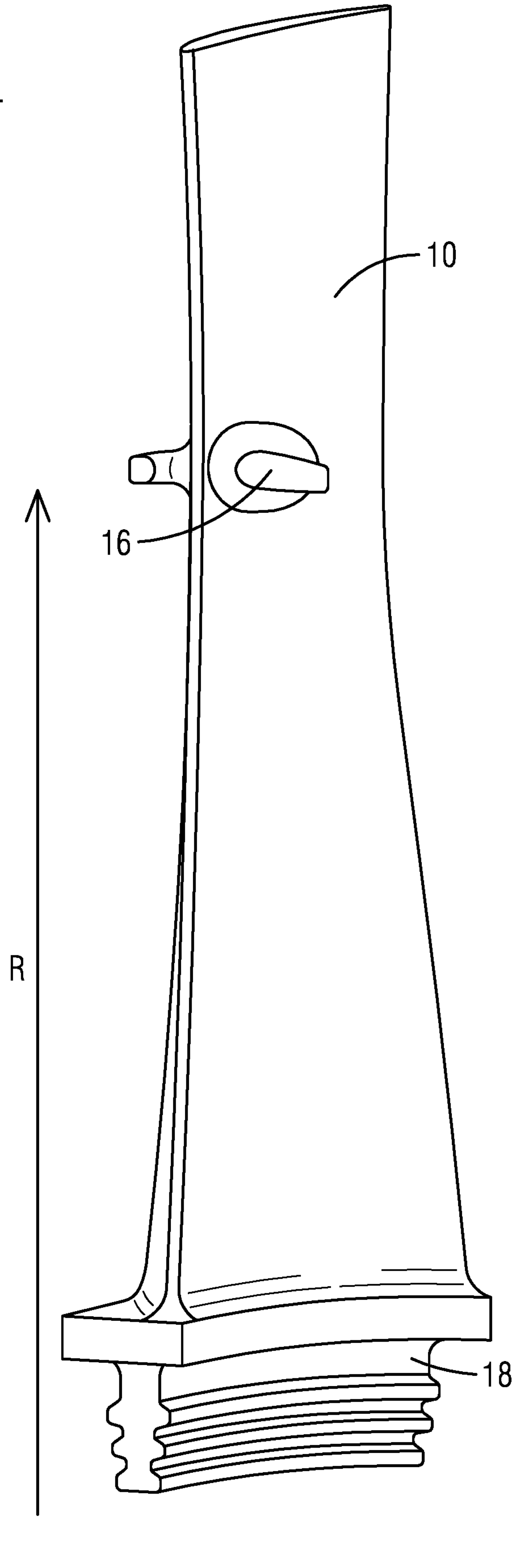
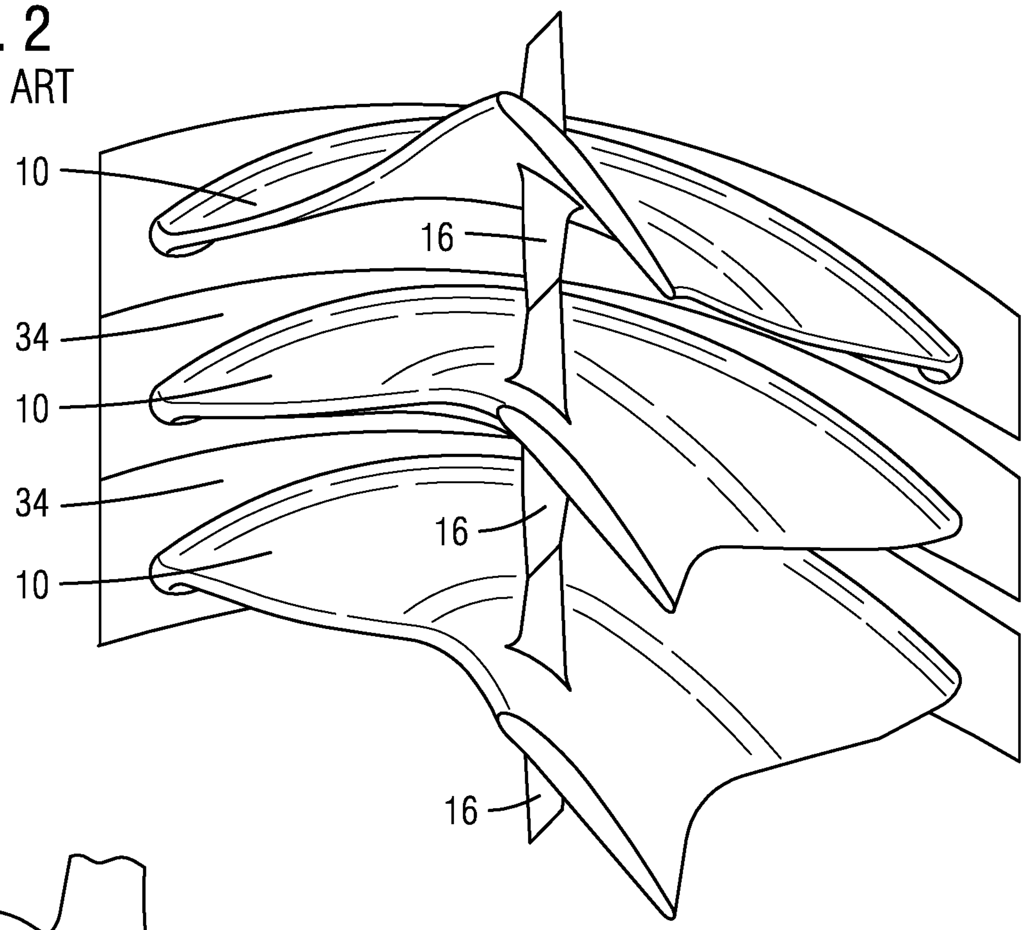


FIG. 2
PRIOR ART



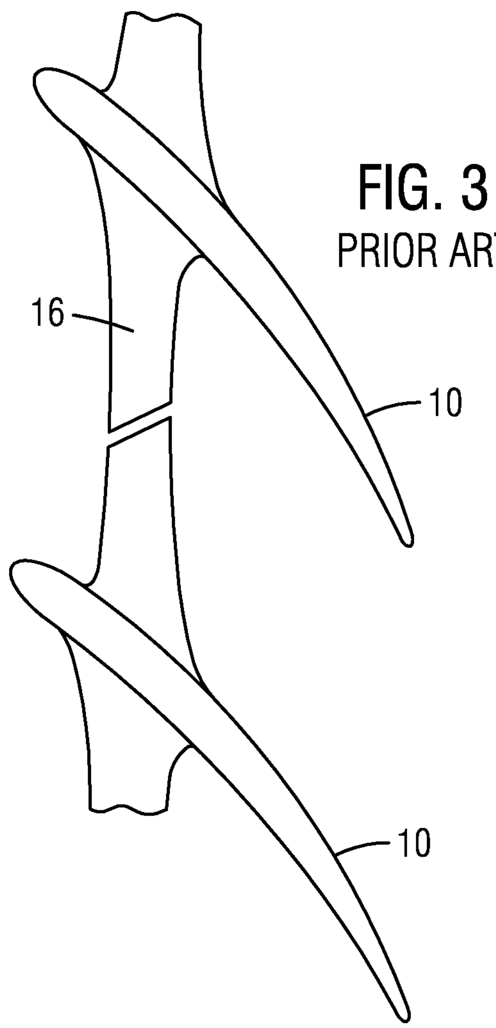


FIG. 3
PRIOR ART

FIG. 4

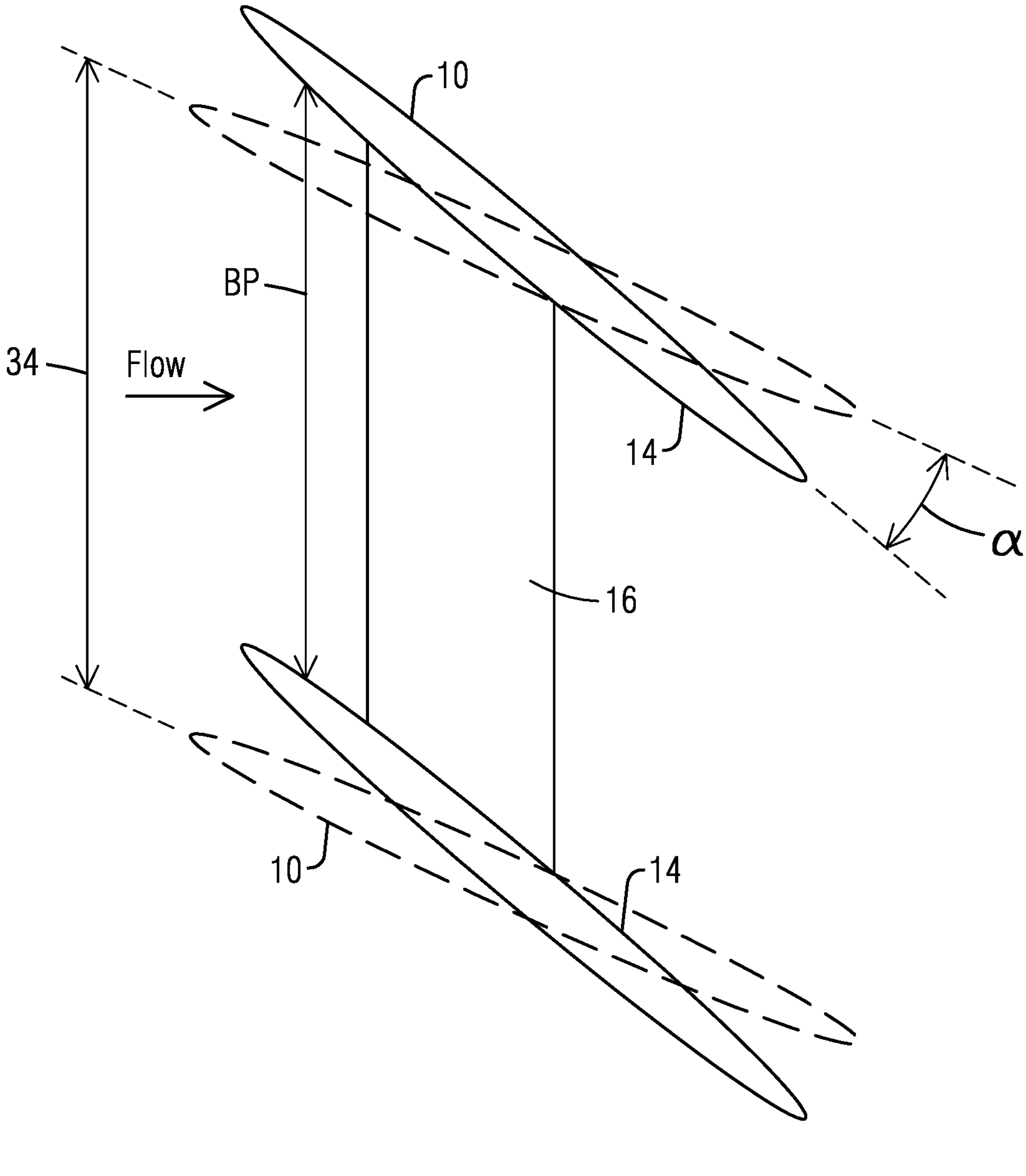


FIG. 6
View A-A

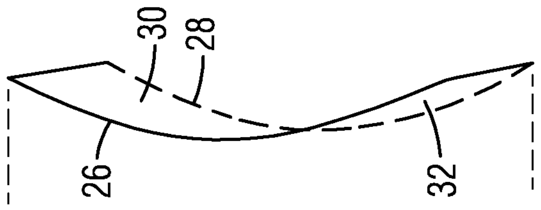
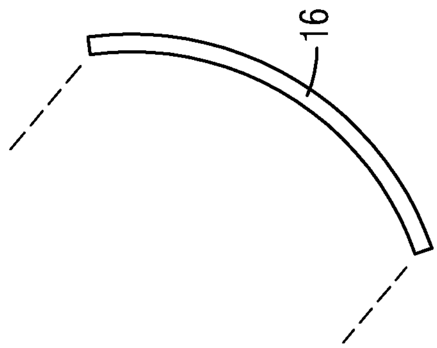


FIG. 7
View B-B



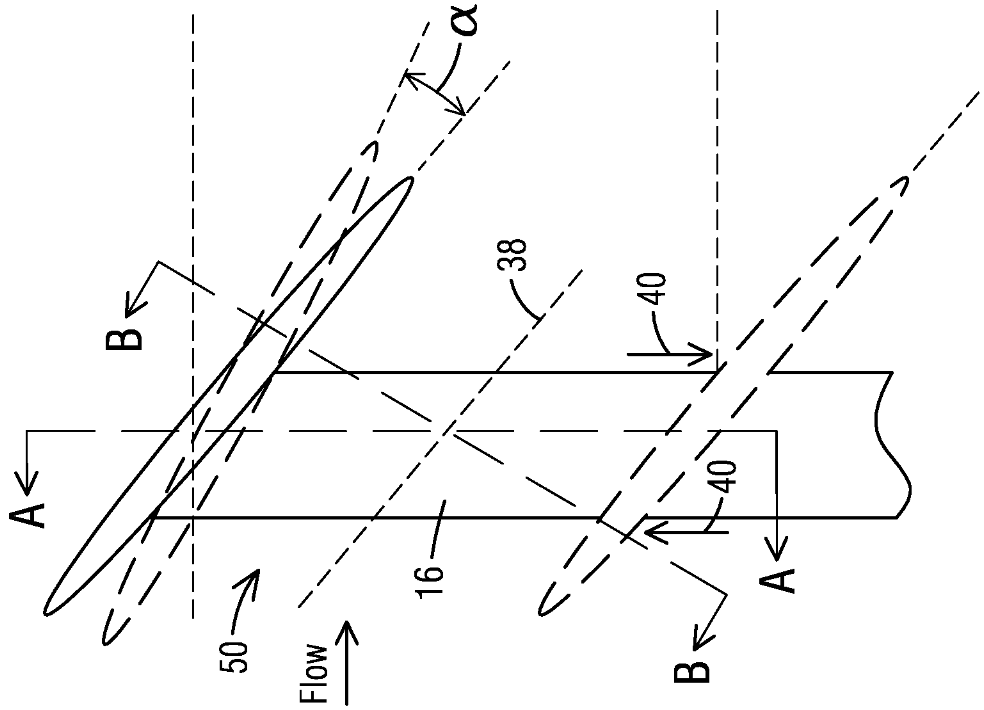


FIG. 5

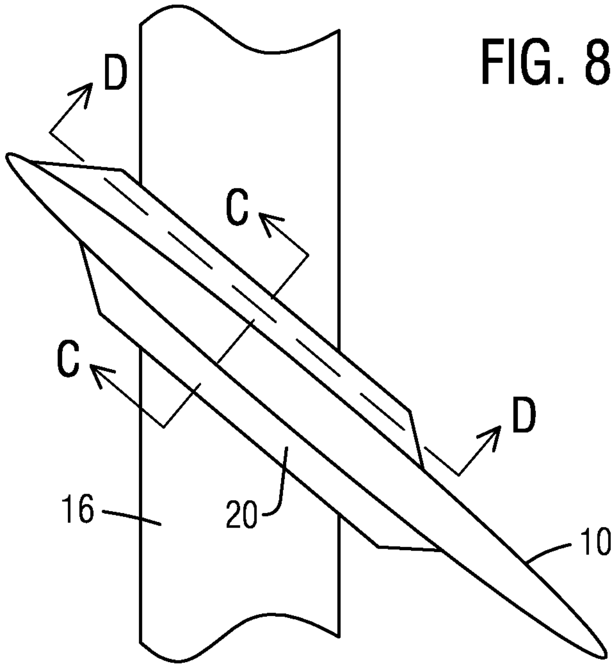
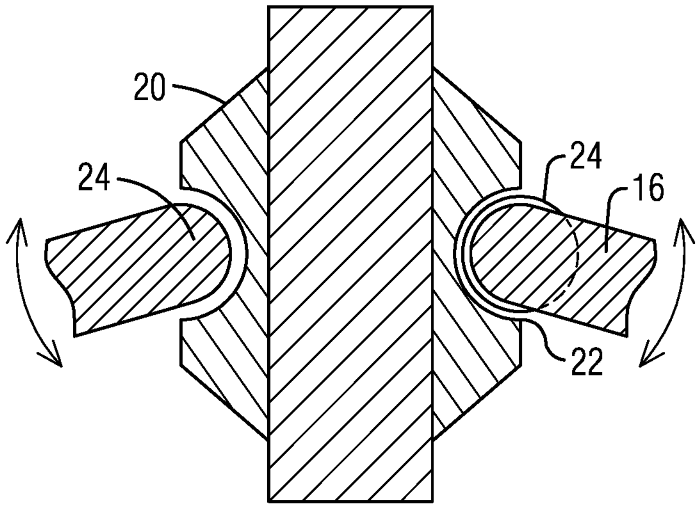


FIG. 8

FIG. 9
View C-C



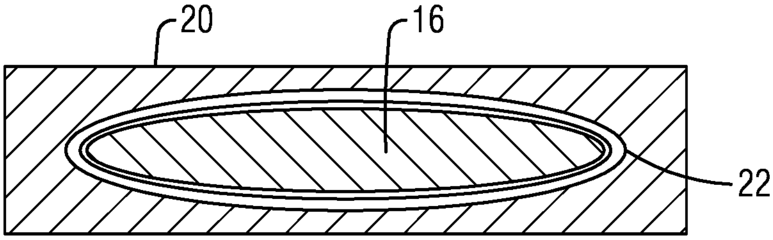


FIG. 10
View D-D

FIG. 11

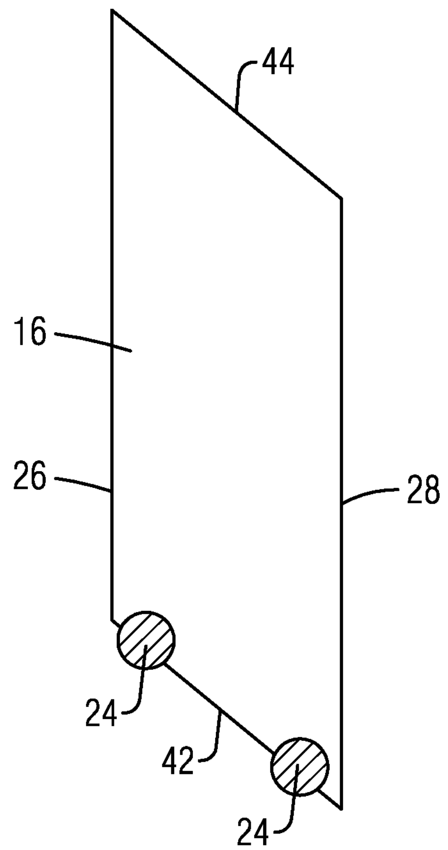


FIG. 12

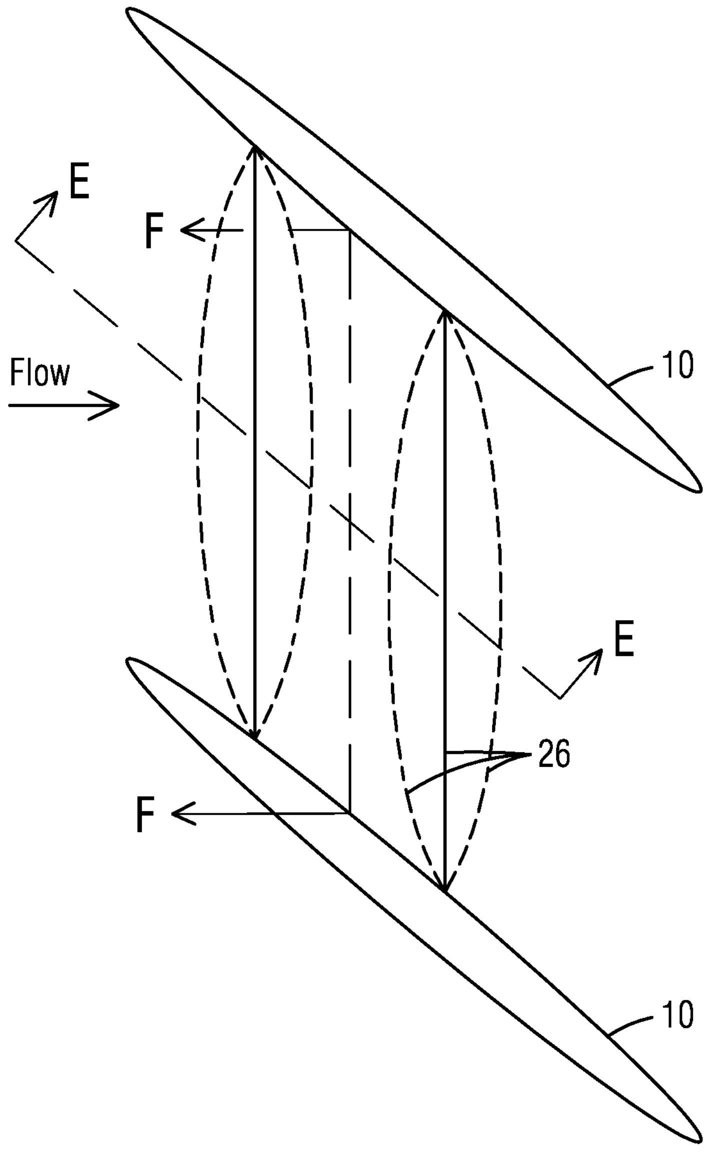


FIG. 13
View E-E

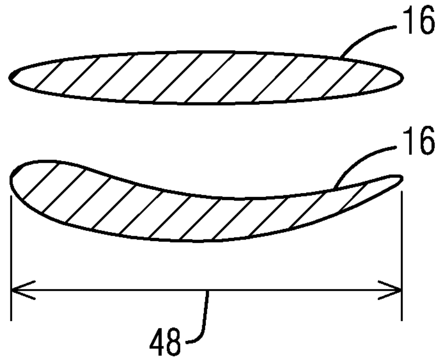


FIG. 14
View F-F

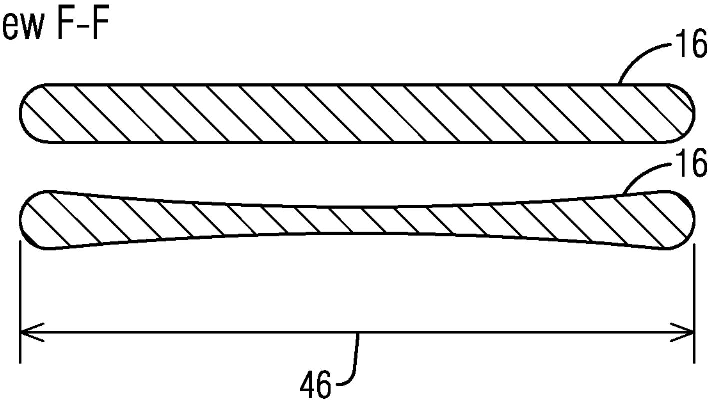
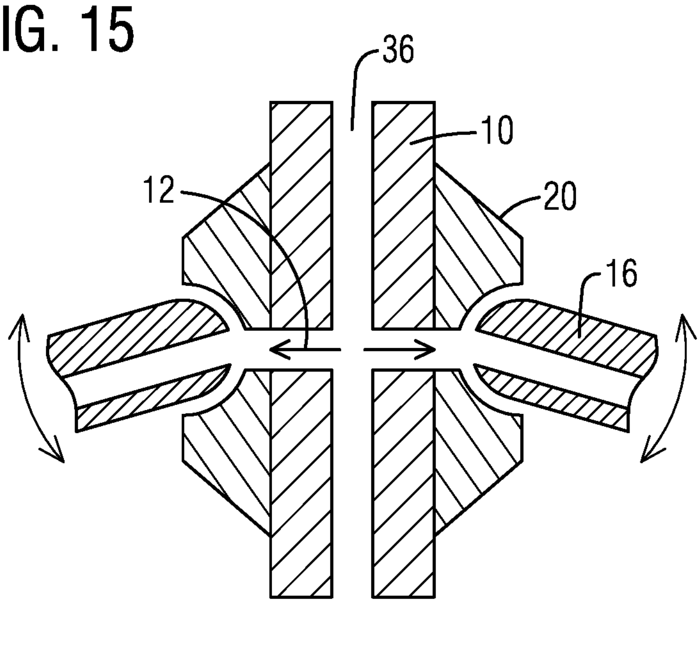


FIG. 15



INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/028533

A. CLASSIFICATION OF SUBJECT MATTER
INV. F01D5/16 F01D5/22
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F01D F04D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	JP S56 92303 A (MITSUBISHI HEAVY IND LTD) 27 July 1981 (1981-07-27) abstract; figures 3,4	1,6,9
Y	US 2011/142650 A1 (BEECK ALEXANDER R [US]) 16 June 2011 (2011-06-16) paragraphs [0025], [0031] - [0039]; figures 1-3	1-9
Y	US 3 990 813 A (IMAI TETSU ET AL) 9 November 1976 (1976-11-09) figures 1-7	1-5,9

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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
12 January 2017	24/01/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Koch, Rafael

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International application No
PCT/US2016/028533

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	US 2014/169935 A1 (SCHWARZ FREDERICK M [US] ET AL) 19 June 2014 (2014-06-19) figures 2-5	3,4
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International application No
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