



- (51) International Patent Classification:  
*F04D 29/44* (2006.01)
- (21) International Application Number:  
PCT/US2010/061754
- (22) International Filing Date:  
22 December 2010 (22.12.2010)
- (25) Filing Language: English
- (26) Publication Language: English
- (71) Applicant (for all designated States except US): **DANFOSS TURBOCOR COMPRESSORS B.V.** [NL/NL];  
Koningslaan 17, 1075 AA Amsterdam (NL).
- (72) Inventors; and
- (75) Inventors/Applicants (for US only): **SUN, Lin** [CA/US];  
8332 Inverness Drive, Tallahassee, FL 32312 (US).  
**BRASZ, Joost** [NL/US]; 1 Landgrove Drive, Fayetteville,  
NY 13066 (US).
- (74) Agent: **GOTTSCHALK, William, S.**; Carlson, Gaskey &  
Olds, P.C., 400 West Maple, Suite 350, Birmingham, MI  
48009 (US).
- (81) Designated States (unless otherwise indicated, for every  
kind of national protection available): AE, AG, AL, AM,

AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

- (84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

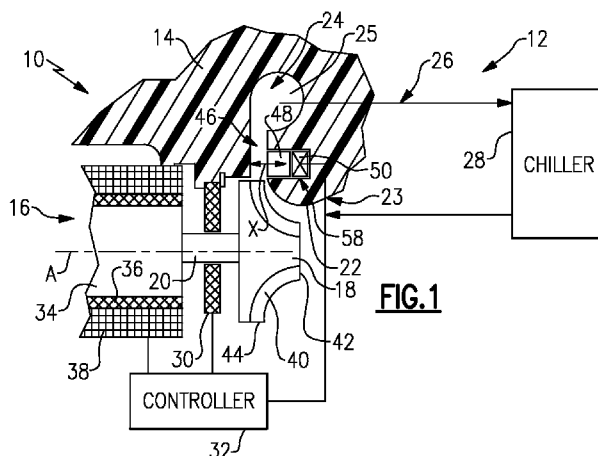
**Declarations under Rule 4.17:**

— of inventorship (Rule 4.17(iv))

**Published:**

— with international search report (Art. 21(3))

(54) Title: VARIABLE-SPEED OIL-FREE REFRIGERANT CENTRIFUGAL COMPRESSOR WITH VARIABLE GEOMETRY DIFFUSER



**FIG.1**

(57) Abstract: A refrigerant compressor includes a housing providing a refrigerant outlet having a throat. An electric motor is provided in the housing to directly drive an impeller via a shaft about an axis in response to a variable speed command. The impeller includes an outlet end aligned with variable geometry diffuser. A magnetic bearing assembly rotationally supports the shaft relative to the housing in response to a magnetic bearing command. A member is arranged to adjust the throat area, and which can move in a direction generally parallel to the axis in response to an actuator receiving a compressor regulation command. A controller is configured to respectively provide the variable speed command, the magnetic bearing command and the compressor regulation command to the electric motor to vary throat area, the magnetic bearing assembly and the actuator to obtain a desired compressor operation without the need of variable inlet geometry.



**VARIABLE-SPEED OIL-FREE REFRIGERANT CENTRIFUGAL  
COMPRESSOR WITH VARIABLE GEOMETRY DIFFUSER**

**BACKGROUND**

[0001] This disclosure relates to a refrigerant compressor with a magnetic bearing assembly and a variable speed electric motor. More particularly, the disclosure relates to such a refrigerant compressor having a variable geometry diffuser.

[0002] Refrigerant compressors are used to circulate refrigerant to a chiller via a refrigerant loop. One type of typical refrigerant compressor operates at fixed speed and has a set of variable inlet guide vanes arranged upstream from the impeller. The variable inlet guide vanes are actuated during operation of the refrigerant compressor to regulate its capacity during various operating conditions.

[0003] Some fixed speed refrigerant compressors have additionally employed a variable-geometry diffuser downstream from the compressor to improve capacity control during the various operating conditions.

[0004] Fixed-speed centrifugal compressors benefit from having both a variable-geometry diffuser and variable- geometry inlet guide vanes. Compressor part-load efficiency and stable operating range both improve. For fixed-speed centrifugal compressors stable operating range is limited without the addition of a variable-geometry diffuser while off-design efficiency suffers without the addition of a set of inlet guide vanes.

[0005] This disclosure describes a centrifugal compressor capacity control apparatus and method using a variable-speed compressor with a variable-geometry diffuser that improves

the stable operating range or turn-down capability of the compressor and results in higher compressor efficiency than a variable speed compressor with inlet guide vanes.

### SUMMARY

[0006] A refrigerant compressor includes a housing providing space for a diffuser and volute downstream of the impeller. An electric motor is provided in the housing and is configured to directly drive an impeller via a shaft about an axis in response to a variable speed command. The impeller includes an outlet end that is aligned with the diffuser. A magnetic bearing assembly is configured to rotationally support the shaft relative to the housing in response to a magnetic bearing control command. A variable geometry member is arranged in the diffuser downstream of the impeller.

[0007] The variable geometry member can be configured in various ways, for example, the variable geometry member moves linearly in a direction generally parallel to the axis in response to an actuator receiving a compressor regulation command. The variable geometry member can also be configured in a variety of other ways.

[0008] A controller is in communication with the electric motor, the magnetic bearing assembly and the variable geometry diffuser actuator. The controller is configured to respectively provide the variable speed command, the magnetic bearing command and the compressor regulation command to the electric motor to vary its speed, to the magnetic bearing assembly to position the shaft, and to the diffuser actuator to vary its throat area in order to obtain a desired compressor operation.

### BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The disclosure can be further understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

[0010] Figure 1 is a highly schematic view of a refrigerant system having a refrigerant compressor with a magnetic bearing.

[0011] Figure 2 is a perspective view of one example variable geometry member.

[0012] Figure 3A is an enlarged, cross-sectional view of the variable geometry member in a generally unrestricted condition.

[0013] Figure 3B is an enlarged, cross-sectional view of the variable geometry member in a restricted condition.

[0014] Figure 4 is a schematic view of a portion of another variable geometry arrangement.

[0015] Figure 5 is a schematic view of a portion of yet another variable geometry arrangement.

[0016] Figure 6 is a schematic view of a portion of another variable geometry arrangement.

[0017] Figure 7 is a schematic view of a portion of still another variable geometry arrangement.

[0018] Figure 8 is a schematic view of a portion of yet another variable geometry arrangement.

## DETAILED DESCRIPTION

[0019] Referring to Figure 1, a refrigeration system 12 includes a refrigerant compressor 10 for circulating a refrigerant. The refrigerant compressor 10 includes a housing 14 within which an electric motor 16 is arranged. The housing 14 is schematically depicted and may comprise one or more pieces. The electric motor 16 rotationally drives an impeller 18 via a shaft 20 about an axis A to compress the refrigerant.

[0020] The impeller 18 includes a refrigerant inlet 42 and a refrigerant outlet 44 in fluid communication with a refrigerant loop 26 that circulates the refrigerant to a load, such as a chiller 28. In the example illustrated in Figure 1, the compressor contains the impeller 18, which is centrifugal. That is, the refrigerant inlet 22 is arranged axially, and the refrigerant outlet 24 is arranged radially. The refrigerant loop 26 includes a condenser, an evaporator, and an expansion device (not shown).

[0021] An oil-free bearing arrangement is provided for support of the shaft 20 so that oil-free refrigerant can be used in the refrigerant compressor 10. In the example, the shaft 20 is rotationally supported relative to the housing 14 by a radial magnetic bearing assembly 30. The magnetic bearing assembly 30 may include radial and/or axial magnetic bearing elements, for example. A controller 32 communicates with the magnetic bearing assembly 30 providing a magnetic bearing command to energize the magnetic bearing assembly 30. The magnetic bearing assembly creates a magnetic field levitating the shaft 20 and controls its characteristics during operation of the refrigerant compressor 10. The controller 32 is depicted schematically, and may include multiple controllers that are located remotely from or near to one another. The controller 32 may include hardware and/or software.

[0022] The electric motor 16 includes a rotor 34 supporting multiple magnets 36 about its circumference in one example. A stator 38 is arranged about the rotor 34 to impart rotational drive to the shaft 20 when energized. In one example, the controller 32 communicates with the stator 38 and provides a variable speed command to rotationally drive the impeller 18 at a variable speed depending upon compressor operating conditions. The controller 32 communicates with multiple sensors (not shown) to monitor and maintain the compressor operating conditions.

[0023] The impeller 18 includes blades 40 that extend from an inlet end 42 generally radially outwardly along an arcuate path to an outlet end 44. The housing 14 includes an upstream region 23 at the refrigerant inlet 22, which has typically contained variable inlet guide vanes in the prior art. The refrigerant compressor 10 does not utilize variable inlet guide vanes at the upstream region 23 in the illustrated embodiment. Instead, a variable geometry member 48 is provided downstream from the outlet end 44 to regulate the flow and pressure across the impeller 18 without the need for or use of inlet guide vanes.

[0024] The refrigerant outlet 24 includes a passage 46 having a throat 47, which is the smallest cross-sectional flow area, immediately adjacent to the outlet end 44, as best illustrated in Figures 3A and 3B. The passage 46 extends to a volute 25. In the example shown, the variable geometry member 48 is provided at the throat 47 adjacent to a corner 62 of the blade 40 at the inlet end 42 and axially aligned with at least a portion of the impeller 18 and radially outward of the outlet end 44. In one example, the passage 46 is without additional structures or vanes, providing a “vaneless” diffuser in a downstream region 64 between the variable geometry member 48 and the volute 25. An actuator 50 is provided in a cavity 58 of the housing 14, for

example, to move the variable geometry member 48 between unrestricted (Figure 3A) and restricted (Figure 3B) conditions.

**[0025]** The passage 46 includes a wall 52 that provides a contour along with an outer surface 54 of the variable geometry member 48. In one example, the variable geometry member 48 is provided by a ring, shown in Figure 2, which is generally continuous about its circumference in one example. An uninterrupted contour 56 is, provided when the wall 52 immediately adjoins the surface 54 in a generally unrestricted condition, as shown in Figure 3A. Flow exiting the inlet end 42 enters the passage 46 generally uninhibited by the variable geometry member 48 in the unrestricted condition.

**[0026]** The variable geometry member 48 is illustrated in a restricted condition in Figure 3B. The variable geometry member 48 is moved between the unrestricted condition and restricted conditions in response to a compressor regulation command to an actuator 50 from the controller 32 to vary the throat area. The variable geometry member 48 has been moved in a direction X, which is generally parallel to the rotational axis A, as compared to the variable geometry member's position in the unrestricted condition illustrated in Figure 3A. The restricted condition creates an interrupted contour 60 in which the wall 52 and the surface 54 are interrupted and disjointed relative to one another, thereby inhibiting flow from the inlet end 42 into the passage 46.

**[0027]** A vaneless variable geometry arrangement is depicted in Figures 3A-3B. Different variable geometry arrangements using vanes, which may be used in the refrigerant system 12, are shown in Figures 4-8.

[0028] Referring to Figure 4, an example variable geometry arrangement 148 includes circumferentially arranged vanes 72 disposed in the refrigerant outlet to provide circumferentially spaced passages 146. A throat 147 is provided in each of the passages 146 at the smallest area between adjacent vanes 72. An axially movable member 74 is arranged downstream from the impeller 18, and in the example, extend into the throat 147 a distance into the passage 146. The member 74 is moved by an actuator, in a manner similar to that described above with respect to member 48, to control the flow of refrigerant through the refrigerant outlet.

[0029] A similar variable geometry arrangement 248 is shown in Figure 5. In this example, the axially movable member 174 surrounds each vane 172 such that the member 174 is provided along the entire passage 246 so the area of the passage 246 is varied along with the area of the throat 247.

[0030] Referring to Figure 6, the variable geometry arrangement 348 includes circumferentially spaced passages 346. The axially movable member 274 is arranged at the throat 347, but does not wrap about the leading edges of the vanes 272 as do the members 74, 174 illustrated in Figures 4 and 5.

[0031] Figure 7 illustrates a variable geometry arrangement 448 depicting vanes 372 that are rotatable between multiple positions (two shown in Figure 7) about pivots 78, which provide axes of rotation normal to the diffuser side walls. Rotation of the vanes 372 adjusts the throat 447 and flow of refrigerant into the passages 446.

[0032] Another example variable geometry arrangement 548 is shown in Figure 8. The vanes 472 include leading edges 82 mounted on a rotatable ring 80 that are movable relative to the rest of the vanes 472 to regulate refrigerant flow through the passages 546. The

circumferentially rotatable ring 80 is supported by the housing and is axially aligned with at least a portion of the impeller and arranged radially outward of the outlet end of the impeller. Unlike the embodiments shown in Figures 4, 5 and 7, the leading edge of the vane does not provide the throat 547 in all vane positions.

[0033] Although example embodiments have been disclosed, a worker of ordinary skill in this art would recognize that certain modifications would come within the scope of the claims. For that reason, the following claims should be studied to determine their true scope and content.

## CLAIMS

What is claimed is:

1. A refrigerant centrifugal compressor comprising:
  - a housing providing an inlet, an outlet consisting of a diffuser having a throat and a volute;
  - an electric motor provided in the housing and configured to directly drive an impeller via a shaft about an axis in response to a variable speed command, the impeller including an outlet end aligned with a variable geometry diffuser;
  - a magnetic bearing assembly configured to rotationally support the shaft relative to the housing in response to a magnetic bearing command;
  - a variable geometry diffuser member downstream of the impeller receiving a compressor regulation command; and
  - a controller in communication with the electric motor, magnetic bearing assembly and the actuator, the controller configured to respectively provide the variable speed command, magnetic bearing command and the compressor regulation command to the electric motor to vary throat area, magnetic bearing assembly and the actuator to obtain a desired compressor operating condition.
2. The refrigerant centrifugal compressor according to claim 1, wherein the variable geometry diffuser member is arranged immediately adjacent to the outlet end of the impeller.

3. The refrigerant centrifugal compressor according to claim 1, wherein the housing includes a vaneless passage upstream of the variable geometry diffuser, the variable diffuser member arranged upstream from the volute.

4. The refrigerant centrifugal compressor according to claim 1, wherein the impeller is a centrifugal impeller with an axial inlet and the outlet end oriented radially.

5. The refrigerant centrifugal compressor according to claim 1, wherein the housing provides a refrigerant inlet upstream from an inlet end of the impeller, the refrigerant inlet is provided without inlet guide vanes.

6. The refrigerant centrifugal compressor according to claim 1, wherein the magnetic bearing assembly includes radially and axially magnetic bearing elements.

7. The refrigerant centrifugal compressor according to claim 1, wherein the variable geometry member is an axially movable ring supported by the housing and aligned with at least a portion of the impeller and arranged radially outward of the outlet end of the impeller.

8. The refrigerant centrifugal compressor according to claim 7, wherein the ring is generally continuous about its circumference.

9. The refrigerant centrifugal compressor according to claim 1, wherein the variable geometry diffuser member consist of a set of individually rotatable vanes with axes of rotation normal to the diffuser side walls.

10. The refrigerant centrifugal compressor according to claim 1, wherein the variable geometry diffuser consists of a circumferentially rotatable ring supported by the housing and axially aligned with at least a portion of the impeller and arranged radially outward of the outlet end of the impeller.

11. The refrigerant centrifugal compressor according to claim 1, wherein the impeller includes a blade having a corner near the variable geometry member and on a side of the impeller with the inlet end.

12. The refrigerant centrifugal compressor according to claim 1, wherein the passage includes a contour provided by a surface of the variable guide member and a wall downstream of the variable guide member adjacent to the surface.

13. The refrigerant centrifugal compressor according to claim 11, comprising a restricted condition corresponding to the contour being interrupted with the surface and the wall disjointed relative to one another.

14. The refrigerant centrifugal compressor according to claim 12, wherein an unrestricted condition includes the contour uninterrupted, the compressor regulation command configured to move the variable geometry member between the unrestricted and restricted conditions.

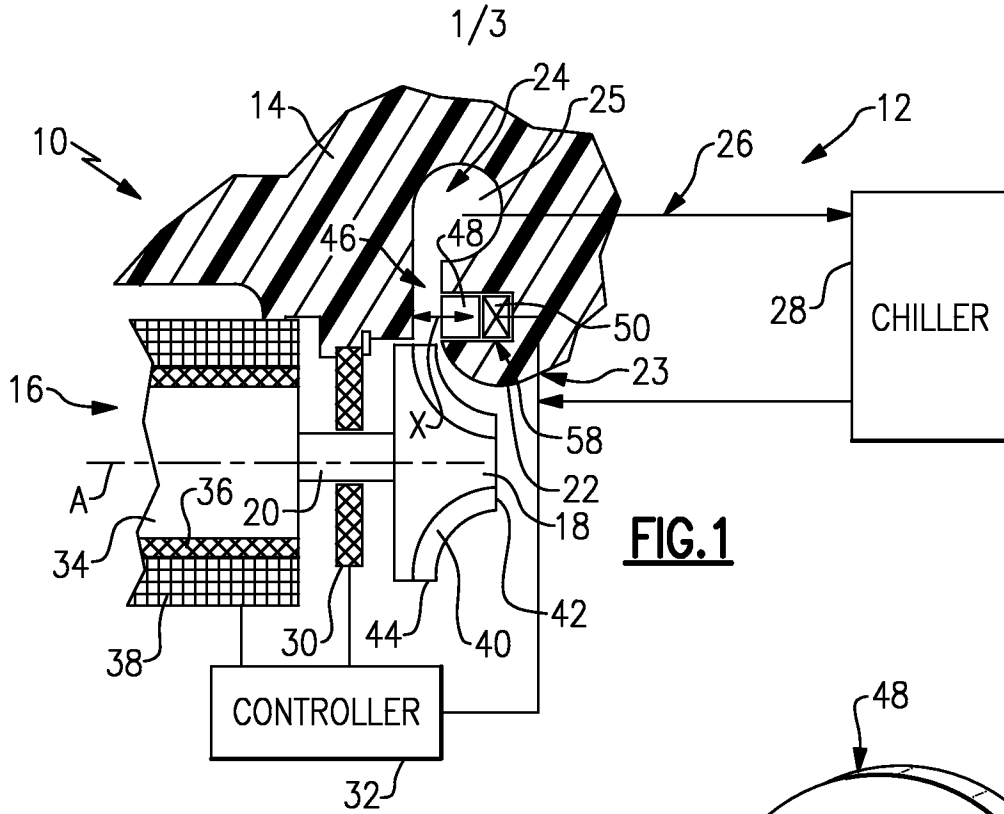
15. A control method for a centrifugal compressor comprising:

a housing providing an inlet to the impeller, an outlet from the impeller consisting of a discrete passage diffuser having a throat and a volute downstream of the variable geometry diffuser;

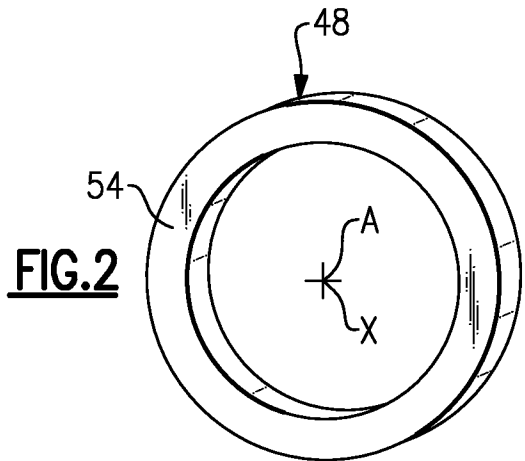
an electric motor provided in the housing and configured to directly drive an impeller via a shaft about an axis in response to a variable speed command, the impeller including an outlet end aligned with a variable geometry diffuser;

an oil-free bearing configured to rotationally support the shaft relative to the housing in response to a magnetic bearing command; and

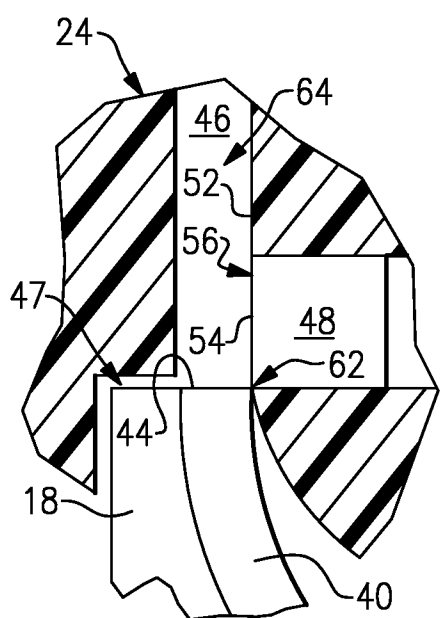
wherein the capacity of the compressor is controlled by adjusting the throat area of the variable geometry diffuser and the pressure ratio is controlled by adjusting the variable speed.



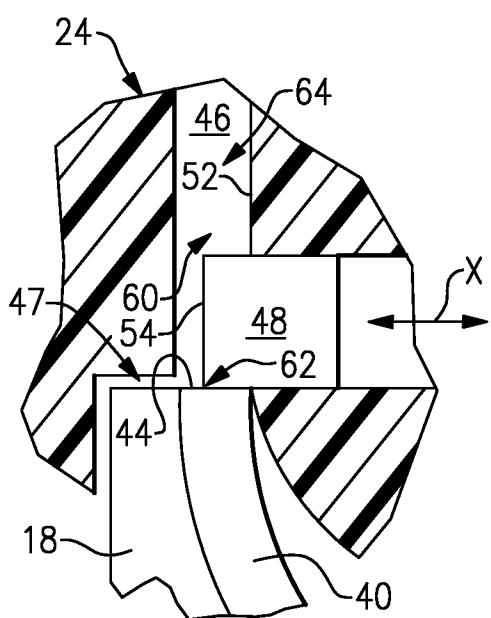
**FIG. 1**



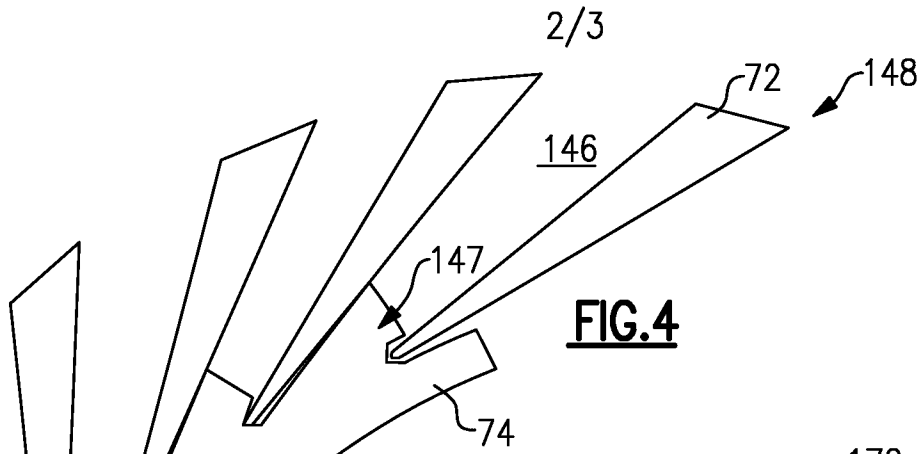
**FIG. 2**



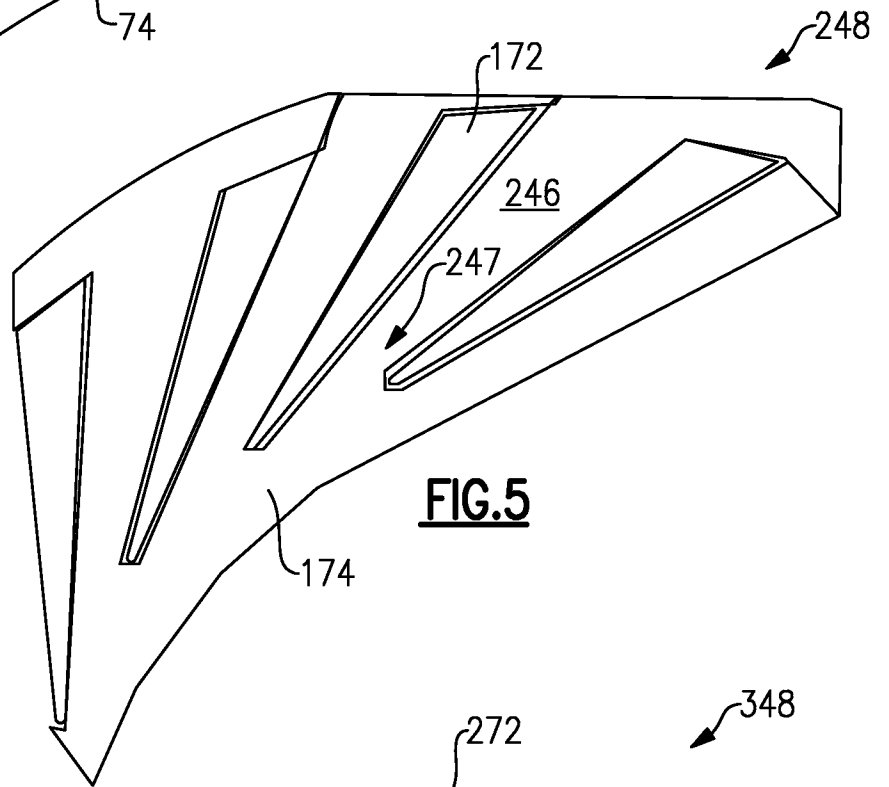
**FIG. 3A**



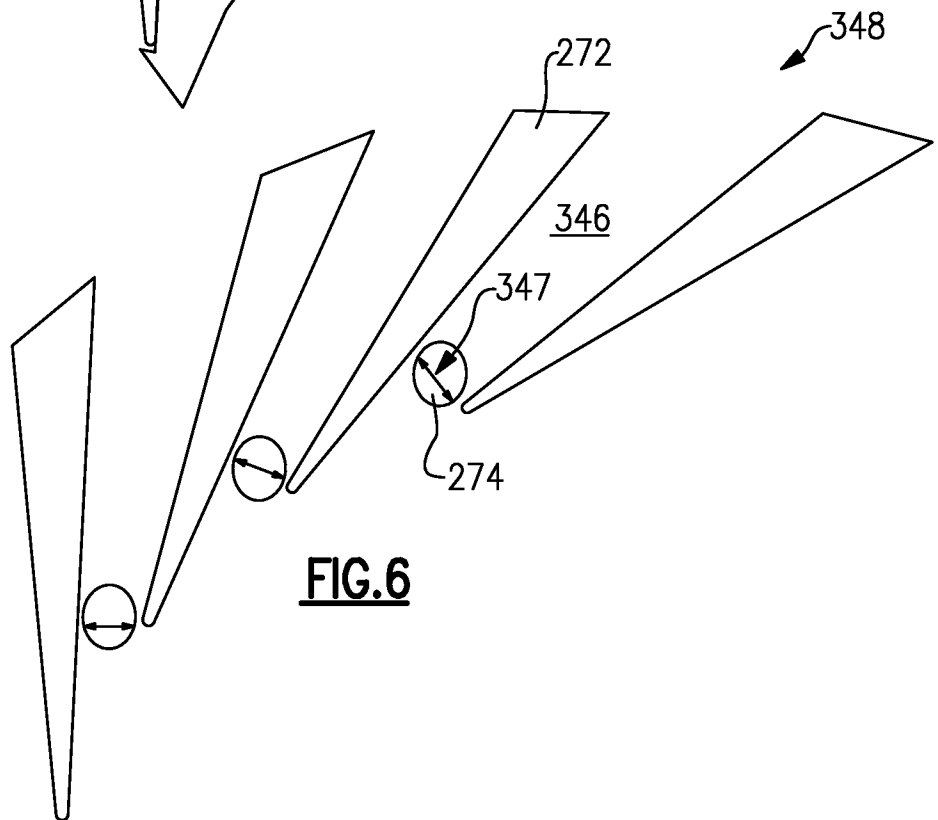
**FIG. 3B**



**FIG. 4**

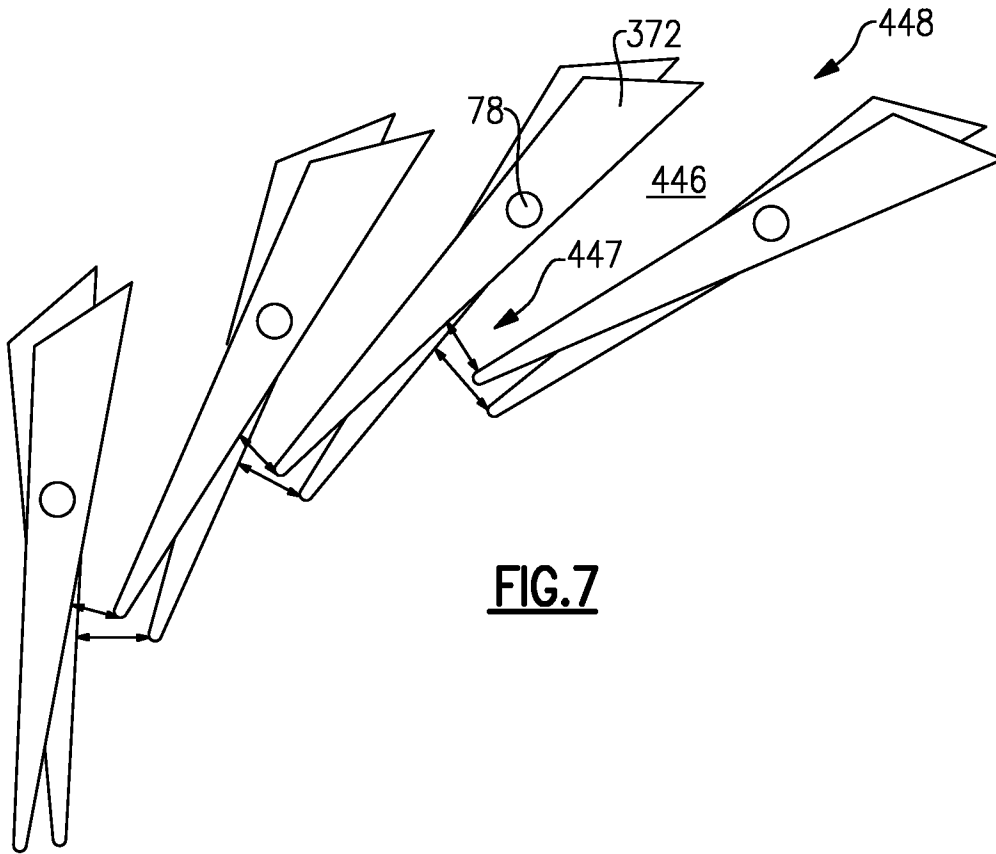


**FIG. 5**

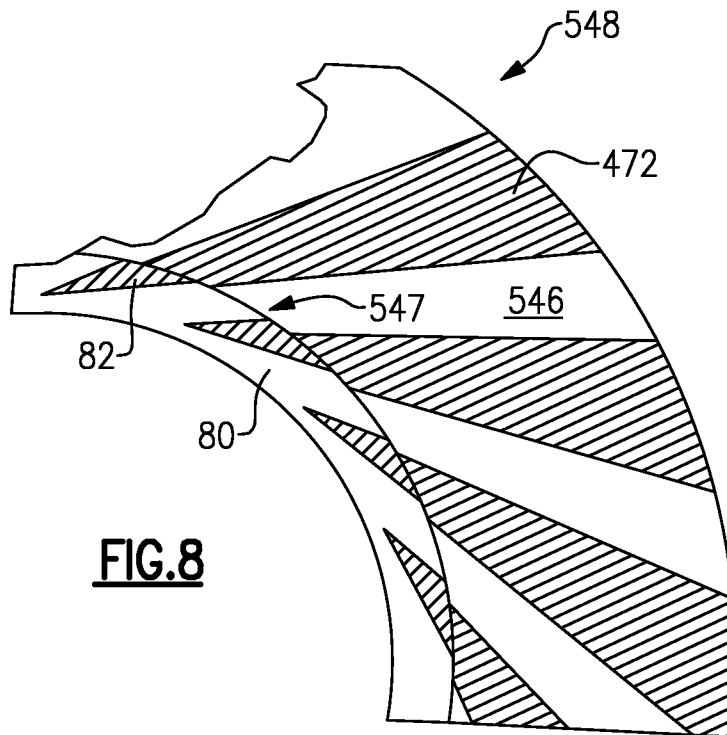


**FIG. 6**

3/3



**FIG. 7**



**FIG. 8**

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 10/61754

<b>A. CLASSIFICATION OF SUBJECT MATTER</b> IPC(8) - F04D 29/44 (2011.01) USPC - 62/408 According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b> Minimum documentation searched (classification system followed by classification symbols) USPC: 62/408		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched USPC: 62/228.4, 228.5; 415/208.1, 224.5, 191; (keyword limited; terms below)		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) PubWEST (PGPB, USPT, EPAB, JPAB); Google Search terms: diffuser, vary, variable, adjustable, throat, volute, ring, collar, sleeve, magnet, bearing, et al.		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,924,847 A (Scaringe et al.) 20 July 1999 (20.07.1999), col 9, ln 54 to col 15, ln 6, Fig 3-3g	1-15
Y	US 2005/0076656 A1 (Bodell et al.) 14 April 2005 (14.04.2005), para [0023]-[0027], Fig 2	1-15
A	US 2002/0184905 A1 (Benedict et al.) 12 December 2002 (12.12.2002), entire document	1-15
A	US 2010/0263391 A1 (Tetu et al.) 21 October 2010 (21.10.2010), entire document	1-15
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/>		
* Special categories of cited documents:		
"A"	document defining the general state of the art which is not considered to be of particular relevance	"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
"E"	earlier application or patent but published on or after the international filing date	"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
"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)	"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
"O"	document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P"	document published prior to the international filing date but later than the priority date claimed	
Date of the actual completion of the international search 21 February 2011 (21.02.2011)		Date of mailing of the international search report <b>07 MAR 2011</b>
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201		Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774