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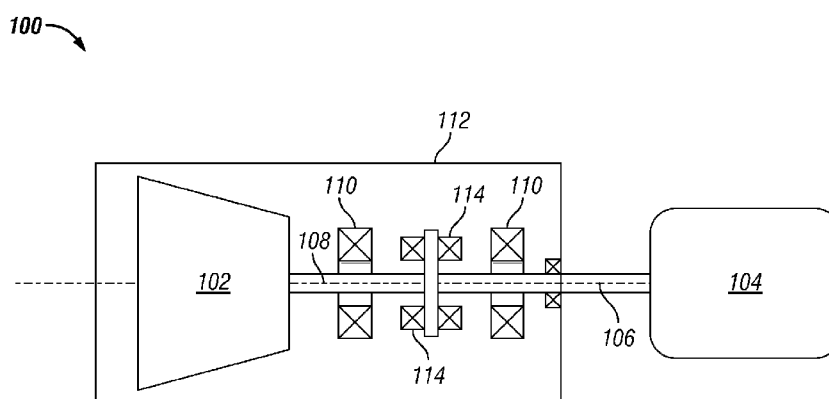
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(54) Title: MOVEABLE INLET GUIDE VANES

**FIG. 1**

(57) Abstract: An inlet guide vane assembly for a compressor is provided. The inlet guide vane assembly may include a hub configured to be disposed in an inlet of the compressor, and an inlet guide vane extending from the hub. The inlet guide vane may include a stationary section configured to be coupled with the inlet and a mobile section disposed adjacent the stationary section. The mobile section may include a rod configured to extend through an opening formed in the inlet. The inlet guide vane assembly may also include at least one biasing member disposed about the rod and configured to exert a biasing force on the mobile section to urge the mobile section radially outward.

MOVEABLE INLET GUIDE VANES

[0001] This invention was made with government support under Government Contract No. DOE-DE-FE0000493 awarded by the U.S. Department of Energy. The government has certain rights in the invention.

[0002] This application claims the benefit of U.S. Provisional Patent Application having Serial No. 62/139,068, which was filed March 27, 2015 and U.S. Utility Patent Application having Serial No. 15/075,537, which was filed March 21, 2016. The aforementioned patent applications are hereby incorporated by reference in their entirety into the present application to the extent consistent with the present application.

[0003] Compressors and systems incorporating compressors have been developed and are often utilized in a myriad of industrial processes (e.g., petroleum refineries, offshore oil production platforms, and subsea process systems). Conventional compressors may be configured to compress a process fluid by adding energy (e.g., kinetic energy) to the process fluid to transport the process fluid from a low pressure environment to a high pressure environment. The compressed process fluid discharged from the compressors may be utilized to efficiently perform work or operate one or more downstream processes. Improvements in the efficiency of conventional compressors has increased the application of the compressors at various oil production sites. Many of the oil production sites (e.g., offshore), however, may be constrained or limited in weight and space. Accordingly, there is an increased interest and demand for smaller and lighter compressors, or compact compressors. In addition to the foregoing, it is often desirable that compression stages in the compact compressors be capable of achieving higher compression ratios (e.g., 10:1 or greater) for increased production while maintaining a compact footprint. The higher compression ratios may result in a compressor where the flow discharged from an impeller has a velocity in excess of local sonic velocity.

[0004] To achieve the higher compression ratios, components (e.g., inlet guide vanes, diffuser vanes, and/or return channel vanes) of the conventional compact compressors may often be adjusted by an operator or user such that the compact compressors may operate at a "design" condition. In addition to achieving the "design" condition, an operator may need to vary or control the performance and efficiency of the compact compressors. However, the adjustment of the components may often be difficult, time-consuming, and/or require the fabrication of new components.

[0005] What is needed, then, is an improved system and method for adjusting internal components of a compact compressor to control the performance of the compact compressor.

[0006] Embodiments of the disclosure may provide an inlet guide vane assembly for a compressor. The inlet guide vane assembly may include a hub configured to be disposed in an

inlet of the compressor, and an inlet guide vane extending from the hub. The inlet guide vane may include a stationary section configured to be coupled with the inlet and a mobile section disposed adjacent the stationary section. The mobile section may include a rod configured to extend through an opening formed in the inlet. The inlet guide vane assembly may also include at least one biasing member disposed about the rod and configured to exert a biasing force on the mobile section to urge the mobile section radially outward.

[0007] Embodiments of the disclosure may also provide a compressor. The compressor may include a casing at least partially defining an impeller cavity, an impeller disposed in the impeller cavity, and an inlet coupled or integral with the casing. An inner surface of the inlet may at least partially define an inlet passageway fluidly coupled with the impeller cavity. The compressor may also include an inlet guide vane assembly. The inlet guide vane assembly may include a hub disposed in the inlet passageway, and at least one inlet guide vane extending between the inner surface and the hub. The at least one inlet guide vane may be configured to control at least one fluid property of a process fluid flowing through the inlet passageway. The inlet guide vane assembly may also include at least one biasing member disposed about a portion of the inlet guide vane. The at least one biasing member may be configured to exert a biasing force on the inlet guide vane to urge the inlet guide vane toward the inner surface of the inlet.

[0008] Embodiments of the disclosure may further provide a compression system including a driver and a compressor coupled with and configured to be driven by the driver. The compressor may include a casing and an inlet coupled with or integral with the casing. The inlet and the casing may at least partially define an inlet passageway of the compressor configured to receive a process fluid. The compressor may also include a rotary shaft disposed in the casing, an impeller coupled with the driver via the rotary shaft, and an inlet guide vane assembly. The rotary shaft may be configured to couple the compressor with the driver. The impeller may be configured to be rotated by the driver via the rotary shaft. The inlet guide vane assembly may include a hub disposed in the inlet passageway, at least one inlet guide vane extending radially between the inlet and the hub, and at least one biasing member disposed about a portion of the at least one inlet guide vane. The at least one inlet guide vane may be configured to control at least one fluid property of the process fluid flowing through the inlet passageway, and the at least one biasing member may be configured to urge the at least one inlet guide vane radially outward.

[0009] The present disclosure is best understood from the following detailed description when read with the accompanying Figures. It is emphasized that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

[0010] Figure 1 illustrates a schematic view of an exemplary compression system including a compressor, according to one or more embodiments disclosed.

[0011] Figure 2A illustrates a partial, cross-sectional view of an exemplary compressor that may be included in the compression system of Figure 1, according to one or more embodiments disclosed.

[0012] Figure 2B illustrates an enlarged view of the portion of the compressor indicated by the box labeled 2B of Figure 2A, according to one or more embodiments disclosed.

[0013] Figure 2C illustrates a partial, perspective view of the actuating assembly of the compressor of Figures 2A and 2B, according to one or more embodiments disclosed.

[0014] It is to be understood that the following disclosure describes several exemplary embodiments for implementing different features, structures, or functions of the invention. Exemplary embodiments of components, arrangements, and configurations are described below to simplify the present disclosure; however, these exemplary embodiments are provided merely as examples and are not intended to limit the scope of the invention. Additionally, the present disclosure may repeat reference numerals and/or letters in the various exemplary embodiments and across the Figures provided herein. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various exemplary embodiments and/or configurations discussed in the various Figures. Moreover, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact, and may also include embodiments in which additional features may be formed interposing the first and second features, such that the first and second features may not be in direct contact. Finally, the exemplary embodiments presented below may be combined in any combination of ways, *i.e.*, any element from one exemplary embodiment may be used in any other exemplary embodiment, without departing from the scope of the disclosure.

[0015] Additionally, certain terms are used throughout the following description and claims to refer to particular components. As one skilled in the art will appreciate, various entities may refer to the same component by different names, and as such, the naming convention for the elements described herein is not intended to limit the scope of the invention, unless otherwise specifically defined herein. Further, the naming convention used herein is not intended to distinguish between components that differ in name but not function. Further, in the following discussion and in the claims, the terms "including" and "comprising" are used in an open-ended fashion, and thus should be interpreted to mean "including, but not limited to." All numerical values in this disclosure may be exact or approximate values unless otherwise specifically stated. Accordingly, various embodiments of the disclosure may deviate from the numbers, values, and ranges disclosed herein without departing from the intended scope. Furthermore, as

it is used in the claims or specification, the term "or" is intended to encompass both exclusive and inclusive cases, *i.e.*, "A or B" is intended to be synonymous with "at least one of A and B," unless otherwise expressly specified herein.

[0016] Figure 1 illustrates a schematic view of an exemplary compression system 100, according to one or more embodiments. The compression system 100 may include, amongst other components, one or more compressors 102 (one is shown), a driver 104, and a drive shaft 106 configured to operatively couple the compressor 102 with the driver 104. The compression system 100 may be configured to compress or pressurize a process fluid. For example, as further described herein, the driver 104 may be configured to drive the compressor 102 via the drive shaft 106 to compress the process fluid. In an exemplary embodiment, the compression system 100 may have a compression ratio of at least about 6:1 or greater. For example, the compression system 100 may compress the process fluid to a compression ratio of about 6:1, about 6.1:1, about 6.2:1, about 6.3:1, about 6.4:1, about 6.5:1, about 6.6:1, about 6.7:1, about 6.8:1, about 6.9:1, about 7:1, about 7.1:1, about 7.2:1, about 7.3:1, about 7.4:1, about 7.5:1, about 7.6:1, about 7.7:1, about 7.8:1, about 7.9:1, about 8:1, about 8.1:1, about 8.2:1, about 8.3:1, about 8.4:1, about 8.5:1, about 8.6:1, about 8.7:1, about 8.8:1, about 8.9:1, about 9:1, about 9.1:1, about 9.2:1, about 9.3:1, about 9.4:1, about 9.5:1, about 9.6:1, about 9.7:1, about 9.8:1, about 9.9:1, about 10:1, about 10.1:1, about 10.2:1, about 10.3:1, about 10.4:1, about 10.5:1, about 10.6:1, about 10.7:1, about 10.8:1, about 10.9:1, about 11:1, about 11.1:1, about 11.2:1, about 11.3:1, about 11.4:1, about 11.5:1, about 11.6:1, about 11.7:1, about 11.8:1, about 11.9:1, about 12:1, about 12.1:1, about 12.2:1, about 12.3:1, about 12.4:1, about 12.5:1, about 12.6:1, about 12.7:1, about 12.8:1, about 12.9:1, about 13:1, about 13.1:1, about 13.2:1, about 13.3:1, about 13.4:1, about 13.5:1, about 13.6:1, about 13.7:1, about 13.8:1, about 13.9:1, about 14:1, or greater.

[0017] The compressor 102 may be a direct-inlet centrifugal compressor. The direct-inlet centrifugal compressor may be, for example, a version of a Dresser-Rand Pipeline Direct Inlet (PDI) centrifugal compressor manufactured by the Dresser-Rand Company of Olean, New York. The compressor 102 may have a center-hung rotor configuration or an overhung rotor configuration, as illustrated in Figure 1. In an exemplary embodiment, the compressor 102 may be an axial-inlet centrifugal compressor. In another embodiment, the compressor 102 may be a radial-inlet centrifugal compressor. As previously discussed, the compression system 100 may include one or more compressors 102. For example, the compression system 100 may include a plurality of compressors (not shown). In another example, illustrated in Figure 1, the compression system 100 may include a single compressor 102. The compressor 102 may be a supersonic compressor or a subsonic compressor. In at least one embodiment, the compression system 100 may include a plurality of compressors (not shown), and at least one

compressor of the plurality of compressors is a subsonic compressor. In another embodiment, illustrated in Figure 1, the compression system 100 includes a single compressor 102, and the single compressor 102 is a supersonic compressor.

[0018] The compressor 102 may include one or more stages (not shown). In at least one embodiment, the compressor 102 may be a single-stage compressor. In another embodiment, the compressor 102 may be a multi-stage centrifugal compressor. Each stage (not shown) of the compressor 102 may be a subsonic compressor stage or a supersonic compressor stage. In an exemplary embodiment, the compressor 102 may include a single supersonic compressor stage. In another embodiment, the compressor 102 may include a plurality of subsonic compressor stages. In yet another embodiment, the compressor 102 may include a subsonic compressor stage and a supersonic compressor stage. Any one or more stages of the compressor 102 may have a compression ratio greater than about 1:1. For example, any one or more stages of the compressor 102 may have a compression ratio of about 1.1:1, about 1.2:1, about 1.3:1, about 1.4:1, about 1.5:1, about 1.6:1, about 1.7:1, about 1.8:1, about 1.9:1, about 2:1, about 2.1:1, about 2.2:1, about 2.3:1, about 2.4:1, about 2.5:1, about 2.6:1, about 2.7:1, about 2.8:1, about 2.9:1, about 3:1, about 3.1:1, about 3.2:1, about 3.3:1, about 3.4:1, about 3.5:1, about 3.6:1, about 3.7:1, about 3.8:1, about 3.9:1, about 4:1, about 4.1:1, about 4.2:1, about 4.3:1, about 4.4:1, about 4.5:1, about 4.6:1, about 4.7:1, about 4.8:1, about 4.9:1, about 5:1, about 5.1:1, about 5.2:1, about 5.3:1, about 5.4:1, about 5.5:1, about 5.6:1, about 5.7:1, about 5.8:1, about 5.9:1, about 6:1, about 6.1:1, about 6.2:1, about 6.3:1, about 6.4:1, about 6.5:1, about 6.6:1, about 6.7:1, about 6.8:1, about 6.9:1, about 7:1, about 7.1:1, about 7.2:1, about 7.3:1, about 7.4:1, about 7.5:1, about 7.6:1, about 7.7:1, about 7.8:1, about 7.9:1, about 8.0:1, about 8.1:1, about 8.2:1, about 8.3:1, about 8.4:1, about 8.5:1, about 8.6:1, about 8.7:1, about 8.8:1, about 8.9:1, about 9:1, about 9.1:1, about 9.2:1, about 9.3:1, about 9.4:1, about 9.5:1, about 9.6:1, about 9.7:1, about 9.8:1, about 9.9:1, about 10:1, about 10.1:1, about 10.2:1, about 10.3:1, about 10.4:1, about 10.5:1, about 10.6:1, about 10.7:1, about 10.8:1, about 10.9:1, about 11:1, about 11.1:1, about 11.2:1, about 11.3:1, about 11.4:1, about 11.5:1, 11 3.6:1, about 11.7:1, about 11.8:1, about 11.9:1, about 12:1, about 12.1:1, about 12.2:1, about 12.3:1, about 12.4:1, about 12.5:1, about 12.6:1, about 12.7:1, about 12.8:1, about 12.9:1, about 13:1, about 13.1:1, about 13.2:1, about 13.3:1, about 13.4:1, about 13.5:1, about 13.6:1, about 13.7:1, about 13.8:1, about 13.9:1, about 14:1, or greater. In an exemplary embodiment, the compressor 102 may include a plurality of compressor stages, where a first stage (not shown) of the plurality of compressor stages may have a compression ratio of about 1.75:1 and a second stage (not shown) of the plurality of compressor stages may have a compression ratio of about 6.0:1.

[0019] The driver 104 may be configured to provide the drive shaft 106 with rotational energy. The drive shaft 106 may be integral or coupled with a rotary shaft 108 of the compressor 102

such that the rotational energy of the drive shaft 106 may be transmitted to the rotary shaft 108. The drive shaft 106 of the driver 104 may be coupled with the rotary shaft 108 via a gearbox (not shown) having a plurality of gears configured to transmit the rotational energy of the drive shaft 106 to the rotary shaft 108 of the compressor 102. Accordingly, the drive shaft 106 and the rotary shaft 108 may spin at the same speed, substantially similar speeds, or differing speeds and rotational directions via the gearbox. The driver 104 may be a motor, such as a permanent magnetic electric motor, and may include a stator (not shown) and a rotor (not shown). It should be appreciated, however, that other embodiments may employ other types of motors including, but not limited to, synchronous motors, induction motors, and brushed DC motors, or the like. The driver 104 may also be a hydraulic motor, an internal combustion engine, a steam turbine, a gas turbine, or any other device capable of driving or rotating the rotary shaft 108 of the compressor 102.

[0020] The compression system 100 may include one or more radial bearings 110 directly or indirectly supported by a housing 112 of the compression system 100. The radial bearings 110 may be configured to support the drive shaft 106 and/or the rotary shaft 108. The radial bearings 110 may be oil film bearings. The radial bearings 110 may also be magnetic bearings, such as active magnetic bearings, passive magnetic bearings, or the like. The compression system 100 may also include one or more axial thrust bearings 114 disposed adjacent the rotary shaft 108 and configured to control the axial movement of the rotary shaft 108. The axial thrust bearings 114 may be magnetic bearings configured to at least partially support and/or counter thrust loads or forces generated by the compressor 102.

[0021] The process fluid pressurized, circulated, contained, or otherwise utilized in the compression system 100 may be a fluid in a liquid phase, a gas phase, a supercritical state, a subcritical state, or any combination thereof. The process fluid may be a mixture, or process fluid mixture. The process fluid may include one or more high molecular weight process fluids, one or more low molecular weight process fluids, or any mixture or combination thereof. As used herein, the term "high molecular weight process fluids" refers to process fluids having a molecular weight of about 30 grams per mole (g/mol) or greater. Illustrative high molecular weight process fluids may include, but are not limited to, hydrocarbons, such as ethane, propane, butanes, pentanes, and hexanes. Illustrative high molecular weight process fluids may also include, but are not limited to, carbon dioxide (CO₂) or process fluid mixtures containing carbon dioxide. As used herein, the term "low molecular weight process fluids" refers to process fluids having a molecular weight less than about 30 g/mol. Illustrative low molecular weight process fluids may include, but are not limited to, air, hydrogen, methane, or any combination or mixtures thereof.

[0022] In an exemplary embodiment, the process fluid or the process fluid mixture may be or include carbon dioxide. The amount of carbon dioxide in the process fluid or the process fluid mixture may be at least about 80%, at least about 85%, at least about 90%, at least about 95%, at least about 96%, at least about 97%, at least about 98%, at least about 99%, or greater by volume. Utilizing carbon dioxide as the process fluid or as a component or part of the process fluid mixture in the compression system 100 may provide one or more advantages. For example, carbon dioxide may provide a readily available, inexpensive, non-toxic, and non-flammable process fluid. In another example, the relatively high working pressure of applications utilizing carbon dioxide may allow the compression system 100 incorporating carbon dioxide (e.g., as the process fluid or as part of the process fluid mixture) to be relatively more compact than compression systems incorporating other process fluids (e.g., process fluids not including carbon dioxide). Additionally, the high density and high heat capacity or volumetric heat capacity of carbon dioxide with respect to other process fluids may make carbon dioxide more "energy dense." Accordingly, a relative size of the compression system 100 and/or the components thereof may be reduced without reducing the performance of the compression system 100.

[0023] The carbon dioxide may be of any particular type, source, purity, or grade. For example, industrial grade carbon dioxide may be utilized as the process fluid without departing from the scope of the disclosure. Further, as previously discussed, the process fluids may be a mixture, or process fluid mixture. The process fluid mixture may be selected for one or more desirable properties of the process fluid mixture within the compression system 100. For example, the process fluid mixture may include a mixture of a liquid absorbent and carbon dioxide (or a process fluid containing carbon dioxide) that may enable the process fluid mixture to be compressed to a relatively higher pressure with less energy input than compressing carbon dioxide (or a process fluid containing carbon dioxide) alone.

[0024] Figure 2A illustrates a partial, cross-sectional view of an exemplary compressor 200 that may be included in the compression system 100 of Figure 1, according to one or more embodiments. Figure 2B illustrates an enlarged view of the portion of the compressor 200 indicated by the box labeled 2B of Figure 2A, according to one or more embodiments. As illustrated in Figure 2A, the compressor 200 may include a casing 202 and an inlet 204 (e.g., an axial inlet). The casing 202 and the inlet 204 may at least partially define a fluid pathway of the compressor 200 through which the process fluid may flow. The fluid pathway may include an inlet passageway 206 configured to receive the process fluid, an impeller cavity 208 fluidly coupled with the inlet passageway 206, a diffuser 210 (e.g., static diffuser) fluidly coupled with the impeller cavity 208, and a collector or volute 212 fluidly coupled with the diffuser 210. The casing 202 may be configured to support and/or protect one or more components of the

compressor 200. The casing 202 may also be configured to contain the process fluid flowing through one or more portions or components of the compressor 200.

[0025] As illustrated in Figure 2A, the compressor 200 may include an inlet guide vane assembly 214 configured to condition a process fluid flowing through the inlet passageway 206 to achieve predetermined or desired fluid properties and/or fluid flow attributes. Such fluid properties and/or fluid flow attributes may include flow pattern (e.g., swirl distribution), velocity, flow rate, pressure, temperature, and/or any suitable fluid property and fluid flow attribute to enable the compressor 200 to function as described herein. The inlet guide vane assembly 214 may include one or more inlet guide vanes 216 disposed in the inlet passageway 206 and configured to impart the one or more fluid properties and/or fluid flow attributes to the process fluid flowing through the inlet passageway 206. The inlet guide vanes 216 may also be configured to vary the one or more fluid properties and/or fluid flow attributes of the process fluid flowing through the inlet passageway 206. For example, respective portions of the inlet guide vanes 216 may be moveable (e.g., adjustable) to vary the one or more fluid properties and/or fluid flow attributes (e.g., swirl, velocity, mass flowrate, etc.) of the process fluid flowing through the inlet passageway 206.

[0026] The inlet guide vanes 216 may extend through at least a portion of the inlet passageway 206 from an inner surface 218 (i.e., inner radial surface) of the inlet 204 to an outer radial surface of a hub 220 of the inlet guide vane assembly 214. As illustrated in Figure 2B, the inner surface 218 of the inlet 204 and the inlet guide vanes 216 may at least partially define an outer radial clearance 222 therebetween, and the hub 220 and the inlet guide vanes 216 may at least partially define an inner radial clearance 224 therebetween. The inlet guide vanes 216 may be circumferentially spaced at substantially equal intervals or at varying intervals about the hub 220 of the inlet guide vane assembly 214. The inlet guide vanes 216 may be airfoil shaped, streamline shaped, or otherwise shaped and configured to at least partially impart the one or more fluid properties and/or fluid flow attributes on the process fluid flowing through the inlet passageway 206. The inlet guide vanes 216 may be configured to at least partially impart the one or more fluid properties on the process fluid while minimizing energy losses in the process fluid. It should be appreciated that each of the inlet guide vanes 216 discussed herein may include similar components, and may be similarly operated. Consequently, discussions herein regarding the components and the operation of a single inlet guide vane 216 may be equally applicable to the remaining inlet guide vanes 216.

[0027] As previously discussed, respective portions of the inlet guide vanes 216 may be moveable (e.g., adjustable) to vary the one or more fluid properties and/or fluid flow attributes (e.g., swirl, velocity, mass flowrate, etc.) of the process fluid flowing through the inlet passageway 206. In an exemplary embodiment, the inlet guide vanes 216 may be configured to

move or adjust within the inlet passageway 206, as disclosed in U.S. 8,632,302, the subject matter of which is incorporated herein to the extent consistent with the present disclosure. In another embodiment, illustrated in Figure 2B, each of the inlet guide vanes 216 may include a stationary section 226 and a mobile section 228 disposed adjacent the stationary section 226. The respective stationary sections 226 of the inlet guide vanes 216 may be coupled or integrally formed with at least a portion of the hub 220 and configured to position and/or support the hub 220 within the inlet passageway 206. The respective stationary sections 226 of the inlet guide vanes 216 may also be disposed upstream of the respective mobile sections 228. As illustrated in Figure 2B, a first end portion 230 of the stationary section 226 may form or include a leading edge of the inlet guide vane 216, and the mobile section 228 may form or include a trailing edge of the inlet guide vane 216.

[0028] The mobile section 228 of the inlet guide vane 216 may be configured to rotate or pivot about an axis 232 disposed proximal a second end portion 234 of the stationary section 226. For example, as illustrated in Figure 2B, a first end portion 236 of the mobile section 228 may be rotatably coupled with the casing 202 and the hub 220 along the axis 232. In an exemplary embodiment, one or more cylindrical projections or rods 238, 240 may extend from the mobile section 228 of the inlet guide vanes 216 to rotatably mount the mobile section 228 with the casing 202. The rods 238, 240 may be coupled or integrally formed with the mobile section 228 of the inlet guide vanes 216. As illustrated in Figure 2B, a first rod 238 may extend radially outward from the first end portion 236 of the mobile section 228, and a second rod 240 may extend radially inward from the first end portion 236 of the mobile section 228. The first rod 238 may extend through at least a portion of an opening 242 formed in the casing 202, and the second rod 236 may extend through at least a portion of an aperture 244 formed in the hub 220 to rotatably mount the inlet guide vane 216 within the inlet passageway 206.

[0029] The inlet guide vane assembly 214 may include one or more bushings or bearings (three are shown 246, 248, 250) configured to facilitate the rotation of the mobile section 228 about the axis 232. For example, as illustrated in Figure 2B, a first bearing 246 and a second bearing 248 may be disposed about the first rod 238 of the inlet guide vane 216, and a third bearing 250 may be disposed about the second rod 240 of the inlet guide vane 216. The combination of the rods 238, 240 with the bearings 246, 248, 250 may be configured to facilitate the rotation of the mobile section 228 about the axis 232. Each of the bearings 246, 248, 250 may be a sleeve bearing, a flanged bearing, a thrust bearing, or the like. For example, as illustrated in Figure 2B, the first bearing 246 and the second bearing 248 may be flanged bearings having flanges 252, and the third bearing 250 may be a sleeve bearing. In another example, the first bearing 246 and the second bearing 248 may be thrust bearings, and the third bearing 250 may be a sleeve bearing.

[0030] The inlet guide vane 216 may include one or more flanges 254 (e.g., cylindrical flanges) coupled or integrally formed with the mobile section 228 and configured to at least partially position the mobile section 228 in the inlet passageway 206 and/or control the rotation of the mobile section 228 about the axis 232. For example, as illustrated in Figure 2B, the mobile section 228 may include flanges 254 extending from the first rod 238. The flanges 254 of the mobile section 228 may be configured to engage the flanges 252 of the second bearing 248 to radially and/or axially position the mobile section 228 of the inlet guide vane 216 in the inlet passageway 206. In at least one embodiment, the first flange 254 may directly engage the flanges 252 of the second bearing 248. In another embodiment, one or more shims 256 (one is shown) may be disposed about the first rod 238. For example, as illustrated the shim 256 may be disposed about the first rod 238 between the flanges 254 of the mobile section 228 and the flanges 252 of the second bearing 248. In another example, the shim 256 may be disposed about the first rod 238 between a rotatable or pivoting member 280 and a spacer 298. The flanges 254 may also be configured to rotate within a groove formed in the casing 202 to facilitate the rotation of the mobile section 228.

[0031] The compressor 200 may include an actuating assembly 258 configured to rotate the respective mobile sections 228 of the inlet guide vanes 216 within the inlet passageway 206. Figure 2C illustrates a partial, perspective view of the actuating assembly 258 of the compressor 200 of Figures 2A and 2B, according to one or more embodiments. As illustrated in Figure 2B and further illustrated in detail in Figure 2C, the actuating assembly 258 may include an actuating member 260 rotatably disposed about a portion of the casing 202 or the inlet 204 and configured to rotate the respective mobile sections 228 of the inlet guide vanes 216 within the inlet passageway 206. As illustrated in Figure 2C, the actuating member 260 may be or include a generally annular body disposed concentrically with the casing 202 or the inlet 204 along a longitudinal axis 262 of the compressor 200 and configured to rotate about the casing 202 or the inlet 204.

[0032] As illustrated in Figure 2C, the annular body of the actuating member 260 may define a plurality of openings 264 at least partially extending therethrough from an outer radial surface 266 to an inner radial surface 268 (see Figure 2B) thereof. In an exemplary embodiment, illustrated in Figure 2C, the plurality of openings 264 may be formed as a plurality of slots. The plurality of slots 264 may be circumferentially spaced (e.g., at equally spaced intervals) about the actuating member 260. At least a portion of the slots 264 may be arcuate or curved. For example, the slots 264 may be curved between a first end portion 270 and a second end portion 272 thereof. The slots 264 may also be substantially linear between the first end portion 270 and the second end portion 272. In at least one embodiment, the first end portion 270 and the second end portion 272 of the slots 264 may be axially offset with respect to one another such

that the slots 264 may be angled or have an angular orientation with respect to the longitudinal axis 262. In another embodiment, the first end portion 270 and the second end portion 272 of the slots 264 may be axially aligned with one another. In an exemplary embodiment, illustrated in Figure 2C, the respective first end portion 270 and the respective second end portion 272 of each of the slots 264 may be axially aligned with one another.

[0033] As previously discussed, the actuating member 260 may be configured to rotate about the longitudinal axis 262 relative to the casing 202 or the inlet 204. In an exemplary embodiment, illustrated in Figure 2C, the actuating member 260 may be driven or rotated with an actuating link or rod 274 operatively coupled therewith. The actuating rod 274 may be pivotally coupled with a projection 276 extending from the outer radial surface 268 of the actuating member 260. The actuating rod 274 may also be coupled with an actuator 276 configured to actuate the actuating rod 274 and thereby rotate the annular body 260. The actuator 276 may be or include any suitable device or assembly capable of actuating the actuating rod 274 to thereby rotate the actuating member 260. Illustrative actuators may include, but are not limited to, one or more servos, motors, hydraulic cylinders, or the like, or any combination thereof. In another embodiment, the actuating member 260 may be driven or rotated via one or more gears (not shown). For example, the annular body of the actuating member 260 may define a plurality of teeth (not shown) at least partially extending along the outer radial surface 268 thereof, and the plurality of teeth may be configured to engage with corresponding teeth of the gear (not shown). Accordingly, the gear may be driven or rotated to correspondingly rotate the actuating member 260. Exemplary gears may include, but are not limited to, spur gears, worm gears, bevel gears, helical gears, or the like, or any combination thereof.

[0034] As previously discussed, the actuating member 260 may be configured to rotate the mobile section 228 of the inlet guide vanes 216. As illustrated in Figures 2B and 2C, the actuating member 260 may be configured to rotate the mobile section 228 of the inlet guide vanes 216 via a system of linkages 278. The system of linkages 278 may include a plurality of rotatable or pivoting members 280 operatively coupled with the actuating member 260 and the mobile section 228 of the inlet guide vanes 216. As illustrated in Figure 2B, a first end portion 282 of the pivoting member 280 may be coupled (e.g., slidably coupled) with the first rod 238 of the mobile section 228. The first end portion 282 of the pivoting members 280 may be coupled with the first rods 238 via one or more mechanical fasteners 284. The first end portion 282 of the pivoting members 280 may also be axially constrained on the first rods 238 via the one or more mechanical fasteners 284. Illustrative mechanical fasteners may include, but are not limited to, one or more bolts, nuts, and/or any other mechanical fasteners known in the art. For example, as illustrated in Figure 2B, a nut may be threaded on the first rod 238 to couple the

pivoting member 280 with the first rod 238. The pivoting member 280 may also be torsionally coupled with the first rod 238. For example, the pivoting member 280 may be torsionally coupled with the first rod 238 via a keyway, a spline, a polygon, or any other torsional coupling method known in the art. In at least one embodiment, a second end portion 288 of the pivoting member 280 may include a projection 286 configured to be slidably disposed in the respective slot 264 of the actuating member 260. The projection 286 may extend from or be coupled with the second end portion 288 of the pivoting member 280. In another embodiment, the second end portion 288 of the pivoting member 280 may be coupled with the actuating member 260 via actuating or pivoting links. For example, the second end portion 288 of the pivoting member 280 may be coupled with the actuating member 260 via an actuating link with spherical ends (not shown), where a first spherical end and a second spherical end may be coupled with the second end portion 288 of the pivoting member 280 and the actuating member 260, respectively.

[0035] As illustrated in Figure 2B, the inlet guide vane assembly 214 may include one or more biasing members 290 (four are shown) configured to apply a biasing load or preload to the mobile section 228 of the inlet guide vanes 216 to at least partially hold or urge the mobile section 228. The one or more biasing members 290 may be configured to apply the biasing load or preload to at least partially hold or urge the mobile section 228 radially outward or radially inward. For example, the biasing members 290 may be disposed about the second rod 240 adjacent the third bearing 250. In another example, the biasing members 290 may be disposed about the first rod 238 between the first and second bearings 246, 248. In yet another example, the biasing members 290 may be disposed about the first rod 238 and the second rod 240. In yet another example, illustrated in Figure 2B, the biasing members 290 may be disposed about the first rod 238 between the pivoting member 280 and the flange 252 of the first bearing 246. As further illustrated in Figure 2B, the casing 202 may define a recess 292 configured to receive the biasing members 290. The biasing members 290 may be disposed in the recess 292 to apply or exert a biasing load to the mechanical fastener 284 via the pivoting member 280, as indicated by arrow 294, to thereby urge the mobile section 228 of the inlet guide vanes 216 radially outward. The mobile section 228 of the inlet guide vanes 216 may be urged radially outward against one or more of the flanges 252. The biasing members 290 may also apply or exert a biasing load to the mobile section 228 of the inlet guide vanes 216 via the bearings 246, 248, as indicated by arrow 296, to thereby urge the mobile section 228 of the inlet guide vanes 216 radially outward. The biasing members 290 may be disposed such that the biasing load urges the mobile section 228 radially inward.

[0036] In an exemplary embodiment, illustrated in Figure 2B, the biasing members 290 may be Belleville washers (four are shown). In another embodiment, the biasing members 290 may

include one or more Belleville washers and/or one or more springs (e.g., leaf springs, coil springs, wave-springs, elastomeric components, *etc.*). An overall spring constant of the biasing members 290 may be varied (*i.e.*, increased or decreased) to optimize the biasing forces 294, 296. For example, the number of biasing members 290 may be increased or decreased to correspondingly increase or decrease the biasing forces 294, 296. In another example, the orientation or stacking direction of the biasing members 290 (e.g., Belleville washers) may increase or decrease the biasing forces 294, 296. The orientation or stacking direction of the biasing members 290 (e.g., Belleville washers) may also vary the deflection of the biasing members 290.

[0037] The biasing members 290 may exert the biasing forces 294, 296 on the pivoting member 280 and/or the bearings 246, 248, 250 directly or indirectly. For example, the biasing members 290 may directly engage the pivoting member 280 and/or the first bearing 246 to apply the biasing forces 294, 296 thereto. In another example, one or more spacers 298 (two are shown) may be interposed between the biasing members 290 and the pivoting members 280 and/or the first bearing 246 such that the biasing members 290 may indirectly engage the pivoting members 280 and/or the first bearing 246 via the spacers 298. The spacers 298 may be configured to facilitate the alignment of the biasing members 290 and/or adjust the load applied to the mobile section 228 of the inlet guide vanes 216.

[0038] As previously discussed, the biasing members 290 may be configured to apply the biasing loads 294, 296 or preload to the mobile section 228 of the inlet guide vanes 216 to at least partially hold or urge the mobile section 228 radially outward or radially inward. The biasing members 290 may also be configured to reduce unintentional motions or deflections of the mobile section 228 of the inlet guide vanes 216. For example, during one or more modes of operating the compressor 200, unintentional forces (e.g., vibrational forces, unsteady fluid dynamic forces, *etc.*) may be exerted on the mobile section 228 of the inlet guide vanes 216 to thereby cause unintentional motions (e.g., fluttering, vibrational motion, rotational motion, axial motion, and/or radial motion) of the mobile section 228. The biasing loads 294, 296 applied by the biasing members 290 may increase frictional forces between the mobile section 228 of the inlet guide vanes 216 and one or more adjacent components (e.g., the casing 202, the spacers 298, the bearings 246, 248, 280, *etc.*) to counter or resist the unintentional forces and thereby reduce the unintentional motions of the mobile section 228 of the inlet guide vanes 216. The increased frictional forces may advantageously increase frictional damping to thereby minimize unintentional motion of the mobile section 228. The biasing members 290 may also be configured to maintain clearances about the inlet guide vanes 216. For example, the biasing members 290 may be configured to urge the mobile section 228 of the inlet guide vanes 216

radially outward or radially inward to maintain the outer radial clearance 222 and/or the inner radial clearance 224.

[0039] Referring back to Figure 2A, the compressor 200 may include an impeller 300 disposed in the impeller cavity 208. The impeller 300 may have a hub 302 and a plurality of blades 304 extending from the hub 302. The impeller 300 may be an open or "unshrouded" impeller. The impeller 300 may be configured to rotate about the longitudinal axis 262 of the compressor 200 to increase the velocity of the process fluid flowing therethrough. For example, the hub 302 of the impeller 300 may be coupled with the rotary shaft 108, and the impeller 300 may be driven or rotated by the driver 104 (see Figure 1) via the rotary shaft 108 and the drive shaft 106. The rotation of the impeller 300 may draw the process fluid into the compressor 200 via the inlet passageway 206. The rotation of the impeller 300 may further draw the process fluid to and through the impeller 300 and accelerate the process fluid to a tip 306 (see Figure 2B) of the impeller 300, thereby increasing the velocity of the process fluid. The plurality of blades 304 may be configured to impart kinetic energy to the process fluid to raise the velocity of the process fluid and direct the process fluid from the impeller 300 to the diffuser 210 fluidly coupled therewith. The diffuser 210 may be configured to convert kinetic energy of the process fluid from the impeller 300 into increased static pressure.

[0040] In one or more embodiments, the process fluid at the tip 306 of the impeller 300 may be subsonic and have an absolute Mach number less than one. For example, the process fluid at the tip 306 of the impeller 300 may have an absolute Mach number less than 1, less than 0.9, less than 0.8, less than 0.7, less than 0.6, less than 0.5, less than 0.4, less than 0.3, less than 0.2, or less than 0.1. Accordingly, in such embodiments, the compressors 102, 200 discussed herein may be "subsonic," as the impeller 300 may be configured to rotate about the longitudinal axis 262 at a speed sufficient to provide the process fluid at the tip 306 thereof with an absolute Mach number of less than one.

[0041] In one or more embodiments, the process fluid at the tip 306 of the impeller 300 may be supersonic and have an absolute Mach number of one or greater. For example, the process fluid at the tip 306 of the impeller 300 may have an absolute Mach number of at least 1, at least 1.1, at least 1.2, at least 1.3, at least 1.4, or at least 1.5. Accordingly, in such embodiments, the compressors 102, 200 discussed herein are said to be "supersonic," as the impeller 300 may be configured to rotate about the longitudinal axis 262 at a speed sufficient to provide the process fluid at the tip 306 thereof with an absolute Mach number of one or greater or with a fluid velocity greater than the speed of sound. In a supersonic compressor or a stage thereof, the rotational or tip speed of the impeller 300 may be about 500 meters per second (m/s) or greater. For example, the tip speed of the impeller 300 may be about 510 m/s, about 520 m/s, about 530 m/s, about 540 m/s, about 550 m/s, about 560 m/s, or greater.

[0042] As illustrated in Figures 2A and 2B, the compressor 200 may include a balance piston 308 configured to balance axial thrust generated by the impeller 300 during one or more modes of operating the compressor 200. In at least one embodiment, the balance piston 308 and the impeller 300 may be separate components. For example, the balance piston 308 and the impeller 300 may be separate annular components coupled with one another. In another embodiment, illustrated in Figures 2A and 2B, the balance piston 308 may be integral with the impeller 300, such that the balance piston 308 and the impeller 300 may be formed from a single or unitary annular piece.

[0043] The compressor 200 may include a shroud 310 disposed proximal the impeller 300. For example, the shroud 310 may be disposed adjacent the plurality of blades 304 of the impeller 300. As further illustrated in Figure 2B, the shroud 310 may extend annularly about the impeller 300 such that an inner surface 312 thereof may be disposed adjacent or proximal the plurality of blades 304 of the impeller 300. During one or more modes of operating the compressor, illustrated in Figure 2B, the inner surface 312 of the shroud 312 and the impeller 300 may define an impeller clearance (not shown) therebetween.

[0044] In an exemplary operation of the compressor 200, with continued reference to Figures 2A and 2B, the driver 104 (see Figure 1) may drive the compressor 200 from rest to the steady state mode of operation by accelerating or rotating the rotary shaft 108 (via the drive shaft 106), the impeller 300, and the balance piston 308 coupled therewith. The impeller 300 and the balance piston 308 may rotate about the longitudinal axis 262. The acceleration and/or rotation of the impeller 300 may draw the process fluid into the compressor 200 via the inlet passageway 206. The inlet guide vanes 216 disposed in the inlet passageway 206 may induce one or more fluid properties (e.g., swirl) to the process fluid flowing therethrough. The rotation of the impeller 300 may further draw the process fluid from the inlet passageway 206 to and through the rotating impeller 300, and urge the process fluid to the tip 306 of the impeller 300, thereby increasing the velocity (e.g., kinetic energy) thereof. The process fluid from the impeller 300 may be discharged from the tip 306 thereof and directed to the diffuser 210 fluidly coupled therewith. The diffuser 210 may receive the process fluid from the impeller 300 and convert the velocity (e.g., kinetic energy) of the process fluid from the impeller 300 to potential energy (e.g., increased static pressure). The diffuser 210 may direct the process fluid downstream to the volute 212 fluidly coupled therewith. The volute 212 may collect the process fluid and deliver the process fluid to one or more downstream pipes and/or process components (not shown). The volute 212 may also be configured to increase the static pressure of the process fluid flowing therethrough by converting the kinetic energy of the process fluid to increased static pressure.

[0045] As previously discussed, the biasing members 290 may be configured to apply the biasing loads 294, 296 to the mobile section 228 of the inlet guide vanes 216, and reduce unintentional motions or deflections of the mobile section 228. For example, the process fluid drawn into the compressor 200 via the inlet passageway 206 may be turbulent, or may exert unintentional forces (e.g., vibrational forces, fluid dynamic forces, etc.) on the on the mobile section to thereby cause unintentional motions or deflections (e.g., fluttering, vibrational motion, rotational motion, axial motion, and/or radial motion) of the mobile section 228. The biasing loads 294, 296 applied by the biasing members 290 may increase frictional forces between the mobile section 228 of the inlet guide vanes 216 and one or more adjacent components (e.g., the casing 202, the bearings 246, 248, 280, etc.) to counter or resist the unintentional forces and thereby reduce the unintentional motions of the mobile section 228 of the inlet guide vanes 216. The biasing members 290 may also be configured to maintain clearances about the inlet guide vanes 216. For example, the biasing members 290 may be configured to urge the mobile section 228 of the inlet guide vanes 216 radially outward or radially inward to maintain the outer radial clearance 222 and/or the inner radial clearance 224.

[0046] The foregoing has outlined features of several embodiments so that those skilled in the art may better understand the present disclosure. Those skilled in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions, and alterations herein without departing from the spirit and scope of the present disclosure.

Claims

We claim:

1. An inlet guide vane assembly for a compressor, comprising:
a hub configured to be disposed in an inlet of the compressor;
an inlet guide vane extending from the hub and comprising:
a stationary section configured to be coupled with the inlet; and
a mobile section disposed adjacent the stationary section and comprising a rod configured to extend through an opening formed in the inlet; and
at least one biasing member disposed about the rod and configured to exert a biasing force on the mobile section to urge the mobile section radially outward.
2. The inlet guide vane assembly of claim 1, wherein the mobile section is configured to rotate about an axis of the rod to vary one or more fluid properties of a process fluid flowing through the inlet of the compressor.
3. The inlet guide vane assembly of claim 2, further comprising at least one bearing disposed about the rod and configured to facilitate the rotation of the mobile section about the axis.
4. The inlet guide vane assembly of claim 3, wherein the at least one bearing is a flanged bearing, and the biasing member is further disposed between the flanged bearing and a rotatable member coupled with the rod.
5. The inlet guide vane assembly of claim 3, further comprising a spacer disposed adjacent the at least one biasing member and configured to facilitate the alignment of the at least one biasing member.
6. The inlet guide vane assembly of claim 4, further comprising an actuating member operably coupled with the rotatable member, the actuating member configured to rotate about the inlet to actuate the rotatable member and the mobile section coupled therewith.
7. The inlet guide vane assembly of claim 6, further comprising an actuator operatively coupled with the actuating member via an actuating link, the actuator configured to rotate the actuating member about the inlet via the actuating link.

8. The inlet guide vane assembly of claim 1, wherein the at least one biasing member is a Belleville washer.
9. A compressor, comprising:
 - a casing at least partially defining an impeller cavity;
 - an impeller disposed in the impeller cavity;
 - an inlet coupled with or integral with the casing, an inner surface of the inlet at least partially defining an inlet passageway fluidly coupled with the impeller cavity; and
 - an inlet guide vane assembly comprising:
 - a hub disposed in the inlet passageway;
 - at least one inlet guide vane extending between the inner surface and the hub, and configured to control at least one fluid property of a process fluid flowing through the inlet passageway; and
 - at least one biasing member disposed about a portion of the inlet guide vane and configured to exert a biasing force on the inlet guide vane to urge the inlet guide vane toward the inner surface of the inlet.
10. The compressor of claim 9, wherein the casing further defines a diffuser fluidly coupled with the impeller cavity, and a volute fluidly coupled with the diffuser.
11. The compressor of claim 9, wherein the process fluid flowing through the inlet passageway comprises carbon dioxide.
12. The compressor of claim 9, further comprising a rotary shaft disposed in the casing and configured to be driven by a driver, wherein the impeller is coupled with and configured to be driven by the rotary shaft.
13. The compressor of claim 12, wherein the impeller is configured to receive the process fluid from the inlet passageway and discharge the process fluid to a diffuser at an absolute Mach number of about 1.3 or greater.
14. The compressor of claim 9, wherein the compressor is configured to compress the process fluid to a compression ratio of at least about 10.1.
15. The compressor of claim 9, wherein the at least one biasing member is a Belleville washer.

16. The compressor of claim 9, wherein the inlet guide vane comprises:
a stationary section coupled with the inlet and the hub; and
a mobile section disposable adjacent the stationary section, the mobile section comprising a rod extending through an opening formed in the inlet.
17. The compressor of claim 16, further comprising at least one flanged bearing disposed about the rod and configured to facilitate the rotation of the mobile section within the opening of the inlet.
18. A compression system, comprising:
a driver; and
a compressor coupled with and configured to be driven by the driver, the compressor comprising:
a casing;
an inlet coupled with or integral with the casing, the inlet and the casing at least partially defining an inlet passageway of the compressor, the inlet passageway configured to receive a process fluid;
a rotary shaft disposed in the casing and configured to couple the compressor with the driver;
an impeller coupled with and configured to be rotated by the driver via the rotary shaft; and
an inlet guide vane assembly comprising:
a hub disposed in the inlet passageway;
at least one inlet guide vane extending radially between the inlet and the hub, and configured to control at least one fluid property of the process fluid flowing through the inlet passageway;
at least one biasing member disposed about a portion of the at least one inlet guide vane and configured to urge the at least one inlet guide vane radially outward.
19. The compression system of claim 18, wherein the impeller is configured to discharge the process fluid to the diffuser at an absolute Mach number of about 1.3 or greater, and wherein the compressor is configured to provide a compression ratio of at least about 10:1.

20. The compression system of claim 19, wherein the at least one biasing member is a Belleville washer.

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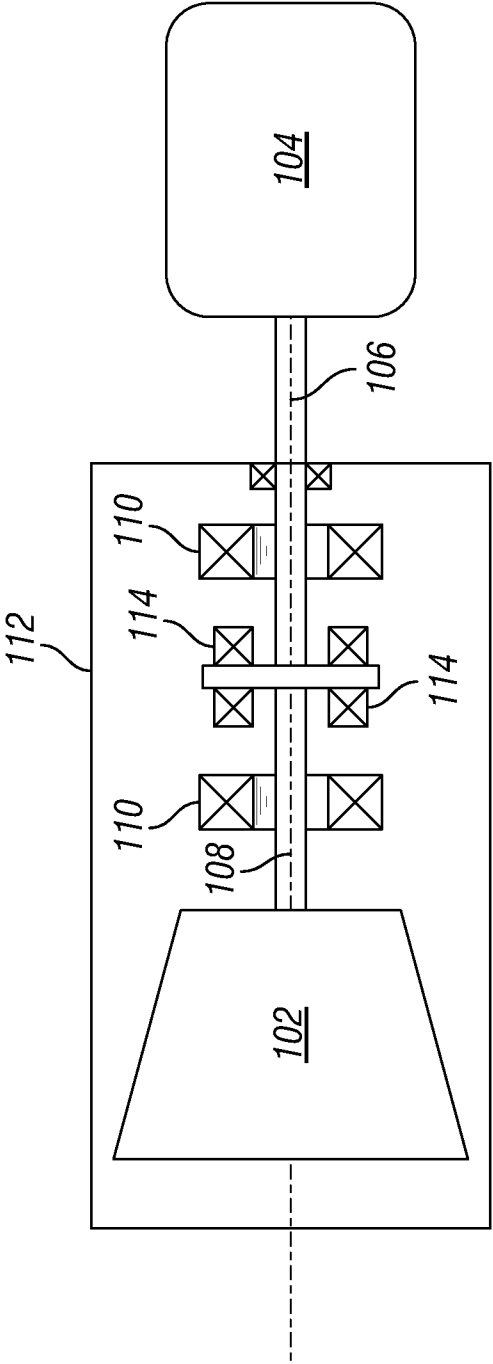


FIG. 1

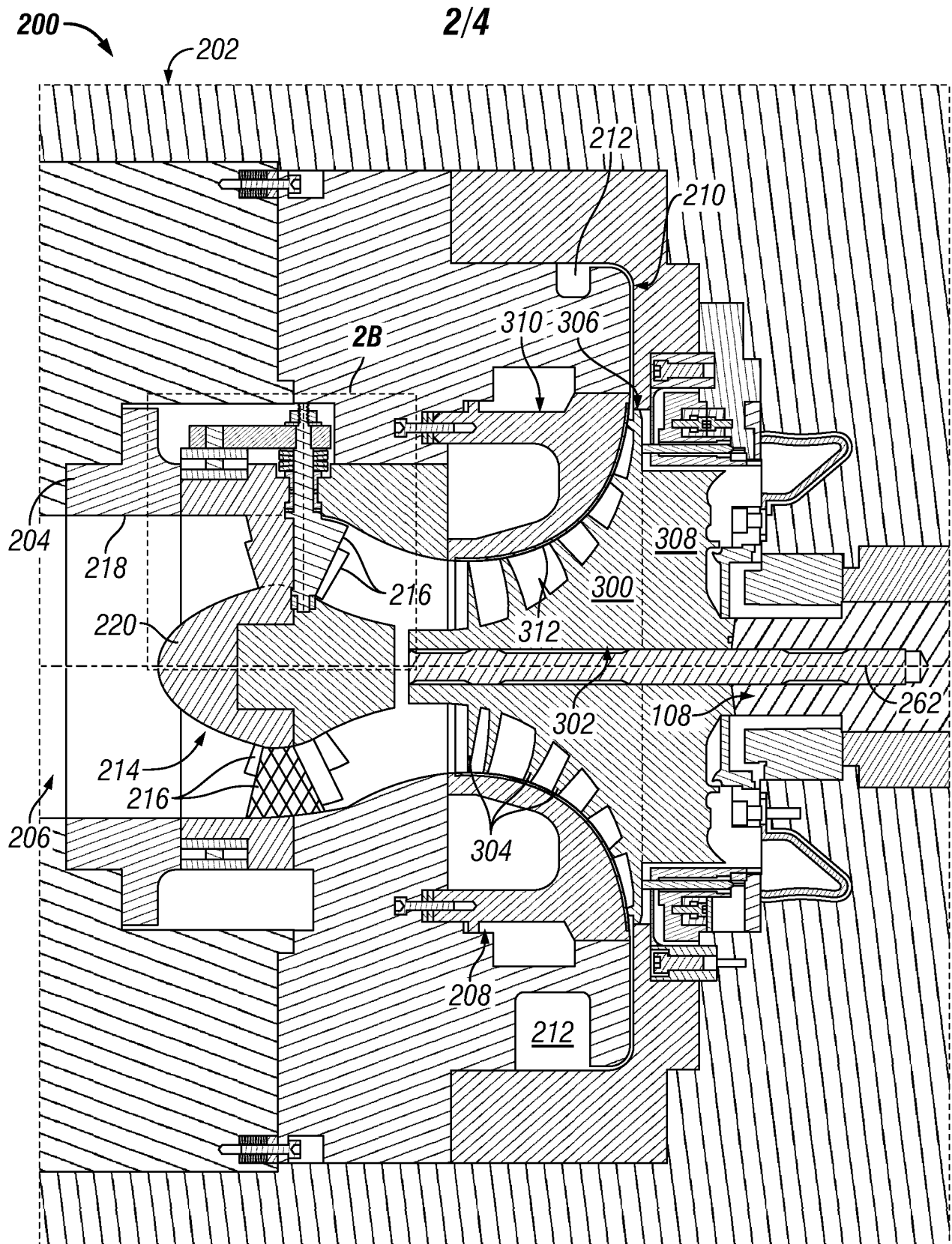


FIG. 2A

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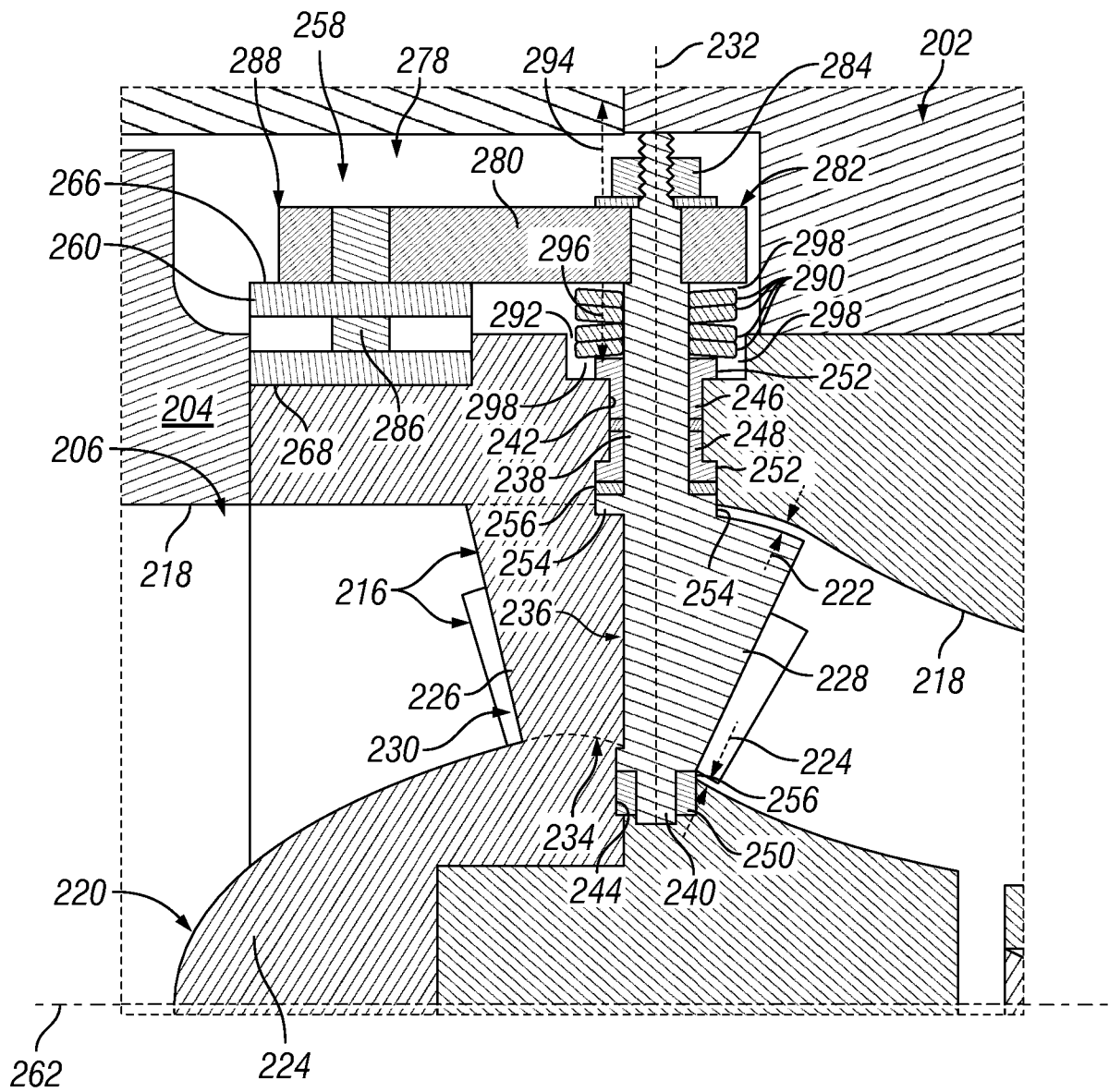


FIG. 2B

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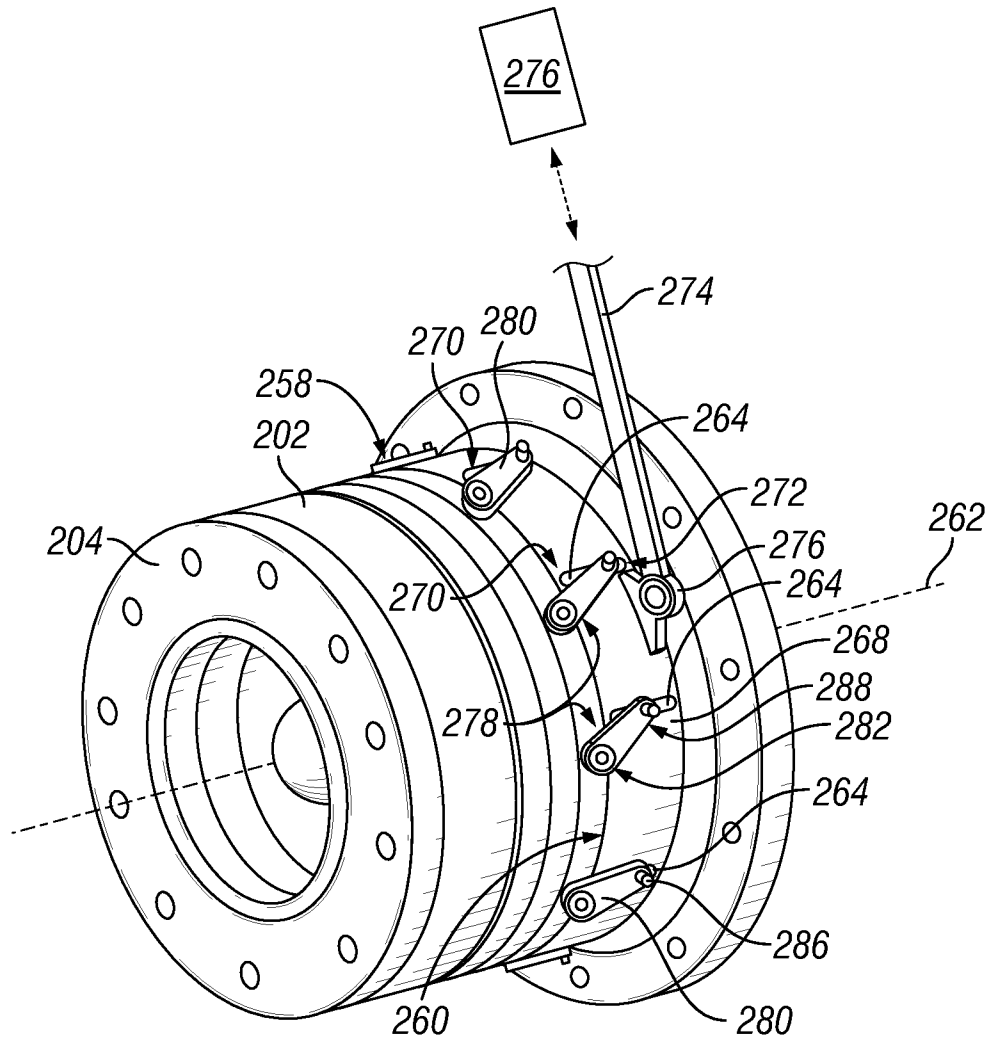


FIG. 2C

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/024014**A. CLASSIFICATION OF SUBJECT MATTER****F04D 29/30(2006.01)i, F04D 17/08(2006.01)i, F04D 29/46(2006.01)i**

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)

F04D 29/30; F03B 3/18; F01D 9/02; F04D 29/42; F04D 29/44; F01D 17/16; F03B 3/14; F01D 1/02; F04D 17/08; F04D 29/46

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: compressor, guide vane, inlet, hub, stationary section, mobile section, biasing, impeller, casing, driver, rotary shaft, bearing, actuating member

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 61-250302 A (TOSHIBA CORP.) 07 November 1986 See page 2, upper right column, line 12 - page 2, lower right column, line 7, and figures 1-6.	1-20
Y	US 4657481 A (MOWILL et al.) 14 April 1987 See abstract, column 4, lines 43-68, column 6, lines 1-22, column 7, lines 31-61, column 8, lines 9-66, and figures 1a, 3a.	1-20
Y	US 2014-0341706 A1 (LARDY et al.) 20 November 2014 See abstract, paragraphs [0017]-[0023], [0029]-[0030], [0036], [0039]-[0040], and figures 1-2.	9-20
A	JP 58-093903 A (HITACHI LTD.) 03 June 1983 See pages 1-3, and figures 1-7.	1-20
A	US 2013-0052003 A1 (RODRIGUEZ et al.) 28 February 2013 See abstract, paragraphs [0024]-[0031], and figures 1-3.	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

18 July 2016 (18.07.2016)

Date of mailing of the international search report

18 July 2016 (18.07.2016)

Name and mailing address of the ISA/KR

International Application Division

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/024014

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 61-250302 A	07/11/1986	None	
US 4657481 A	14/04/1987	EP 0161559 A3 JP 61-040499 A NO 851985 A	13/05/1987 26/02/1986 18/11/1985
US 2014-0341706 A1	20/11/2014	None	
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US 2013-0052003 A1	28/02/2013	US 8894361 B2	25/11/2014