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(54) **RADIAL DIFFUSER VANE FOR CENTRIFUGAL COMPRESSORS**

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USPC **415/191**; 29/889.2; 415/207

(57) **ABSTRACT**

A turbo machine comprising a rotor assembly comprising at least one impeller, a bearing connected to the rotor assembly, wherein the bearing is configured to rotatably support the rotor assembly, and a stator comprising at least one diffuser connected to an exit portion of the at least one impeller, wherein the at least one diffuser comprises a plurality of diffuser vanes, wherein at least one of the plurality of diffuser vanes comprising a camber line defined by a function comprising an inflection point.

FIG. 1A
BACKGROUND ART

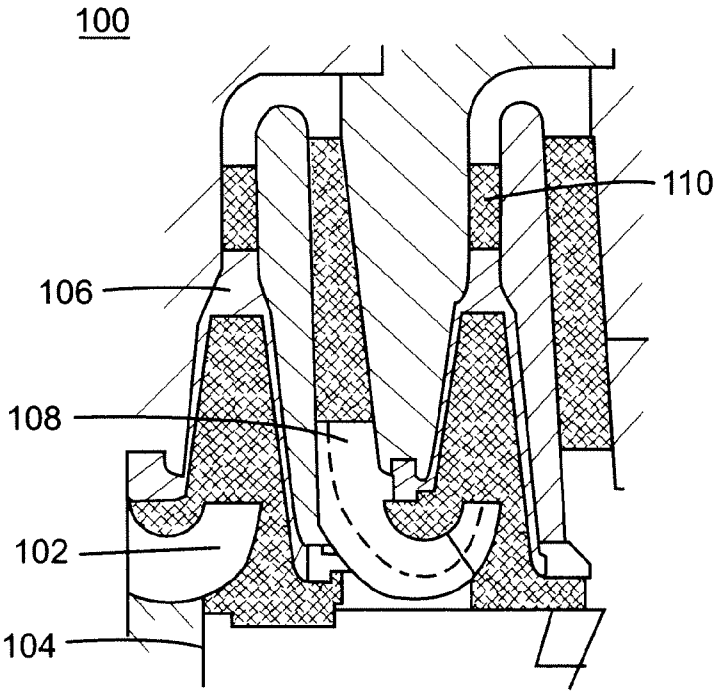


FIG. 1B
BACKGROUND ART

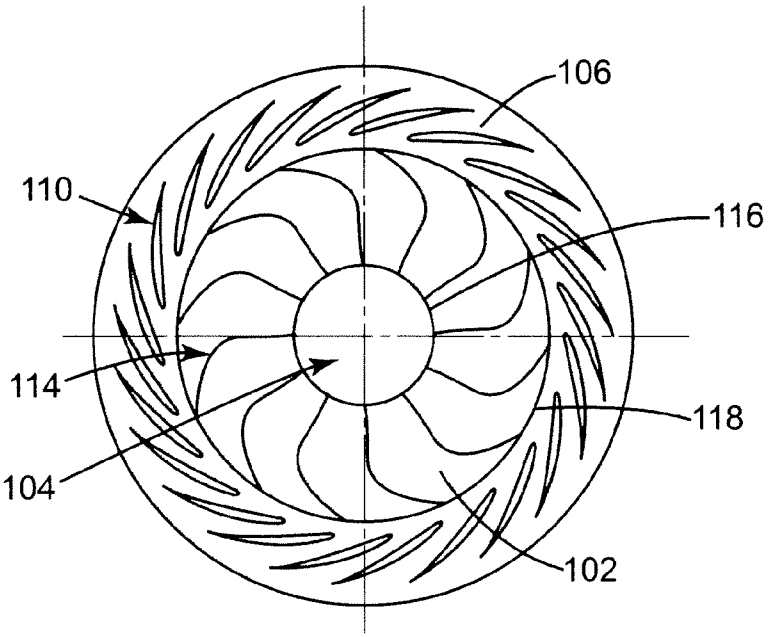


FIG. 1C
BACKGROUND ART

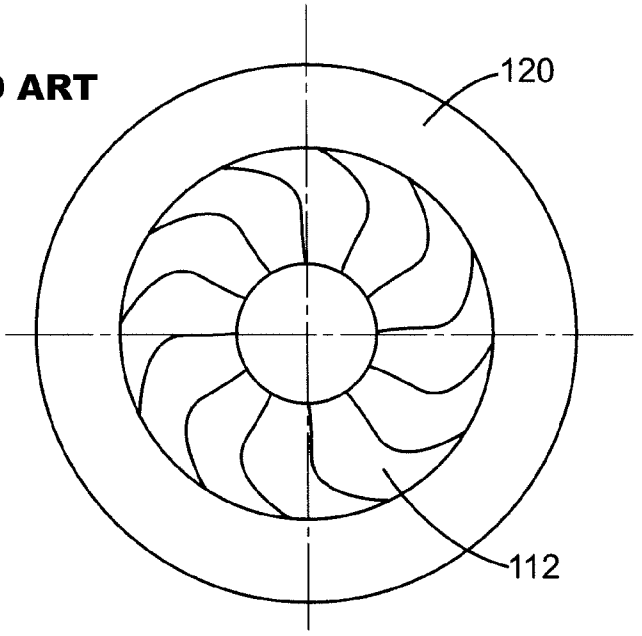


FIG. 1D
BACKGROUND ART

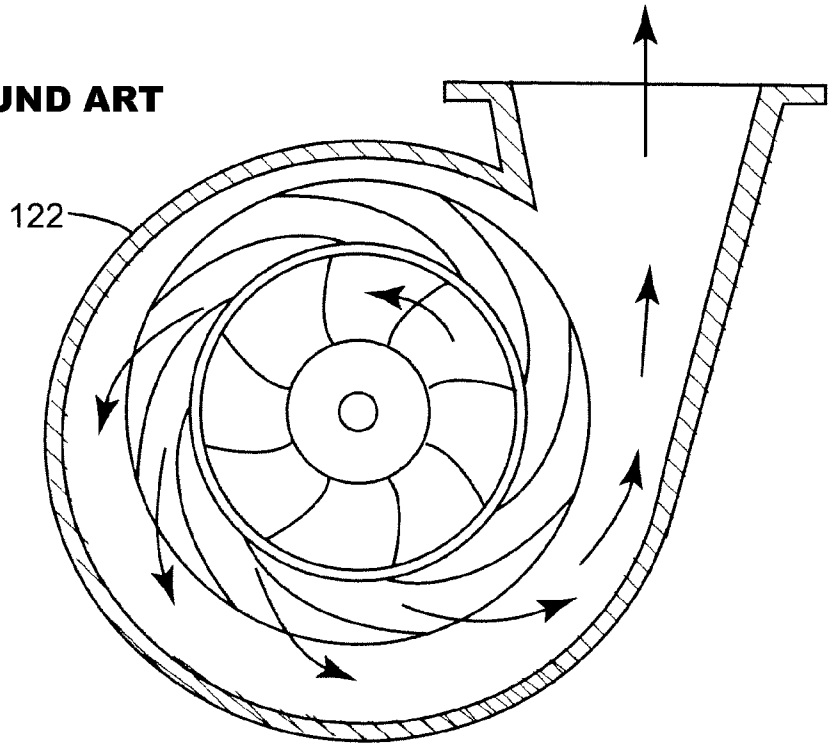


FIG. 2A
BACKGROUND ART

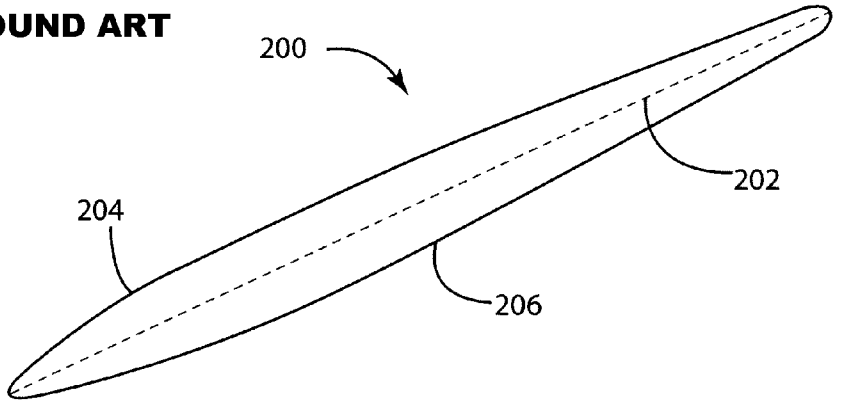


FIG. 2B
BACKGROUND ART

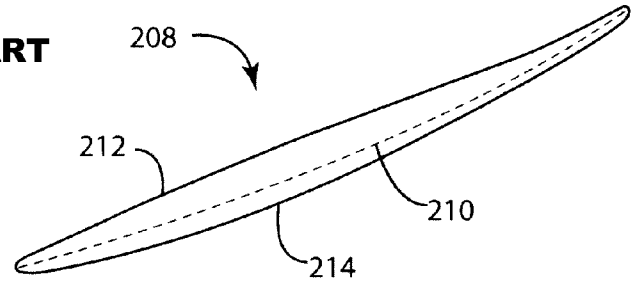


FIG. 3

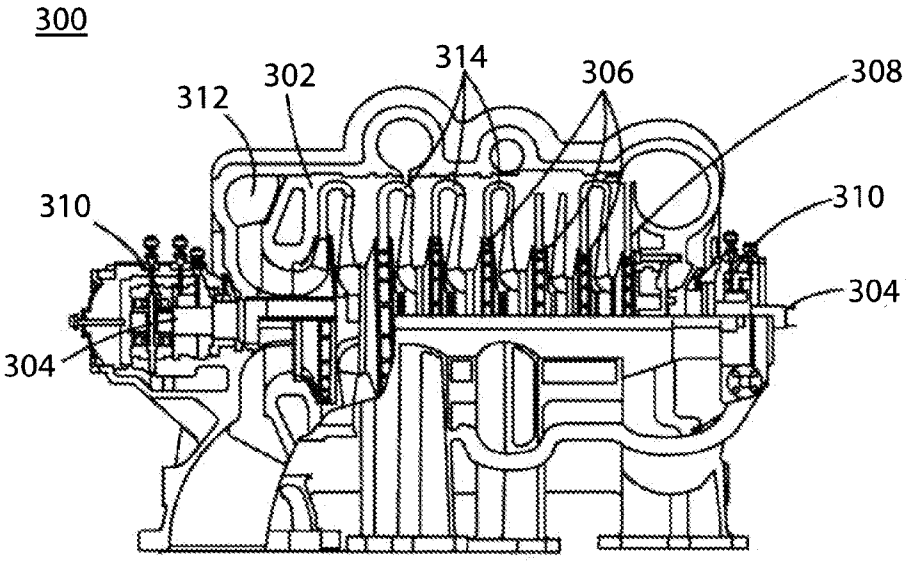


FIG. 4

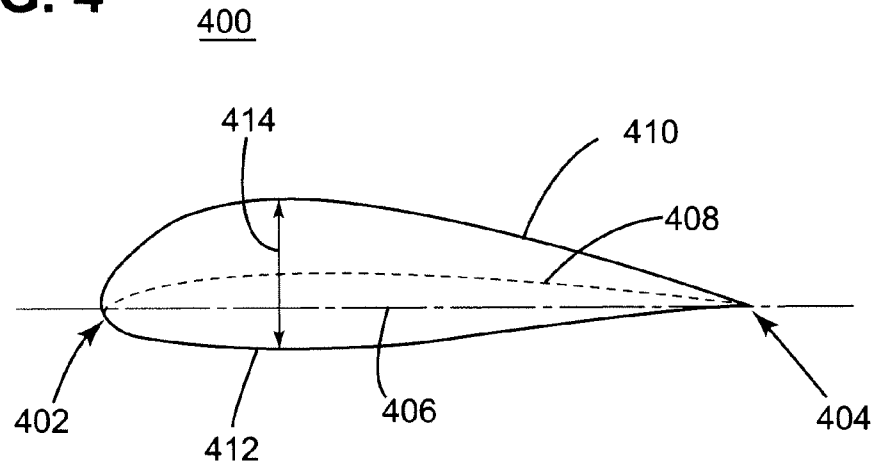

400
414
410
408
402
412
406
404

FIG. 5

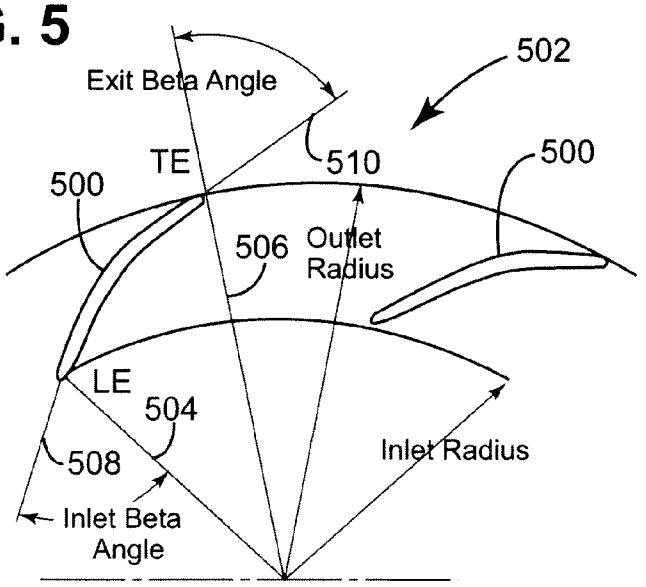

Exit Beta Angle
502
TE
510
500
500
506
Outlet
Radius
LE
504
508
Inlet Radius
Inlet Beta
Angle

FIG. 6

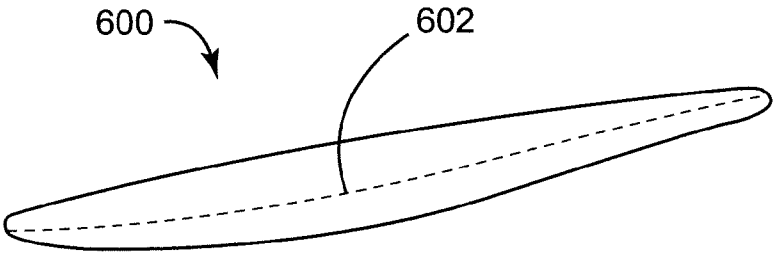

600
602

FIG. 7

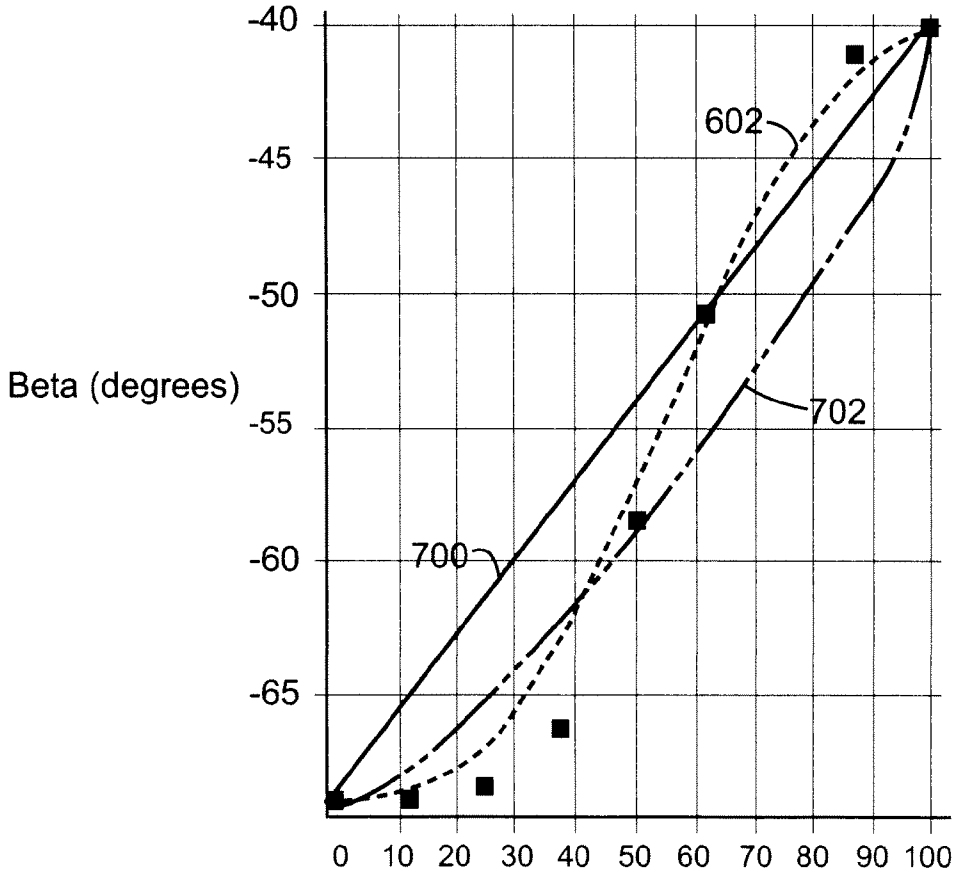

-40
-45
-50
-55
-60
-65
Beta (degrees)
602
702
700
0 10 20 30 40 50 60 70 80 90 100

FIG. 8

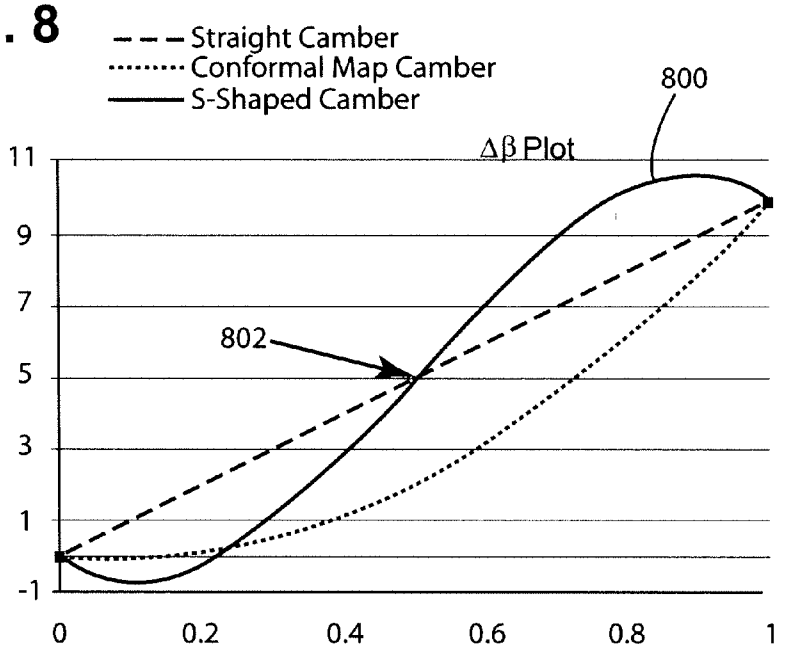
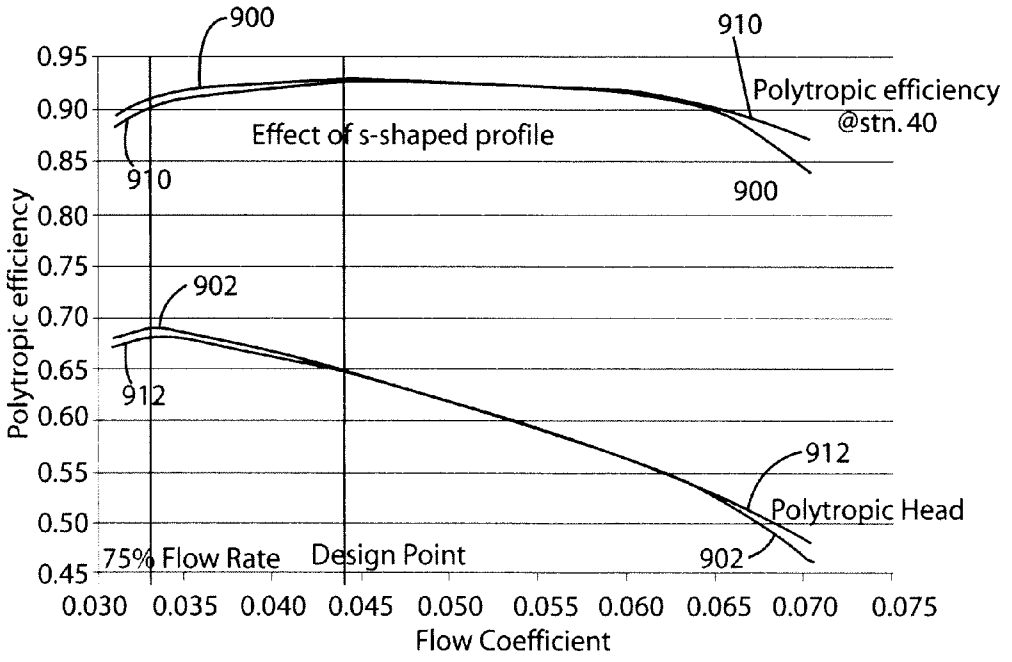

Straight Camber
Conformal Map Camber
S-Shaped Camber
800
Δβ Plot
11
9
7
5
3
1
-1
802
0
0.2
0.4
0.6
0.8
1

FIG. 9


900
910
Polytropic efficiency
@stn. 40
Effect of s-shaped profile
910
900
902
912
912
Polytropic Head
902
75% Flow Rate
Design Point
Polytropic efficiency
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.030
0.035
0.040
0.045
0.050
0.055
0.060
0.065
0.070
0.075
Flow Coefficient

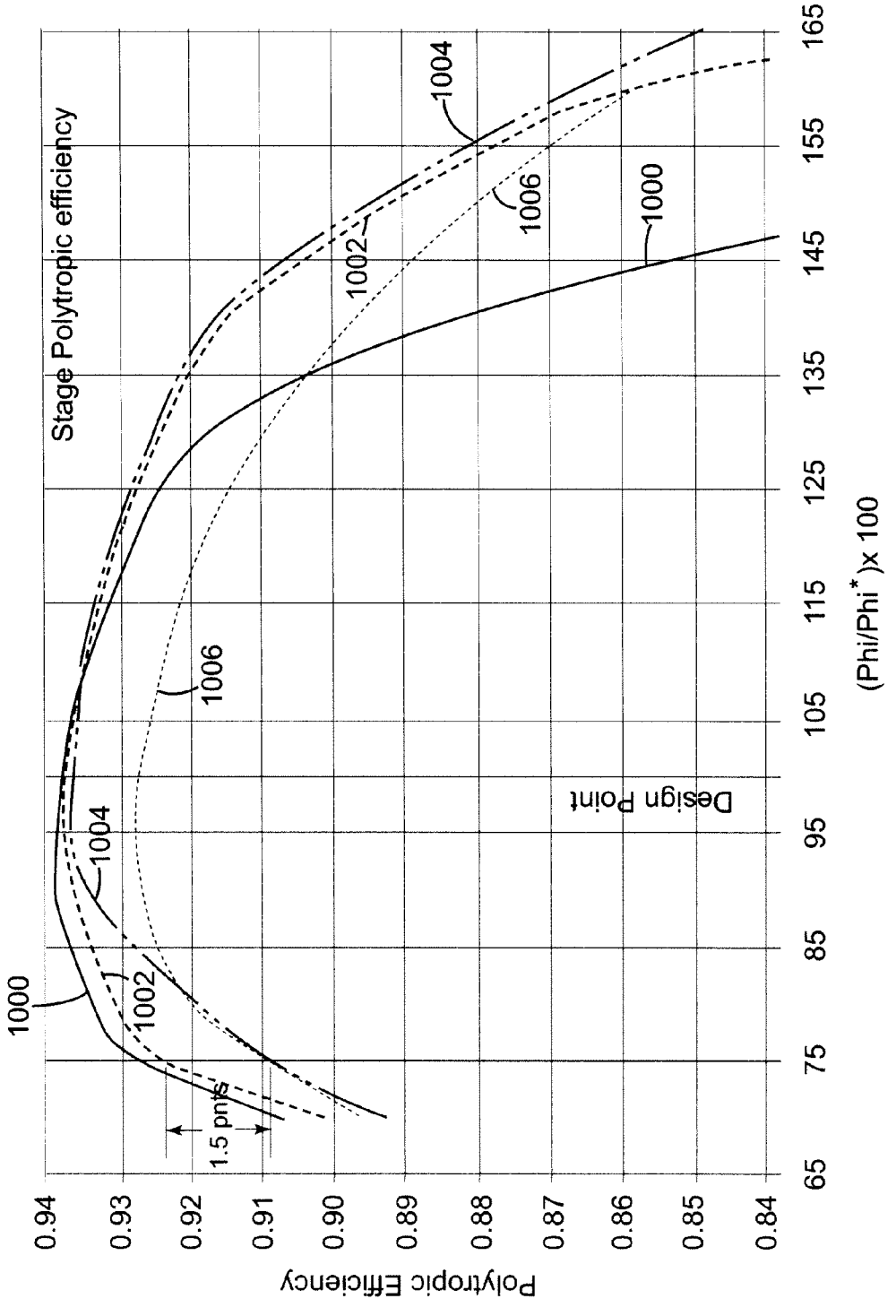

Stage Polytropic efficiency
Polytropic Efficiency
(Phi/Phi*)x 100
Design Point
1.5 pnts
1000
1002
1004
1006
0.94
0.93
0.92
0.91
0.90
0.89
0.88
0.87
0.86
0.85
0.84
65
75
85
95
105
115
125
135
145
155
165

FIG. 10

FIG. 11

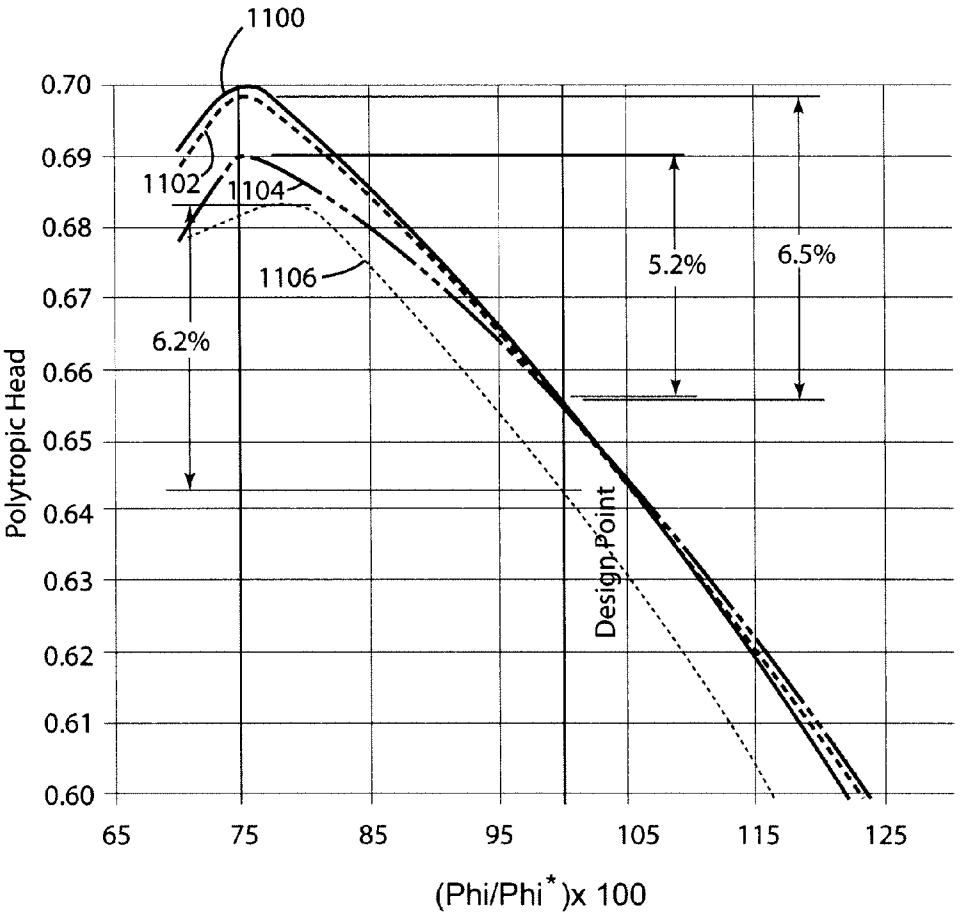

1100
1102
1104
1106
6.2%
5.2%
6.5%
Design Point
Polytropic Head
0.70
0.69
0.68
0.67
0.66
0.65
0.64
0.63
0.62
0.61
0.60
65
75
85
95
105
115
125
(Phi/Phi*)x 100

FIG. 12

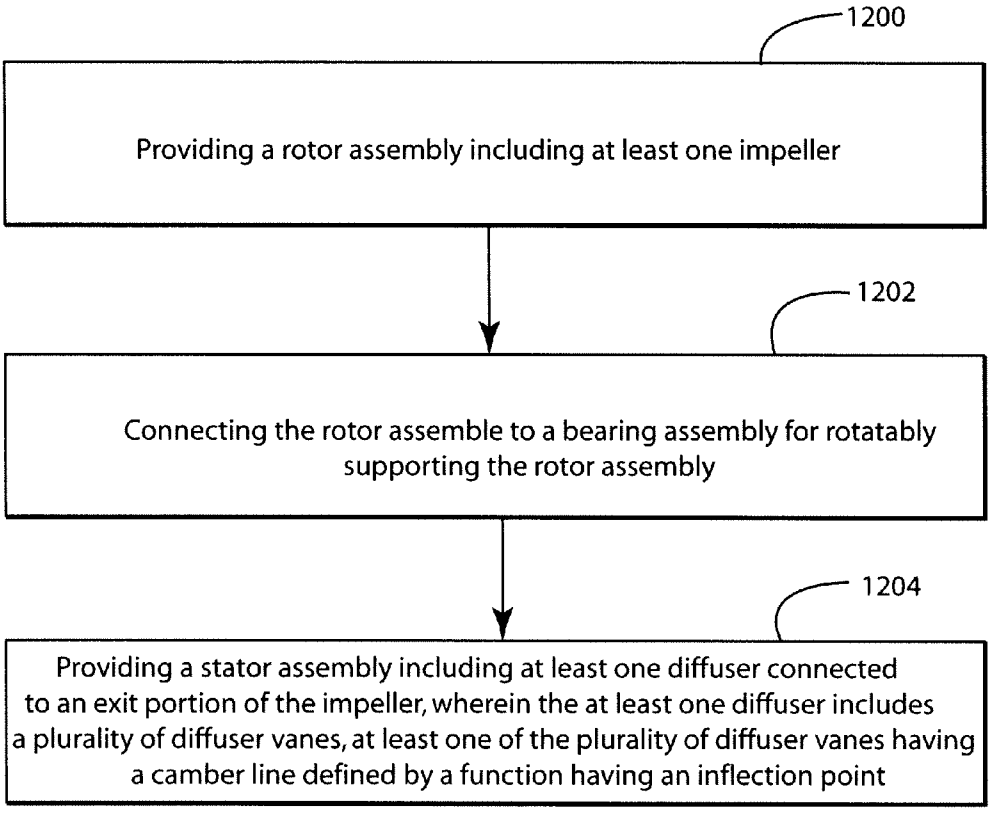

1200
Providing a rotor assembly including at least one impeller
1202
Connecting the rotor assemble to a bearing assembly for rotatably supporting the rotor assembly
1204
Providing a stator assembly including at least one diffuser connected to an exit portion of the impeller, wherein the at least one diffuser includes a plurality of diffuser vanes, at least one of the plurality of diffuser vanes having a camber line defined by a function having an inflection point

FIG. 13

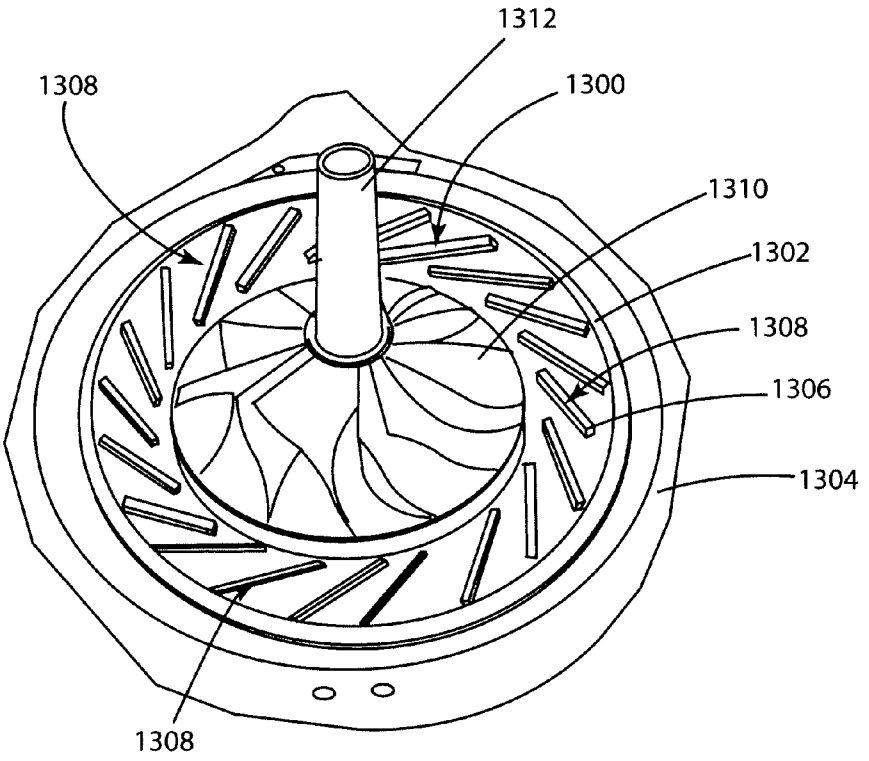
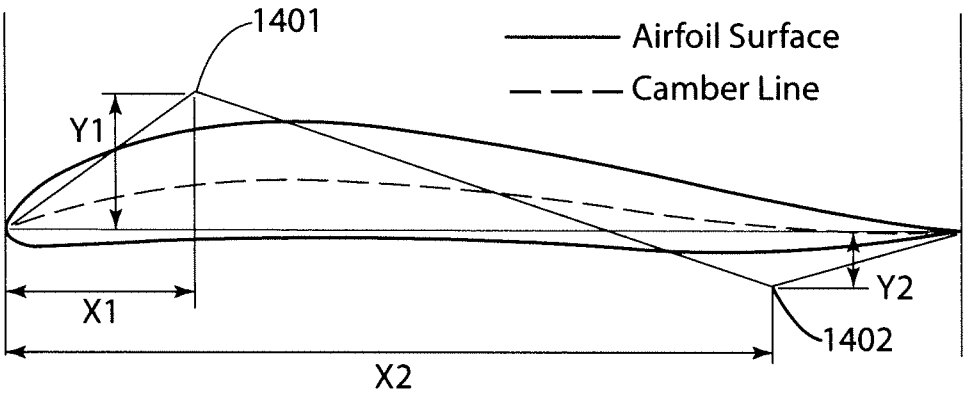


FIG. 14



RADIAL DIFFUSER VANE FOR CENTRIFUGAL COMPRESSORS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This is a national stage application under 35 U.S.C. §371(c), PCT application number PCT/EP2010/061788 filed on Aug. 12, 2010, the disclosure of which is hereby incorporated in its entirety by reference herein.

BACKGROUND OF THE INVENTION

[0002] Embodiments of the present invention relate generally to compressors and, more specifically, to diffuser vanes for centrifugal compressors.

[0003] A compressor is a machine which accelerates gas particles to, ultimately, increase the pressure of a compressible fluid, e.g., a gas, through the use of mechanical energy. Compressors are used in a number of different applications, including operating as an initial stage of a gas turbine engine. Among the various types of compressors are the so-called centrifugal compressors, in which mechanical energy operates on gas input to the compressor by way of centrifugal acceleration, e.g., by rotating a centrifugal impeller (sometimes also called a "rotor") by which the compressible fluid is passing. More generally, centrifugal compressors can be said to be part of a class of machinery known as "turbo machines" or "turbo rotating machines".

[0004] Centrifugal compressors can be fitted with a single impeller, i.e., a single stage configuration, or with a plurality of impellers in series, in which case they are frequently referred to as multistage compressors. Each of the stages of a centrifugal compressor typically includes an inlet conduit (inducer section) for gas to be compressed, an impeller which is capable of imparting kinetic energy to the input gas and a diffuser which converts the kinetic energy of the gas leaving the rotor/impeller into pressure energy.

[0005] More specifically, as shown in the exemplary side-sectional view of FIG. **1**A taken along the axis of a compressor in the direction of the process gas flow, a centrifugal compressor stage **100** includes an impeller **102** attached to a rotor **104** followed by a diffuser **106** and a return channel or exit scroll **108**. The diffuser **106** collects the high velocity fluid from the impeller **102**'s exit and allows the fluid to slow down, thereby converting the dynamic pressure to a static pressure. To provide another perspective of this structure, FIG. **1**B shows a cross-sectional view of the compressor stage **100** taken along the other axis, i.e., perpendicular to the direction of the process gas flow. Therein, the rotor **104** is seen in the center of the Figure surrounded by an impeller **102** having a number of impeller blades **114**. The impeller blades **114** can be connected, on one end, to a hub portion **116** of the impeller **112**, and on the other end to a shroud portion **118** of the impeller **102**.

[0006] Of more interest for the present application is the diffuser section **106**. Vaned diffusers **106** (i.e., those diffusers having a circumferential array of airfoils (diffuser blades **110**) along the flow passage as best seen in FIG. **1**B) are employed to achieve higher stage efficiency by directing the highly tangential fluid flow at the impeller exit to be more radial towards the diffuser exit. By way of contrast, some centrifugal compressors have vaneless diffuser sections **120**, as shown in FIG. **1**C. Making the fluid flow more radial inside the diffuser **106** by using vanes reduces the distance taken by the fluid to travel through the diffuser **106**. This concept is illustrated by the flow arrows in the centrifugal pump illustrated in FIG. **1**D.

[0007] Reducing the distance taken by the fluid reduces the friction losses associated with the travel of the process fluid and thereby increases the efficiency of compressors which use vaned diffusers relative to compressors using vaneless diffusers. On the other hand, centrifugal compressor stages employing vaned diffusers **106** are also known for their reduced operating range as compared to their vaneless counterparts.

[0008] The operating range of a centrifugal compressor **100** including a vaned diffuser **106** is determined based, at least in part, on the shape of the diffuser blades **110** which are employed. The shape of a diffuser blade (or more generally any airfoil) can be expressed by its camber line, (i.e., a line drawn halfway between the upper surface of the diffuser blade and the lower surface of the diffuser blade), and the thickness distribution along the camber line. Two previously used diffuser blade shapes are shown in FIGS. **2**A and **2**B. Starting with FIG. **2**A, a diffuser blade **200** having a straight camber line **202**, i.e., a camber line with no change in slope, drawn as a dotted line between the upper diffuser blade surface **204** and the lower diffuser blade surface **206** is illustrated.

[0009] Employing diffuser blades **200** having a straight camber line in a centrifugal compressor is problematic because, for example, the leading edge of the diffuser vane with that shape is relatively highly loaded and the compressor has a relatively low stall limit.

[0010] FIG. **2**B shows an alternative diffuser blade **208** having a different shape which is referred to as a conformal mapped blade camber. Shown by dotted line **210**, between its upper surface **212** and lower surface **214**, the conformal mapped blade camber line can be defined, e.g., using coordinates of the camber line of an airfoil in the rectangular plane (x, y), and polar coordinates (r, θ) in the circular plane, as:

$$r = r_0 \times e^{[(mx-y)/(m^2+1)]}$$

$$\theta = \frac{my + x}{m^2 + 1}$$

$$m = \mathrm{Cot}\alpha_3$$

where, r_o is the radius of the diffuser vane leading edge radial position, and α_3 is the angle of absolute velocity at diffuser vane leading edge.

[0011] This diffuser blade shape also results in certain drawbacks when employed as part of a diffuser in a centrifugal compressor. For example, employing diffuser blades **208** having a conformal mapped camber line in a centrifugal compressor is problematic because the trailing edge of the diffuser vane with that shape is relatively highly loaded and the compressor has a relatively low choke limit.

[0012] Accordingly, it would be desirable to design and provide diffuser blades having shapes which improve the performance of centrifugal compressors and which address the aforementioned drawbacks of existing diffuser blade shapes.

BRIEF SUMMARY OF THE INVENTION

[0013] Various devices, systems and methods according to exemplary embodiments of the present invention provide dif-

fusers, e.g., as part of a turbo machine, with diffuser vanes having S-shaped camber lines. Such S-shaped camber lines are defined by functions having an inflection point along their length, or a portion of such curves. Using diffuser vanes having such shapes results in, among other things, an operational characteristic wherein a portion of the diffuser vanes disposed near a leading edge is substantially unloaded when operating at design conditions and wherein the load gradually increases to a maximum loading value towards a middle portion of the diffuser vanes.

[0014] According to an exemplary embodiment, a turbo machine includes a rotor assembly having at least one impeller, a bearing connected to, and for rotatably supporting, the rotor assembly, and a stator including at least one diffuser connected to an exit portion of the impeller, wherein the at least one diffuser includes a plurality of diffuser vanes, at least one of the plurality of diffuser vanes having a camber line defined by a function having an inflection point.

[0015] According to another exemplary embodiment, a method of manufacturing a turbo machine includes providing a rotor assembly including at least one impeller, connecting the rotor assembly to a bearing assembly to rotatably support the rotor assembly, and providing a stator assembly including at least one diffuser connected to an exit portion of the impeller, wherein the at least one diffuser includes a plurality of diffuser vanes, at least one of the plurality of diffuser vanes having a camber line defined by a function having an inflection point.

[0016] According to another exemplary embodiment, a diffuser includes an inner annular wall, an outer annular wall, a plate portion disposed between the inner annular wall and the outer annular wall, and a plurality of diffuser vanes disposed on the plate portion, at least one of the plurality of diffuser vanes having a camber line defined by a function having an inflection point.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The accompanying drawings illustrate exemplary embodiments, wherein:

[0018] FIGS. **1**A, **1**B, **1**C, and **1**D illustrate background art associated with diffusers used in centrifugal compressors;

[0019] FIGS. **2**A and **2**B show conventional straight camber line and conformal mapped camber line diffuser blades, respectively;

[0020] FIG. **3** depicts an exemplary centrifugal compressor in which diffusers manufactured according to exemplary embodiments of the present invention can be employed;

[0021] FIG. **4** illustrates airfoil concepts according to exemplary embodiments of the present invention;

[0022] FIG. **5** describes beta angles associated with diffuser implementations according to exemplary embodiments of the present invention;

[0023] FIG. **6** depicts a diffuser blade profile having an S-shaped camber line according to an exemplary embodiment of the present invention;

[0024] FIG. **7** is a graph depicting an S-shaped camber line according to an exemplary embodiment of the present invention relative to other camber lines;

[0025] FIG. **8** is a graph depicting an S-shaped camber line and its inflection point according to an exemplary embodiment of the present invention;

[0026] FIGS. **9**, **10** and **11** are plots depicting simulation results according to exemplary embodiments of the present invention;

[0027] FIG. **12** is a flowchart illustrating a method of manufacturing a turbo machine according to an exemplary embodiment of the present invention;

[0028] FIG. **13** shows a diffuser according to an exemplary embodiment of the present invention; and

[0029] FIG. **14** illustrates usage of Bezier curves to define an S-shaped camber line according to an exemplary embodiment of the present invention.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS OF THE INVENTION

[0030] The following detailed description of the exemplary embodiments refers to the accompanying drawings. The same reference numbers in different drawings identify the same or similar elements. Also, the following detailed description does not limit the invention. Instead, the scope of the invention is defined by the appended claims.

[0031] To provide some context for the subsequent discussion relating to diffuser blades and diffuser blade shapes according to the exemplary embodiments, FIG. **3** schematically illustrates an exemplary multistage, centrifugal compressor **300** in which such diffuser blades may be employed. Therein, the compressor **300** includes a box or housing (stator) **302** within which is mounted a rotating compressor shaft **304** that is provided with a plurality of centrifugal rotors or impellers **306**. The rotor assembly **308** includes the shaft **304** and rotors **306** and is supported radially and axially through bearings **310** which are disposed on either side of the rotor assembly **308**.

[0032] The multistage centrifugal compressor **300** operates to take an input process gas from duct inlet **312**, to accelerate the process gas particles through operation of the rotor assembly **308**, and to subsequently deliver the process gas through various interstage ducts **314** (which include diffusers and diffuser blades described below) at an output pressure which is higher than its input pressure. The process gas may, for example, be any one of atmospheric air, carbon dioxide, hydrogen sulfide, butane, methane, ethane, propane, natural gas, or a combination thereof. Between the impellers **306** and the bearings **310**, sealing systems (not shown) are provided to prevent the process gas from flowing to the bearings **310**. The housing **302** is configured so as to cover both the bearings **310** and the sealing systems, so as to prevent the escape of gas from the centrifugal compressor **300**. Those skilled in the art will appreciate that the centrifugal compressor **300** illustrated in FIG. **3** is purely exemplary and that the diffusers and diffuser blades described below can be used in other compressors, e.g., in-line, back-to-back, axial compressors, centrifugal pumps, turbines, turbo expanders, etc.

[0033] Turning now to the discussion of diffusers and diffuser blade shapes, a brief discussion of airfoils and airfoil terminology will assist the reader to better understand the exemplary embodiments. Looking at FIG. **4**, a generic airfoil **400** has a leading edge (LE) **402** and a trailing edge (TE) **404**, the leading edge **402** being the end of the airfoil which first contacts the fluid and which thereby separates the fluid into upper and lower streams, and the trailing edge **404** being the other end of the airfoil where the fluid streams converge. The chord line **406** is a straight line between the LE **402** and TE **404**, while the mean camber line **408** (also sometimes called simply "the camber line") is disposed midway between an upper surface **410** of the airfoil **400** and a lower surface **412** of the airfoil **400**. An airfoil **400** can have a point of maximum thickness **414** which may be located at a predetermined dis-

tance from the leading edge **402**. Varying these (and other) parameters associated with the airfoil **400** will result in varying aerodynamic performance.

[0034] FIG. **5** illustrates some additional terminology which is relevant for the usage of airfoils as diffuser blades **500** in a diffuser section **502** of a centrifugal compressor **300**. Camber lines can, for example, be plotted as a function of beta angles (or change in beta angles) across the length of a diffuser blade **500**. For example, the orientation of the diffuser blades **500**, as well as their shape, defines inlet and outlet beta angles relative to the leading and trailing edges, respectively, of the diffuser blades **500**. More specifically, as shown in FIG. **5**, the inlet and outlet beta angles are defined relative to (1) radii **504**, **506** associated with circles or arcs, and representing the position of the leading edge and the trailing edge, drawn through (from the axis of rotation of shaft **104**) and (2) the projections (tangent to the blade camber line) **508**, **510** associated with the instantaneous curvature at the point of interest. Although shown in FIG. **5** only for the inlet and outlet points on the diffuser blade **500**, the beta angles of the metallic diffuser vanes **500** can also be computed for any point between the leading and trailing edges and are used to plot the camber lines as a function of the distribution of beta angles as described below.

[0035] According to exemplary embodiments, the camber lines of diffuser vanes are "5-shaped" which results in, among other things, more balanced loading between the leading and trailing edges of the vane as compared to the earlier described diffuser vane shapes and associated camber lines. An example of a diffuser vane **600** having an S-shaped camber line **602** according to an exemplary embodiment is provided as FIG. **6**. Although not easy to see in FIG. **6**, the S-shape of the camber line **602** is more apparent in FIG. **7** which shows the S-shaped camber line **602** as a function of the beta angle across the length of the vane **600** from the leading edge (0 on the x-axis) to the trailing edge (100 on the x-axis). For comparative purposes, a straight camber line **700** and conformal mapped camber line **702** are also illustrated on the same plot.

[0036] Although described generally as "S-shaped" camber lines herein, diffuser blades or vanes according to these exemplary embodiments have camber lines which are more specifically defined by, for example, at least third order algebraic equations or functions. By way of contrast, the conventional diffuser vanes described above with respect to FIGS. **2**A and **2**B have camber lines which are defined linearly or by quadratic equations, i.e., first and second order equations. Thus camber lines **602** associated with diffuser blades **600** according to some exemplary embodiments can be defined by functions of the form:

$$y=ax^3+bx^2+cx+d$$

where a, b, c and d are constants. As will be discussed below, however, camber lines associated with diffuser blades according to other exemplary embodiments may be described by other types of functions.

[0037] Another S-shaped camber line **800** associated with a diffuser blade according to an exemplary embodiment is illustrated in FIG. **8**. Therein, the change in beta angle is plotted across the length of the diffuser blade revealing again the s-shape characteristic of the camber line. A characteristic of third order equations is that they possess an inflection point **802**, i.e., a point in the function or graph wherein the curvature (second derivative) changes signs. By way of contrast, camber line functions associated with conventional designs do not have inflection points, as shown by the straight camber line and conformal map camber line which are also plotted in FIG. **8**. It should be noted that the entirety of the S-shaped curves described herein need not be used in generating diffuser blades according to exemplary embodiments, i.e., the curves can be cutoff and still provide the benefits described herein. For example, the part of the curve shown in FIG. **8** from 0.6 to 1 on the x-axis could be used to shape a diffuser blade according to an exemplary embodiment. Among other things, this provides for diffuser shapes having camber lines according to some exemplary embodiments with $\Delta\beta$ values which are greater than those associated with a straight camber line shape (and also, therefore, a conformal mapped camber line as seen in FIG. **8**). Thus it will be appreciated by those skilled in the art that the phrase "diffuser vanes having a camber line defined by a function having an inflection point" includes diffuser vanes having shapes defined by a cutoff version of such functions, e.g., including those where the inflection point defined by the function has been cutoff.

[0038] By employing S-shaped diffuser vanes as described above, the result is an unloading of the portion of the blade near to the leading edge at design conditions and a gradual load increase to a maximum loading towards the blade middle portion. An unloaded leading edge according to exemplary embodiments will suffer less flow separation at lower flow rates, thereby increasing the left operating limit of the compressor. These benefits associated with exemplary embodiments are shown by various simulation results described below and illustrated in FIGS. **9**-**11**.

[0039] FIG. **9** illustrates results associated with two simulations carried out for (1) a vaned diffuser with a straight camber line, plotted as lines **910**, **912** and (2) a vaned diffuser with an S-shaped profile (based on a Sigmoid function as described below) according to these exemplary embodiments, shown by lines **900** and **902**. The turbulence model used in the simulation was the Wilcox k-w turbulence model, with a computational domain consisting of one impeller blade passage (inducer, one full-length blade and one splitter blade in case of splitter impeller), and one diffuser blade passage. The diffuser vanes in this simulation were designed as low solidity vanes. The interface between the rotating domain and the non-rotating domain in this simulation was specified as 50% of the distance between the impeller trailing edge and the diffuser vane leading edge. Computations associated with this simulation were carried out with total pressure and total temperature specified at inlet and mass flow rate specified at outlet. All external walls were assumed adiabatic and leakage flow through the impeller seals is assumed negligible and was not modeled. The impeller upstream was simulated as having a design flow coefficient of 0.0206 and peripheral Mach number of 0.3.

[0040] The results plotted in FIG. **9** show about a 0.5 point increase in efficiency at the design point of the centrifugal compressor and about a 2 point increase in efficiency near the left hand side of the graph, i.e., at 75% flow. This result tends to confirm the conclusion mentioned above that exemplary embodiments increase the stall limit for centrifugal compressors. A fall in the efficiency on the right hand side of the graph relative to a centrifugal compressor simulated with diffuser vanes having a straight camber line is also noted.

[0041] Another simulation, the results of which are plotted in FIGS. **10** and **11**, was conducted relative to centrifugal compressors employing diffuser blades with conformal mapped camber lines (functions **1000** and **1100**), straight

camber lines (functions **1004**, **1104**), and vaneless diffusers (functions **1006**, **1106**), with an exemplary S-shaped camber line result plotted as functions **1002** and **1102**. FIG. **10** illustrates the higher overall efficiency of the exemplary embodiments. More specifically, this comparison shows that, for example, this exemplary embodiment had an efficiency improvement of about 1.5 points on the left hand side of the operating range relative to the centrifugal compressor employing the straight camber line diffusers, albeit a slightly lower efficiency than the conformal mapped camber line compressor. Additionally, on the right hand side of the graph in FIG. **10**, it can be seen that the S-shaped camber according to exemplary embodiments performed much better in terms of efficiency than the conformal mapped camber, and only slightly below the straight camber.

[0042] To summarize, some of the efficiency benefits and advantages associated with using diffuser vanes or blades having S-shaped camber lines in centrifugal compressors include: higher efficiency toward the left (lower) operating range, thereby increasing the stall limit of the compressor, better or comparable efficiency at the design point relative to other designs and lower efficiency towards the choke limit relative to some designs (i.e., except conformal mapped camber line designs).

[0043] This simulation also showed a higher polytropic head raise for the S-shaped camber line diffuser according to an exemplary embodiment relative to the straight camber line diffuser and vaneless diffuser as shown in FIG. **11**. Therein, it can be seen that a head raise of 6.5% was measured for the S-shaped camber line diffuser function **1102** according to an exemplary embodiment relative to a 5.2% head raise for the straight camber line diffuser function **1104** and 6.2% head raise for the vaneless diffuser. The conformal mapped diffuser function **1100** shows a just slightly better head raise than that of the exemplary embodiment **1102**.

[0044] Exemplary embodiments also include a method of manufacturing a turbo machine which can be expressed a shown in the flowchart of FIG. **12**. Therein, a rotor assembly is provided including at least one impeller **1200**. The rotor assembly is connected **1202** to a bearing assembly which rotatably supports the rotor assembly. A stator assembly is provided **1204** including at least one diffuser connected to an exit portion of the impeller, wherein the at least one diffuser includes a plurality of diffuser vanes, at least one of the plurality of diffuser vanes having a camber line defined by a function having an inflection point.

[0045] In addition to manufacturing centrifugal compressors with diffuser vanes having S-shaped camber lines according to these various exemplary embodiments, it may further be desirable to retrofit existing centrifugal compressors having vaneless diffusers or diffusers with differently shaped diffuser vanes, with diffusers having S-shaped camber lines according to the exemplary embodiments to, for example, increase efficiency relative to vaneless diffusers or reduce the loss of range associated with existing vaned diffusers. Thus exemplary embodiments further contemplate the manufacture of diffusers themselves for retrofitting and/or repair of existing compressors. FIG. **13** illustrates an exemplary diffuser **1300** including an inner annular wall **1302**, an outer annular wall **1304**, a plate portion **1306** disposed between the inner annular wall **1302** and the outer annular wall **1304**, and a plurality of diffuser vanes **1308** disposed on the plate portion **1306**. One or more of the diffuser vanes or blades **1308** have an S-shaped camber line, i.e., defined by a function having an inflection point. The diffuser **1300** can be a high solidity airfoil diffuser or a low solidity airfoil diffuser. According to some exemplary embodiments, the S-shaped diffuser vanes discussed herein can be employed with diffusers **1300** which have more than 10 vanes **1308**.

[0046] As mentioned above, third order algebraic equations can be used to define camber lines according to some exemplary embodiments. However other types of equations, e.g., exponential equations, can also be used to define camber lines according to exemplary embodiments. For example, Sigmoid functions or Gompertz functions can also be used to define camber lines according to exemplary embodiments. Sigmoid functions, also known as logistic functions, can be expressed as:

$$Y = \frac{1}{1 + e^{-x}}$$

while Gompertz functions take the form of:

$$y = ae^{[-be^{(-cx)}]}$$

Like the above described third order algebraic equations, these exponential equations also generate functions which have inflection points.

[0047] Additionally, higher order polynomial functions, e.g., fourth order or higher, can also be used to obtain the same s-shape. Moreover, according to other exemplary embodiments, more complicated shapes (with multiple inflection points) can be custom designed for a particular application. One way to define such generalized curves is through Bezier Curves. A Bezier curve forming the s-shape of camber lines according to exemplary embodiments can be described as shown in FIG. **14**. Therein, the shape of the camber line is defined by the values of co-ordinates of the control points **1401** and **1402** having coordinates (X1, Y1) and (X2, Y2), respectively. A greater number of control points can be used to define higher order curves having multiple inflection points.

[0048] Devices, systems and methods according to exemplary embodiments provide diffusers, e.g., as part of a turbo machine **300**, with diffuser vanes having S-shaped camber lines **408**. Such S-shaped camber lines **408** are defined by functions having an inflection point. Using diffuser vanes **400** having such shapes results in, among other things, an operation characteristic wherein a portion of the diffuser vanes **400** disposed near a leading edge **402** is substantially unloaded when operating at design conditions and wherein the load gradually increases to a maximum loading value towards a middle portion of the diffuser vanes.

[0049] The above-described exemplary embodiments are intended to be illustrative in all respects, rather than restrictive, of the present invention. Thus the present invention is capable of many variations in detailed implementation that can be derived from the description contained herein by a person skilled in the art. All such variations and modifications are considered to be within the scope and spirit of the present invention as defined by the following claims. No element, act, or instruction used in the description of the present application should be construed as critical or essential to the invention unless explicitly described as such. Also, as used herein, the article "a" is intended to include one or more items.

What is claimed is:

1. A turbo machine comprising:

a rotor assembly comprising at least one impeller;

a bearing connected to the rotor assembly, wherein the bearing is configured to rotatably support the rotor assembly; and

a stator comprising at least one diffuser connected to an exit portion of the at least one impeller, wherein the at least one diffuser comprises:

a plurality of diffuser vanes, wherein at least one of the plurality of diffuser vanes comprising a camber line defined by a function comprising an inflection point.

2. The turbo machine of claim **1**, wherein the function is $y=ax^3+bx^2+cx+d$, where a, b, c and d are constants.

3. The turbo machine of claim **1**, wherein the function is one of a higher order polynomial function, a Sigmoid function, a Gompertz function, and a Bezier curve.

4. The turbo machine of claim **1**, wherein the function is an exponential function.

5. The turbo machine of claim **1**, wherein a portion of the at least one of the plurality of diffuser vanes disposed near a leading edge is substantially unloaded when operating at design conditions, and wherein a load gradually increases to a maximum loading towards a middle portion of the at least one of the plurality of diffuser vanes.

6. The turbo machine of claim **1**, wherein each of the plurality of diffuser vanes is attached to one of a hub or shroud.

7. The turbo machine of claim **1**, wherein the function is a Bezier curve.

8. A method of manufacturing a turbo machine, the method comprising:

providing a rotor assembly comprising at least one impeller;

connecting the rotor assembly to a bearing assembly configured to rotatably support the rotor assembly; and

providing a stator assembly comprising at least one diffuser connected to an exit portion of the at least one impeller, wherein the at least one diffuser comprises:

a plurality of diffuser vanes, wherein at least one of the plurality of diffuser vanes comprises a camber line defined by a function comprising an inflection point.

9. The method of claim **8**, wherein the function is $y=ax^3+bx^2+cx+d$, where a, b, c and d are constants.

10. The method of claim **8**, wherein the function is one of a higher order polynomial function, a Sigmoid function, a Gompertz function, and a Bezier curve.

11. The method of claim **8**, wherein the function is an exponential function.

12. The method of claim **8**, wherein a portion of the at least one of the plurality of diffuser vanes disposed near a leading edge is substantially unloaded when operating at design conditions and wherein a load gradually increases to a maximum loading towards a middle portion of the at least one of the plurality of diffuser vanes.

13. The method of claim **8**, further comprising:

attaching each of the plurality of diffuser vanes to one of a hub or shroud.

14. The method of claim **8**, wherein the function is a Bezier curve.

15. A diffuser comprising:

an inner annular wall;

an outer annular wall;

a plate portion disposed between the inner annular wall and the outer annular wall; and

a plurality of diffuser vanes disposed on the plate portion, wherein at least one of the plurality of diffuser vanes comprises a camber line defined by a function comprising an inflection point.

16. The diffuser of claim **15**, wherein the function is $y=ax^3+bx^2+cx+d$, where a, b, c and d are constants.

17. The diffuser of claim **15**, wherein the function is one of a higher order polynomial function, a Sigmoid function, a Gompertz function, and a Bezier curve.

18. The diffuser of claim **15**, wherein the function is an exponential function.

19. The diffuser of claim **15**, wherein a portion of the at least one of the plurality of diffuser vanes disposed near a leading edge is substantially unloaded when operating at design conditions, and wherein a load gradually increases to a maximum loading towards a middle portion of the at least one of the plurality of diffuser vanes.

20. The diffuser of claim **15**, wherein the function is a Bezier curve.

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