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(54) **CENTRIFUGAL COMPRESSOR HAVING ADJUSTABLE INLET GUIDE VANES**

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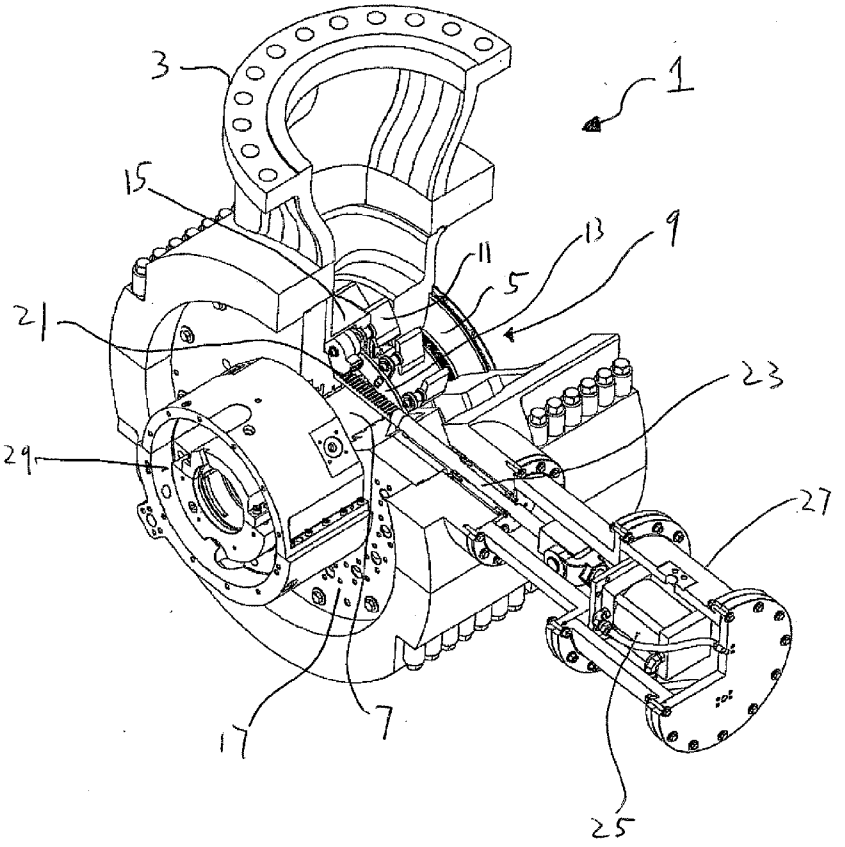
(52) **U.S. Cl.** **415/163**

(57) **ABSTRACT**

An apparatus for adjustment of inlet guide vanes of a compressor includes a ring having a plurality of slots spaced around a circumference thereof; a plurality of lever arm assemblies each having a pin that includes a body with a first end and a second end and a lever arm extending perpendicularly from the second end of the body of the pin; a plurality of vanes each coupled to an end of one of the plurality of lever arms by a shaft; and a rack and pinion drive mechanism. The pin of each of the lever arm assemblies is configured to be positioned within each of the plurality of slots such that the first end of the pin extends into the slot. The rack and pinion drive mechanism includes a pinion coupled to the shaft of one of the plurality of vanes, thereby creating a drive vane; and a driven rack operationally coupled to the pinion. The drive vane is configured to rotate the ring via the rack and pinion drive mechanism, thereby adjusting an angular position of the plurality of vanes.



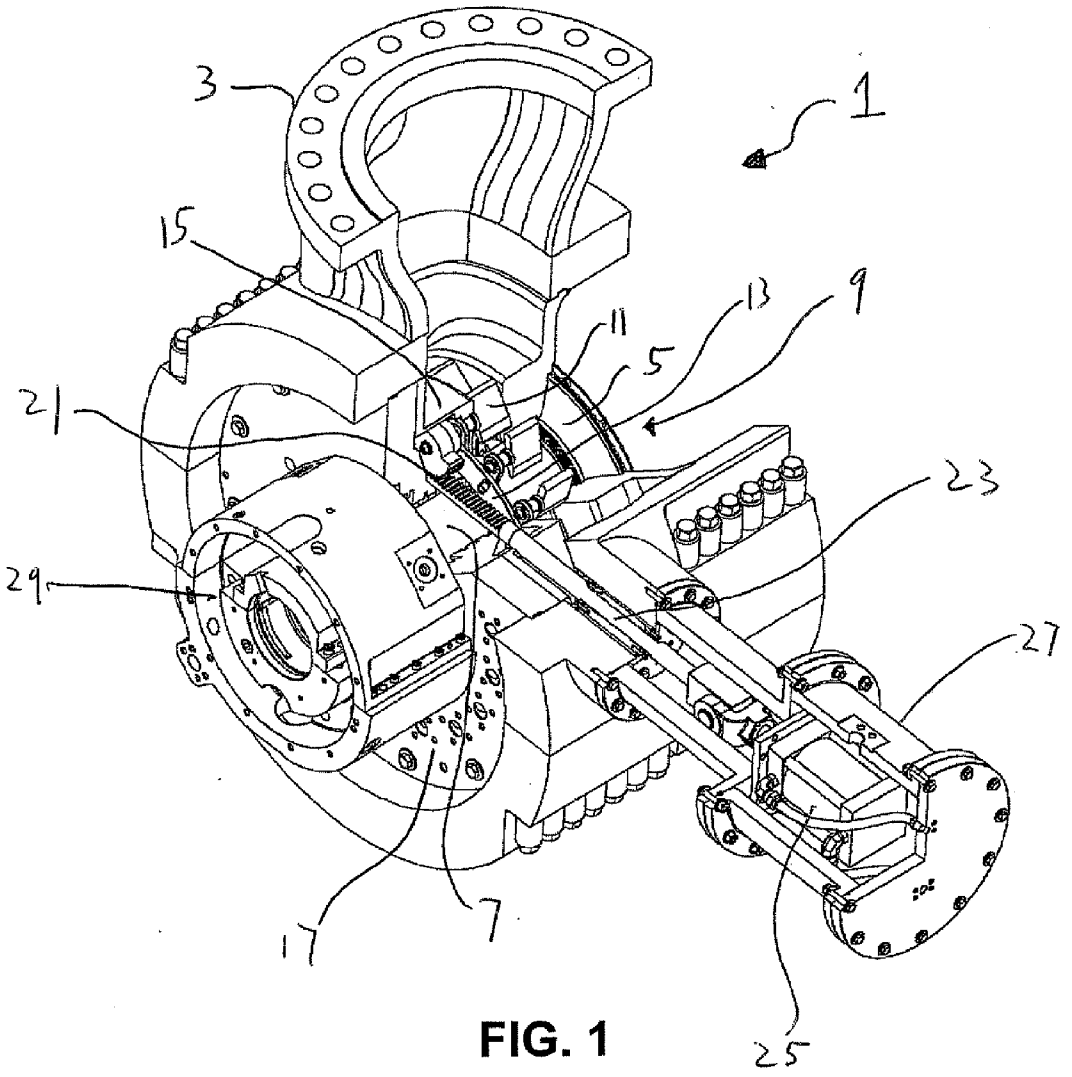


FIG. 1

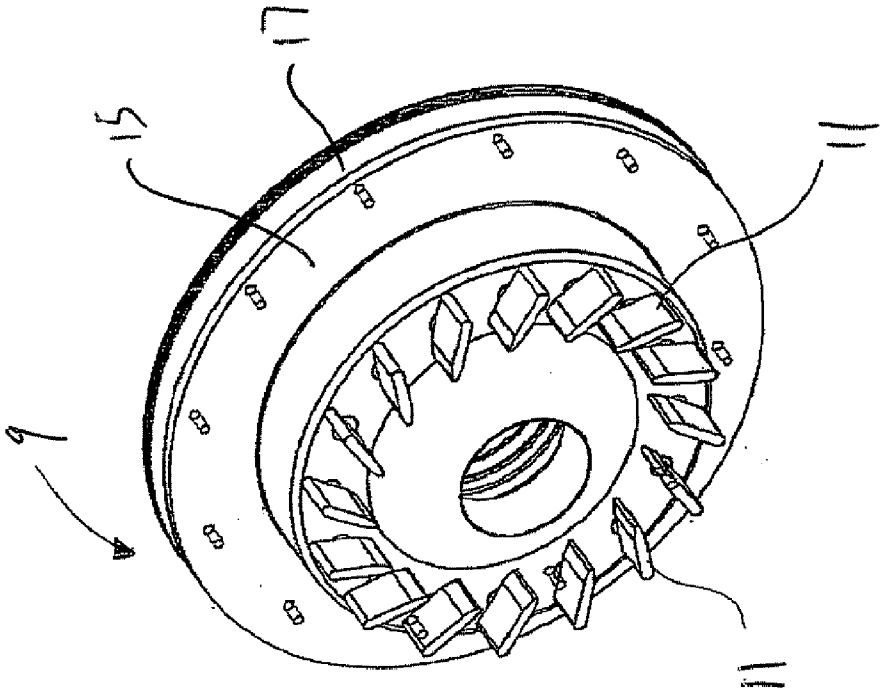


FIG. 2

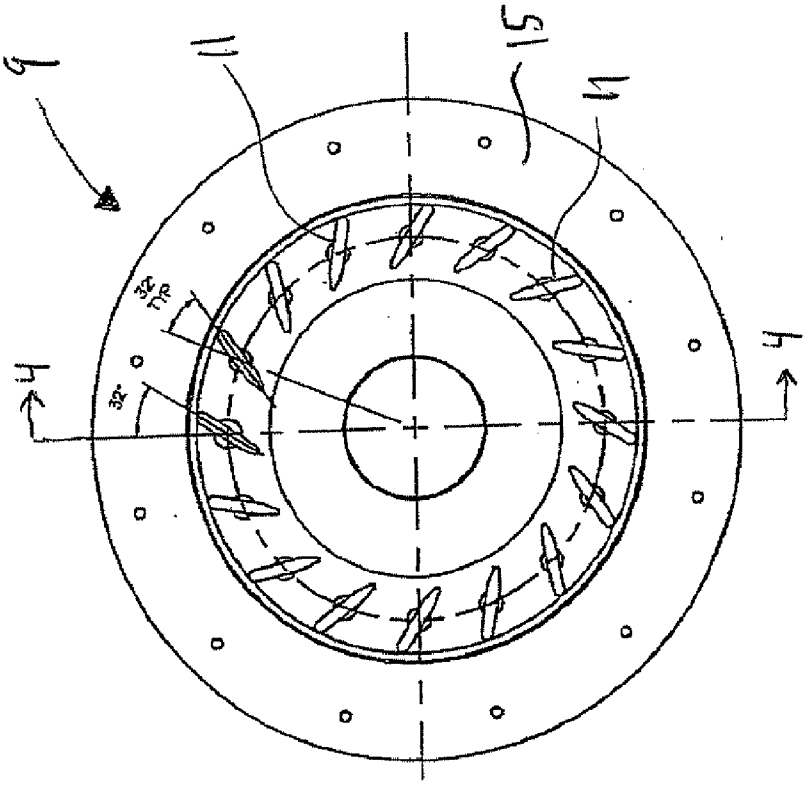


FIG. 3

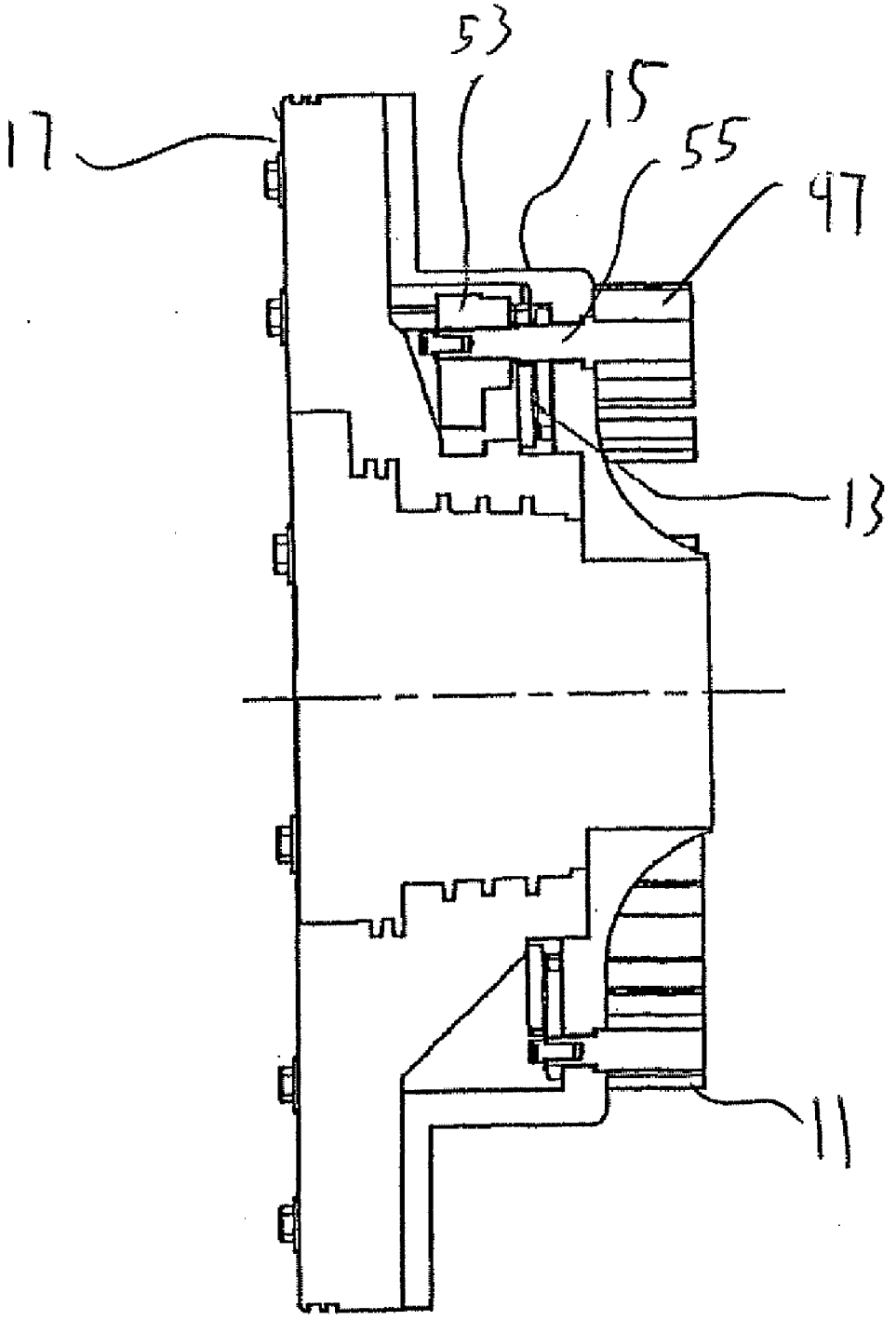


FIG. 4

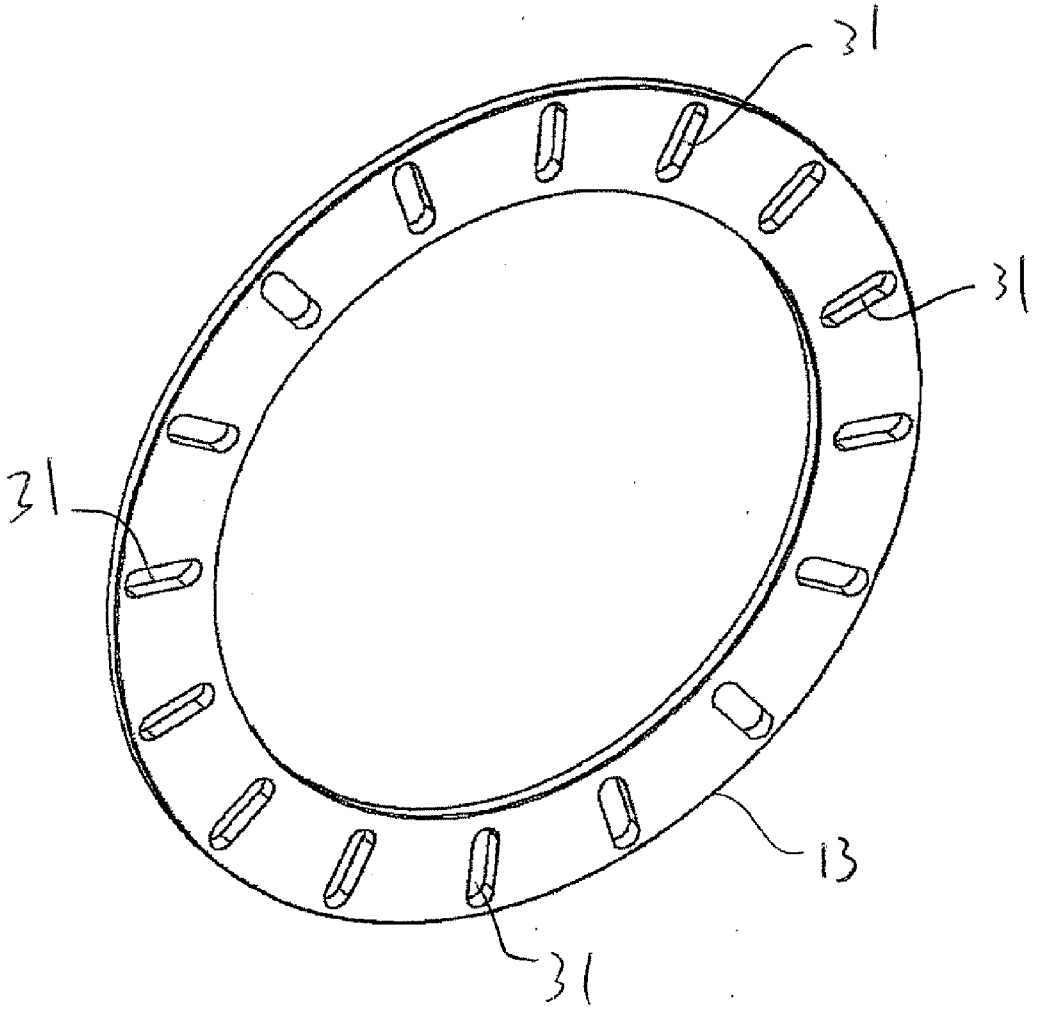


FIG. 5

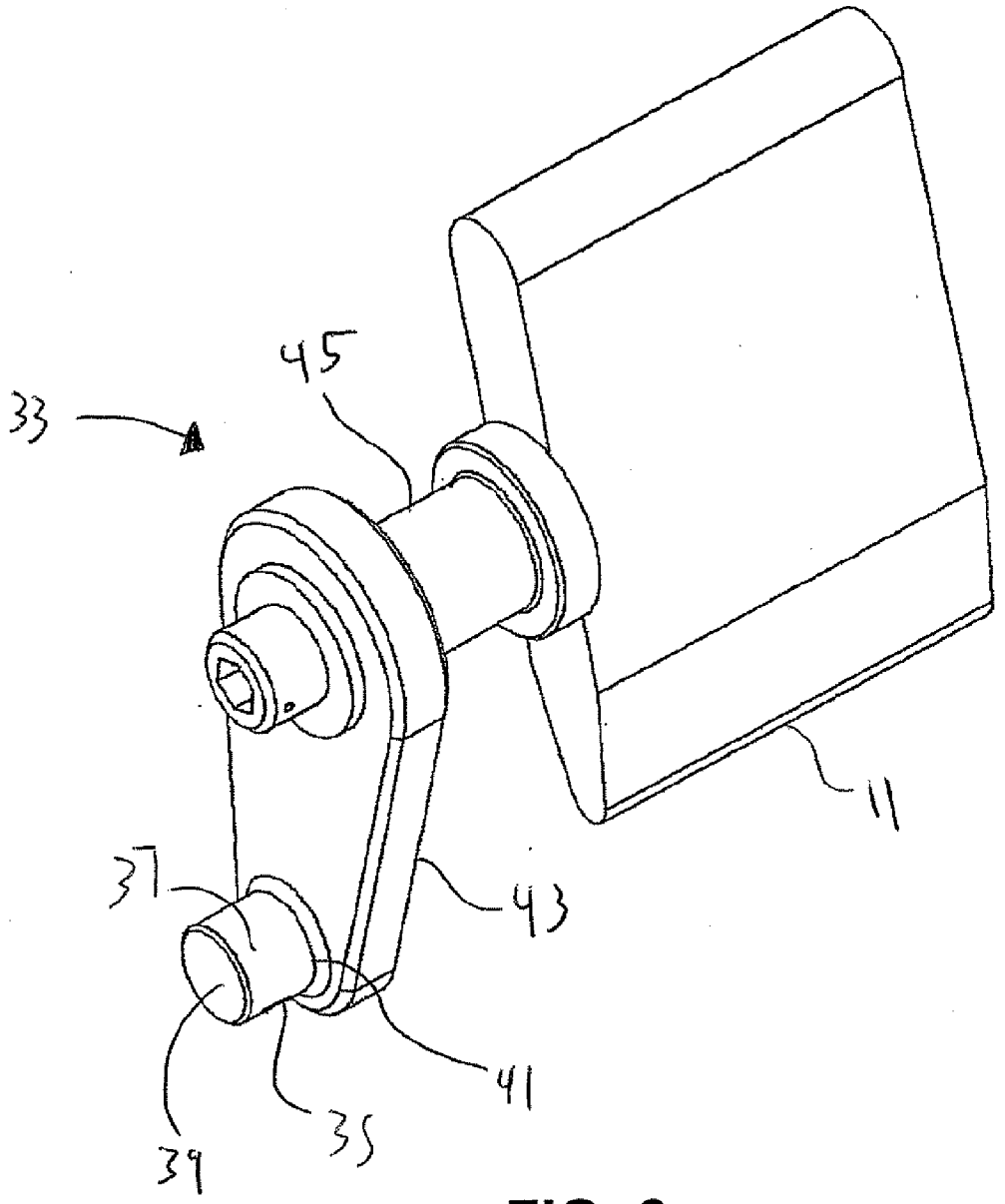


FIG. 6

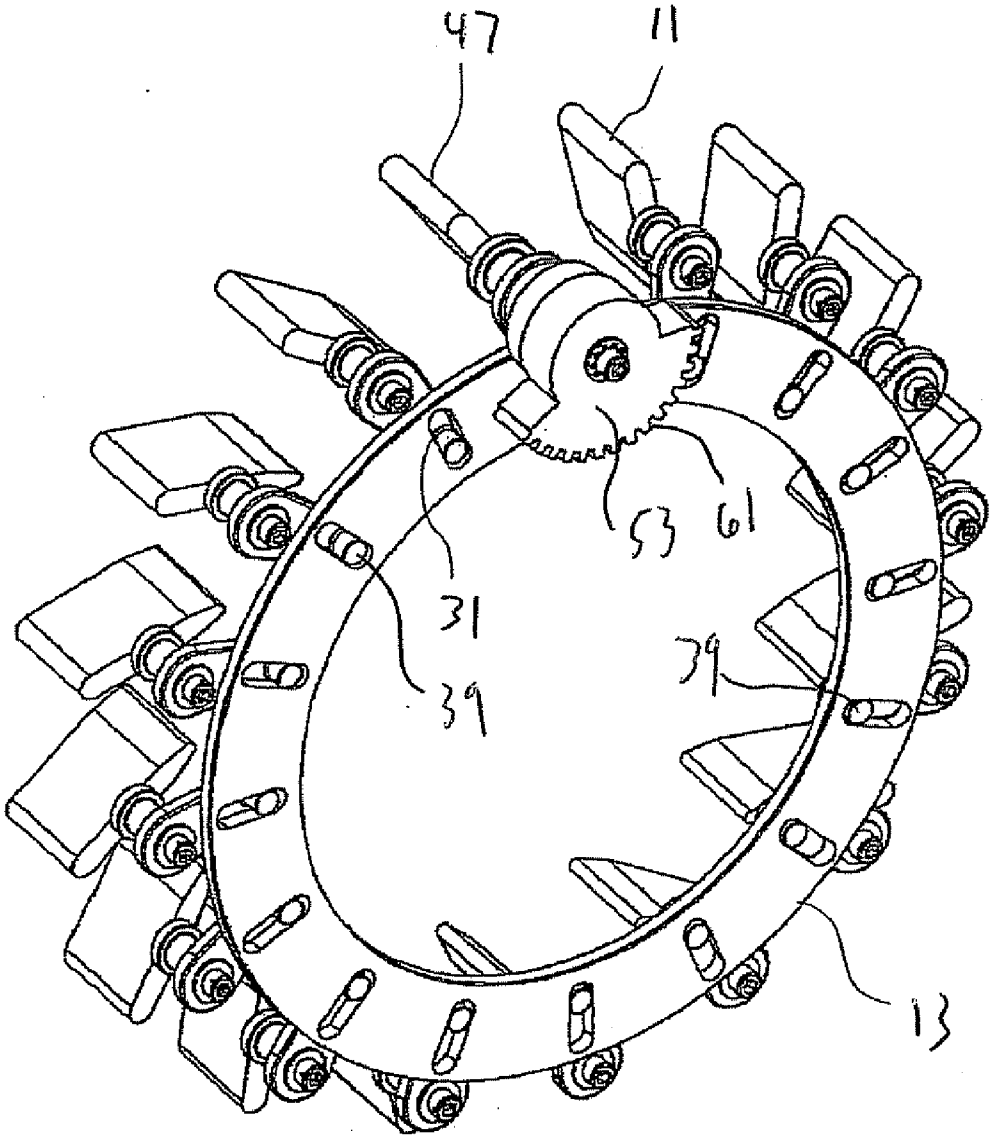


FIG. 7

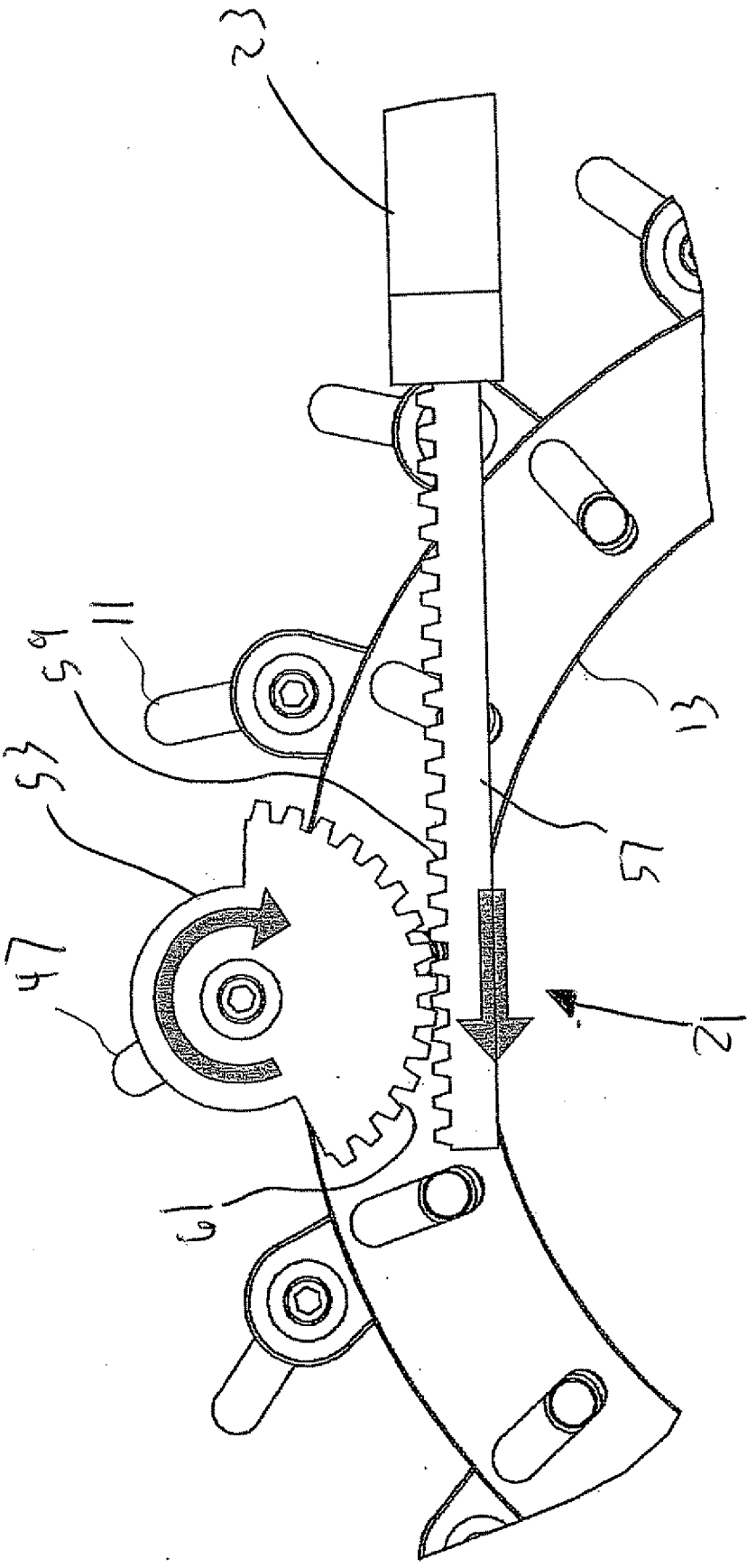


FIG. 8

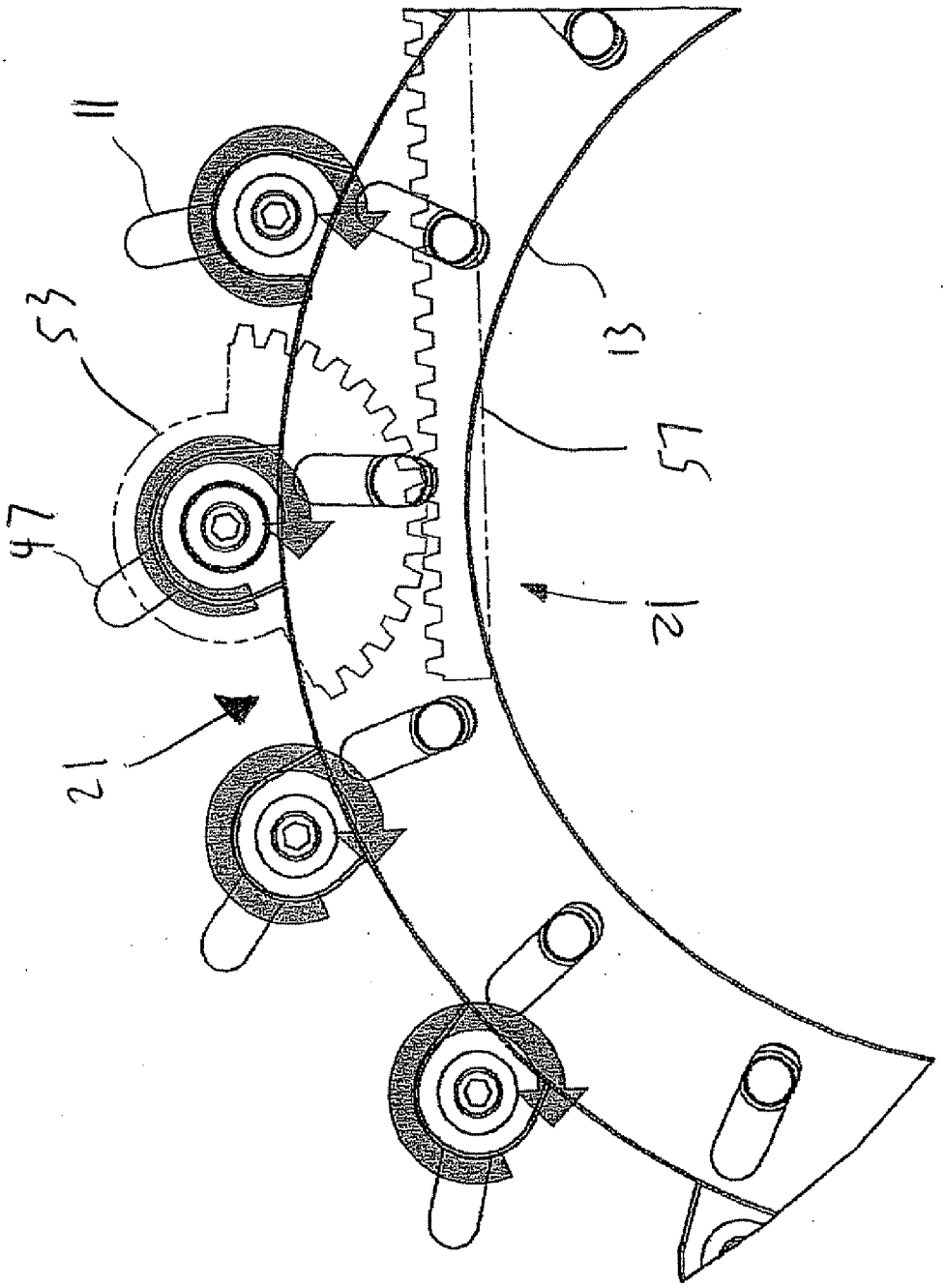


FIG. 9

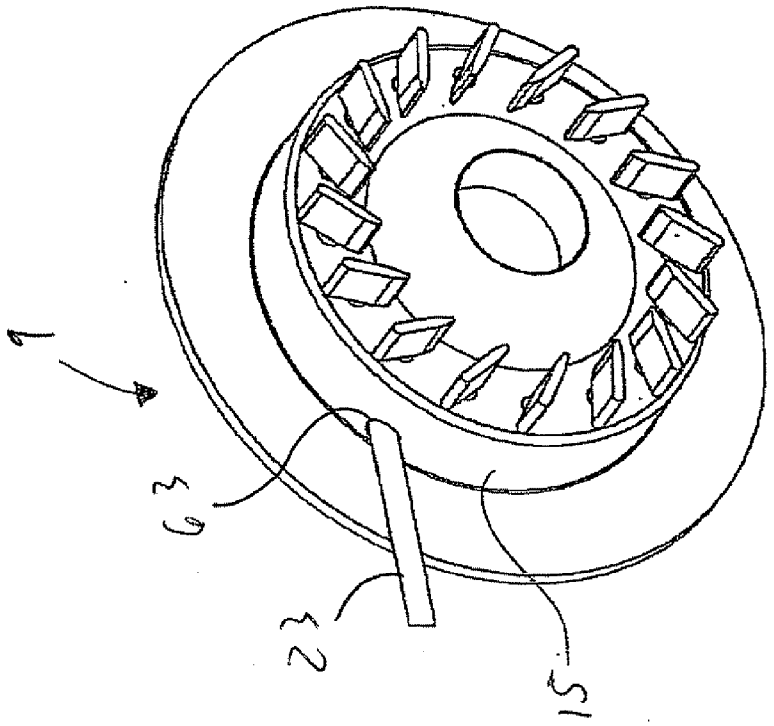


FIG. 10

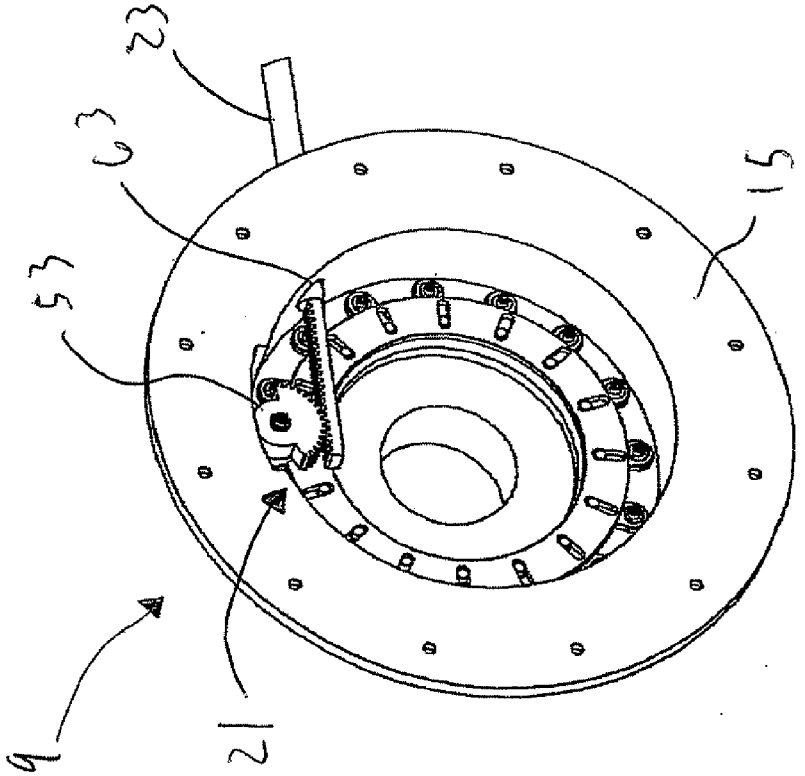


FIG. 11

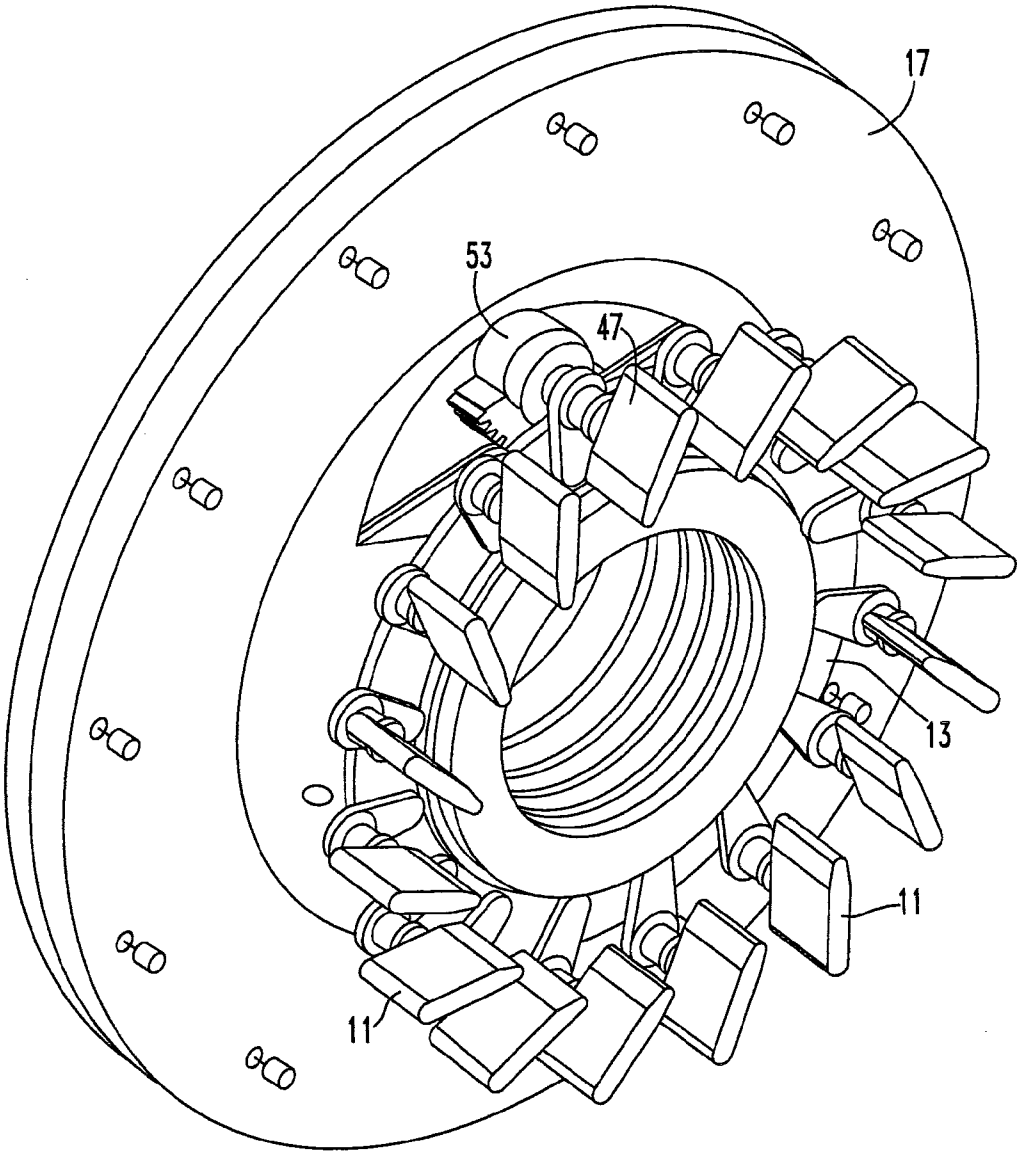


FIG.12

CENTRIFUGAL COMPRESSOR HAVING ADJUSTABLE INLET GUIDE VANES

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 60/922,713 entitled "Centrifugal Compressor Having Adjustable Inlet Guide Vanes" filed Apr. 10, 2007, which is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to the field of compressors and, more particularly, to an apparatus for the adjustment of inlet guide vanes to the compressor.

[0004] 2. Description of Related Art

[0005] Centrifugal compressors are commonly used in the liquefied natural gas industry. This application requires a large range of compressor performance characteristics due to the nature of the liquification process. In order to achieve all the variations of performance needed, it is common industry practice to use a compressor that is able to vary the angle of its vanes near the inlet stage. The ability to change the angle of the inlet vanes for various processes allows a user to achieve a broader range of performance characteristics.

[0006] U.S. Pat. No. 6,679,057 (the ∝057 patent) to Arnold discloses a turbocharger guide vane arrangement including a plurality of vanes coupled to a unison ring. The unison ring is rotated by rotation of an actuator crank, which causes an actuating lever arm to move around a longitudinal axis of the actuator crank, which in turn effects rotation of the unison ring via an actuating pin. The actuating mechanism in the '057 patent is shown in further detail in U.S. Pat. No. 6,269,642 to Arnold et al.

[0007] The prior art shows how it is possible to rotate the unison ring using gearing engaging an outer periphery of the unison ring or to use a crank arm engaged with a unison ring to rotate the ring. U.S. Pat. Nos. 6,269,642 and 6,679,057 disclose using such a crank arm to effect rotation of a unison ring with the crank arm being actuated by a rack and pinion arrangement.

[0008] However, the crank arm of the prior art is not coupled to any of the guide vanes, especially in the context of a rack and pinion gear driven master vane. Accordingly, the mechanisms for moving vanes may be improved upon.

SUMMARY OF THE INVENTION

[0009] The present invention is directed to an apparatus for adjustment of inlet guide vanes of a compressor. The apparatus includes a ring having a plurality of slots spaced around a circumference thereof; a plurality of lever arm assemblies each having a pin that includes a body with a first end and a second end and a lever arm extending perpendicularly from the second end of the body of the pin; a plurality of vanes each coupled to an end of one of the plurality of lever arms by a shaft; and a rack and pinion drive mechanism. The pin of each of the lever arm assemblies is configured to be positioned within each of the plurality of slots such that the first end of the pin extends into the slot. The rack and pinion drive mechanism includes a pinion coupled to the shaft of one of the plurality of vanes, thereby creating a drive vane; and a driven rack operationally coupled to the pinion. The drive vane is configured to rotate the ring via the rack and pinion drive mechanism, thereby adjusting an angular position of the plurality of vanes.

[0010] The driven rack may be coupled to a drive shaft that is powered by a hydraulic cylinder located externally from the compressor. The apparatus may be positioned such that it is isolated from a flow path of the compressor by an endwall cover plate. The ring may be constrained axially in the compressor by an end wall and the end wall cover plate. The plurality of vanes may be each rotated to the same angle when the drive vane rotates the ring via the rack and pinion drive mechanism, thereby adjusting the angular position of the plurality of vanes.

[0011] The present invention is also directed to a compressor including a casing; a rotor having a shaft and an impeller positioned within the casing; and a vane adjustment mechanism positioned within the casing and surrounding the rotor. The vane adjustment mechanism includes a ring having a plurality of slots spaced around a circumference thereof; a plurality of lever arm assemblies each having a pin that includes a body with a first end and a second end and a lever arm extending perpendicularly from the second end of the body of the pin; a plurality of vanes each coupled to an end of one of the plurality of lever arms by a shaft; and a rack and pinion drive mechanism. The pin of each of the lever arm assemblies is configured to be positioned within each of the plurality of slots such that the first end of the pin extends into the slot. The rack and pinion drive mechanism includes a pinion coupled to the shaft of one of the plurality of vanes, thereby creating a drive vane; and a driven rack operationally coupled to the pinion. The drive vane is configured to rotate the ring via the rack and pinion drive mechanism, thereby adjusting an angular position of the plurality of vanes.

[0012] The driven rack may be coupled to a drive shaft that is powered by a hydraulic cylinder located externally from the compressor. The apparatus may be positioned such that it is isolated from a flow path of the compressor by an endwall cover plate. The ring may be constrained axially in the compressor by an end wall and the end wall cover plate. The plurality of vanes may be each rotated to the same angle when the drive vane rotates the ring via the rack and pinion drive mechanism, thereby adjusting the angular position of the plurality of vanes.

[0013] In addition, the present invention is directed to a vane adjustment mechanism for a compressor. The vane adjustment mechanism includes a ring; and a plurality of vanes pivotally attached around a circumference of the ring. One of the plurality of vanes is a drive vane configured to rotate the ring via a rack and pinion drive mechanism, thereby adjusting an angular position of the plurality of vanes.

[0014] The ring may include a plurality of slots spaced around a circumference thereof. The vane adjustment mechanism may further include a plurality of lever arm assemblies each including a pin having a body with a first end and a second end and a lever arm extending perpendicularly from the second end of the body of the pin. The pin of each of the lever arm assemblies may be configured to be positioned within each of the plurality of slots such that the first end of the pin extends into the slot. The plurality of vanes may be each coupled to an end of one of the plurality of lever arms by a shaft.

[0015] The rack and pinion drive mechanism may include a pinion coupled to the shaft of one of the plurality of vanes, thereby creating a drive vane; and a driven rack operationally

coupled to the pinion. The driven rack may be coupled to a drive shaft and a hydraulic cylinder may be provided to power the drive shaft to drive the driven rack.

[0016] These and other features and characteristics of the present invention, as well as the methods of operation and functions of the related elements of structures, and the combination of parts and economies of manufacture, will become more apparent upon consideration of the following description and the appended claims with reference to the accompanying drawings, all of which form a part of this specification, wherein like reference numerals designate corresponding parts in the various figures. As used in the specification and the claims, the singular form of "a", "an", and "the" include plural referents unless the context clearly dictates otherwise.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. **1** is a cutaway perspective view of an apparatus for adjusting an angular position of a plurality of inlet guide vanes situated within a compressor in accordance with the present invention;

[0018] FIG. **2** is a perspective view of the apparatus for adjusting the angular position of a plurality of inlet guide vanes for a compressor, in accordance with the present invention;

[0019] FIG. **3** is a front plan view of the apparatus shown in FIG. **2**;

[0020] FIG. **4** is a cross-sectional view of the apparatus taken along lines **4-4** of FIG. **3**;

[0021] FIG. **5** is a perspective view of a rotating ring of the apparatus;

[0022] FIG. **6** is a perspective view of a vane with a lever arm of the apparatus;

[0023] FIG. **7** is a perspective view of a plurality of vanes secured within the ring via the corresponding lever arms thereof;

[0024] FIG. **8** is a partial front plan view of the ring with a rack and pinion mechanism of the apparatus;

[0025] FIG. **9** is a partial rear plan view of the ring with the rack and pinion mechanism of the apparatus;

[0026] FIG. **10** is a front perspective view of the apparatus showing the rack;

[0027] FIG. **11** is a rear perspective view of the apparatus showing the rack and pinion mechanism; and

[0028] FIG. **12** is a perspective view of the apparatus showing the ring centered on an endwall.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

[0029] For purposes of the description hereinafter, the terms "upper", "lower", "right", "left", "vertical", "horizontal", "top", "bottom", "lateral", "longitudinal" and derivatives thereof shall relate to the invention as it is oriented in the drawing figures. However, it is to be understood that the invention may assume various alternative variations, except where expressly specified to the contrary. It is also to be understood that the specific devices illustrated in the attached drawings, and described in the following specification, are simply exemplary embodiments of the invention. Hence, specific dimensions and other physical characteristics related to the embodiments disclosed herein are not to be considered as limiting.

[0030] With reference to FIG. **1**, a centrifugal compressor, denoted generally as reference numeral **1**, includes a casing **3** with a rotor positioned therein. The rotor includes an impeller **5** and a shaft **7**. An apparatus, or vane adjustment mechanism, denoted generally as reference numeral **9**, for adjusting an angular position of a plurality of inlet guide vanes **11** is positioned within casing **3** and surrounds shaft **7** of the rotor. Compressor **1** further includes a bearing housing **29** coupled to endwall **17**.

[0031] Vane adjustment mechanism **9** includes a rotating ring **13** with the plurality of inlet guide vanes **11** positioned around a circumference thereof as will be described in greater detail hereinafter. Vane adjustment mechanism **9** is positioned within casing **3** of compressor **1**, such that it is isolated from a flow path of compressor **1** by an endwall cover plate **15**. By keeping the vane rotation mechanism **9** out of the flow path, aerodynamic efficiency and performance of the inlet stage may be maintained. Additionally, rotating ring **13** constrained axially in compressor **1** by an endwall **17** and endwall cover plate **15**. Rotating ring **13** should also be aligned with the centerline of compressor **1** to ensure that vanes **11** rotate at the same angle. This is achieved by centering rotating ring **13** on a surface of endwall **17**, as shown in FIG. **12**, for instance. Vane adjustment mechanism **9** also includes a rack and pinion drive mechanism **21** as will be discussed in greater detail hereinafter. Rack and pinion drive mechanism **21** is coupled to a drive shaft **23** that is powered by a hydraulic cylinder **25** located in a housing **27** positioned externally from compressor **1**.

[0032] With reference to FIGS. **2-6**, and with continuing reference to FIG. **1**, vane adjustment mechanism **9** includes a plurality of adjustable inlet guide vanes **11** positioned around the circumference of rotating ring **13**. While vane adjustment mechanism **9** illustrated in the figures includes sixteen adjustable inlet guide vanes **11**, this is not to be construed as limiting the present invention as any suitable number of vanes may be utilized. Generally, in order for the aerodynamic design of the adjustable inlet guide vanes **11** to be effective, each vane **11** in the inlet section of compressor **1** should be rotated at the same angle. As shown in FIG. **5**, vane adjustment mechanism **9** achieves the aforementioned design criteria by using a rotating ring **13** that can accommodate each vane **11** within an elongated slot **31** thereof via a lever arm assembly **33**.

[0033] With specific reference to FIG. **6**, each lever arm assembly **33** includes a pin **35** having a body **37** with a first end **39** and a second end **41** and a lever arm **43** extending perpendicularly from second end **41** of body **37** of pin **35**. Vanes **11** are each coupled to an end of one of the plurality of lever arms **43** by a shaft **45**. Body **37** of pin **35** of each lever arm assembly **33** is configured to be positioned within elongated slots **31** of rotating ring **13**, such that first end **39** of pin **35** extends into elongated slot **31**. As rotating ring **13** rotates, each vane **11** is rotated by the same angle.

[0034] With reference to FIGS. **7** through **12**, and with continuing reference to FIGS. **1-6**, vane adjustment mechanism **9** also includes a rack and pinion drive mechanism **21** configured to drive one of the plurality of vanes **11**, thereby creating a drive vane **47**. Rack and pinion drive mechanism **9** includes a pinion **53** coupled to an elongated shaft **55** (see FIG. **4**) of drive vane **47** and a driven rack **57**. Driven rack **57** includes a plurality of teeth **59** that are configured to engage a plurality of teeth **61** on the pinion **53**, thereby operationally coupling driven rack **57** to pinion **53**. An end of driven rack **57**

is coupled to drive shaft **23** that is powered by hydraulic cylinder **25**. Hydraulic cylinder **25** is positioned in a housing **27** positioned externally from the casing **3** of compressor **1** to keep the hydraulic cylinder **25** at a higher temperature than compressor **1**. Drive shaft **23** imparts linear motion to driven rack **57** which is converted to rotational motion in pinion **53**. Drive shaft **23** is coupled to driven rack **57** through a hole **63** provided in endwall cover plate **15**.

[0035] In operation, drive shaft **23** imparts linear motion to driven rack **57**. This linear motion is converted to rotational motion in pinion **53**, thereby rotating drive vane **47**. Drive vane **47** transfers torque to rotating ring **13** due to the positioning of pin **35** of lever arm assembly **33** within elongated slot **31** of rotating ring **13**. The torque is thereby transmitted to the remaining vanes **11** as shown in FIGS. **8** and **9**. More specifically, as drive vane **47** rotates, pin **35** of lever arm assembly **33** moves within elongated slot **31** of rotating ring **13**, thereby causing pins **35** of lever arm assemblies **33** of the other vanes **11** to move within their respective slots of rotating ring **13**. This causes the respective vanes **11** to synchronously change their angular position at the same angle. Accordingly, drive vane **47** is configured to rotate rotating ring **13** via rack and pinion drive mechanism **21** to adjust the angular position of the plurality of vanes **11**.

[0036] Although the invention has been described in detail for the purpose of illustration based on what is currently considered to be the most practical and preferred embodiments, it is to be understood that such detail is solely for that purpose and that the invention is not limited to the disclosed embodiments, but, on the contrary, is intended to cover modifications and equivalent arrangements that are within the spirit and scope of the appended claims. For example, it is to be understood that the present invention contemplates that, to the extent possible, one or more features of any embodiment can be combined with one or more features of any other embodiment.

The invention claimed is:

1. An apparatus for adjustment of inlet guide vanes of a compressor comprising:
- a ring having a plurality of slots spaced around a circumference thereof;
- a plurality of lever arm assemblies each comprising a pin having a body with a first end and a second end and a lever arm extending perpendicularly from the second end of the body of the pin, the pin of each of the lever arm assemblies configured to be positioned within each of the plurality of slots, such that the first end of the pin extends into the slot;
- a plurality of vanes each coupled to an end of one of the plurality of lever arms by a shaft; and
- a rack and pinion drive mechanism comprising:
  - a pinion coupled to the shaft of one of the plurality of vanes, thereby creating a drive vane; and
  - a driven rack operationally coupled to the pinion,
- wherein the drive vane is configured to rotate the ring via the rack and pinion drive mechanism, thereby adjusting an angular position of the plurality of vanes.

2. The apparatus for adjustment of inlet guide vanes of a compressor of claim **1**, wherein the driven rack is coupled to a drive shaft.

3. The apparatus for adjustment of inlet guide vanes of a compressor of claim **2**, wherein a hydraulic cylinder powers the drive shaft to drive the driven rack.

4. The apparatus for adjustment of inlet guide vanes of a compressor of claim **3**, wherein the hydraulic cylinder is located external to the compressor.

5. The apparatus for adjustment of inlet guide vanes of a compressor of claim **1**, wherein the apparatus is isolated from a flow path of the compressor by an endwall cover plate.

6. The apparatus for adjustment of inlet guide vanes of a compressor of claim **5**, wherein the ring is constrained axially in the compressor by an end wall and the end wall cover plate.

7. The apparatus for adjustment of inlet guide vanes of a compressor of claim **1**, wherein the plurality of vanes are each rotated to the same angle when the drive vane rotates the ring via the rack and pinion drive mechanism, thereby adjusting the angular position of the plurality of vanes.

8. A compressor comprising:
- a casing;
- a rotor comprising a shaft and an impeller positioned within the casing; and
- a vane adjustment mechanism positioned within the casing and surrounding the rotor, the vane adjustment mechanism comprising:
  - a ring having a plurality of slots spaced around a circumference thereof;
  - a plurality of lever arm assemblies each comprising a pin having a body with a first end and a second end and a lever arm extending perpendicularly from the second end of the body of the pin, the pin of each of the lever arm assemblies configured to be positioned within each of the plurality of slots, such that the first end of the pin extends into the slot;
  - a plurality of vanes each coupled to an end of one of the plurality of lever arms by a shaft; and
  - a rack and pinion drive mechanism comprising:
    - a pinion coupled to the shaft of one of the plurality of vanes, thereby creating a drive vane; and
    - a driven rack operationally coupled to the pinion,
  - wherein the drive vane is configured to rotate the ring via the rack and pinion drive mechanism, thereby adjusting an angular position of the plurality of vanes.

9. The compressor of claim **8**, wherein the driven rack is coupled to a drive shaft.

10. The compressor of claim **9**, wherein a hydraulic cylinder powers the drive shaft to drive the driven rack.

11. The compressor of claim **10**, wherein the hydraulic cylinder is positioned within a housing located external to the casing of the compressor.

12. The compressor of claim **8**, wherein the vane adjustment mechanism is isolated from a flow path of the compressor by an endwall cover plate.

13. The compressor of claim **8**, wherein the ring is constrained axially in the compressor by an end wall and the end wall cover plate.

14. The compressor of claim **8**, wherein the plurality of vanes are each rotated to the same angle when the drive vane rotates the ring via the rack and pinion drive mechanism, thereby adjusting the angular position of the plurality of vanes.

15. A vane adjustment mechanism for a compressor comprising:
- a ring; and
- a plurality of vanes pivotally attached around a circumference of the ring,

wherein one of the plurality of vanes is a drive vane configured to rotate the ring via a rack and pinion drive mechanism, thereby adjusting an angular position of the plurality of vanes.

16. The vane adjustment mechanism of claim **15**, wherein the ring includes a plurality of slots spaced around a circumference thereof.

17. The vane adjustment mechanism of claim **16**, further comprising a plurality of lever arm assemblies each comprising a pin having a body with a first end and a second end and a lever arm extending perpendicularly from the second end of the body of the pin, the pin of each of the lever arm assemblies configured to be positioned within each of the plurality of slots such that the first end of the pin extends into the slot.

18. The vane adjustment mechanism of claim **17**, wherein the plurality of vanes are each coupled to an end of one of the plurality of lever arms by a shaft.

19. The vane adjustment mechanism of claim **15**, wherein the rack and pinion drive mechanism comprises:

a pinion coupled to the shaft of one of the plurality of vanes, thereby creating a drive vane; and

a driven rack operationally coupled to the pinion.

20. The vane adjustment mechanism of claim **8**, wherein the driven rack is coupled to a drive shaft and a hydraulic cylinder powers the drive shaft to drive the driven rack.

* * * * *