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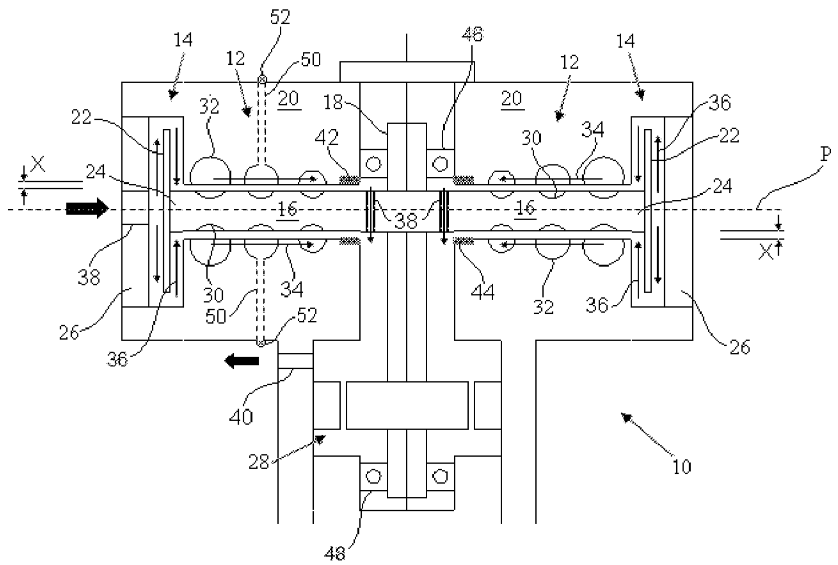
(54) Title: VACUUM PUMP

FIG. 1



(57) Abstract: The present invention relates to a vacuum pump (10) comprising a regenerative pumping mechanism (12) and a drag pumping mechanism (14). The regenerative pumping mechanism (12) comprises a generally disc-shaped member (16) mounted on an axial shaft (8) for rotation relative to a stator (20) of the regenerative pumping mechanism. The drag pumping mechanism (14) comprising a generally cylindrical-shaped member (22) mounted at an outer circumferential portion (24) of the disc-shaped member (16) for rotation about the axial shaft (18) relative to a stator of the drag pumping mechanism.

WO 2014/125238 A1

VACUUM PUMP

The present invention relates to a vacuum pump comprising regenerative pumping mechanism and a drag pumping mechanism.

WO2010/133866 is an earlier application of the present applicant. The earlier application discloses a vacuum pump comprising a regenerative pumping mechanism and a drag pumping mechanism. The regenerative pumping mechanism and the drag pumping mechanism comprise respective generally disc-shaped members which are mounted to an axial drive shaft at axially spaced locations on the drive shaft. Fluid flow paths are generated for conveying fluid through the drag pumping mechanism and then radially outwardly through the regenerative pumping stage towards the outlet. Fluid conveyed through the drag pumping mechanism passes over a first surface of the disc-shaped rotor and then over a second surface of the disc-shaped rotor. The pressure of the fluid over the two surfaces is different (the pressure over the first surface is lower than the pressure over the second surface) and gives rise to different forces. The disc-shaped rotor is not therefore balanced and this can give rise to problems in certain pumping conditions.

The present invention seeks to provide an improved vacuum pump.

The present invention provides a vacuum pump comprising a regenerative pumping mechanism and a drag pumping mechanism, the regenerative pumping mechanism comprising a generally disc-shaped member mounted on an axial shaft for rotation relative to a stator of the regenerative pumping mechanism, the drag pumping mechanism comprising a generally cylindrical-shaped member mounted at an outer circumferential portion of the disc-shaped member for rotation about the axial shaft relative to a stator of the drag pumping mechanism, rotation of the disc-shaped member and the cylindrical-shaped member by the axial shaft causing fluid to flow radially inwardly in series through the drag pumping mechanism and the regenerative pumping mechanism.

Other preferred and/or optional aspects of the invention are defined in the accompanying claims.

In order that the present invention may be well understood, an embodiment thereof, which is given by way of example only, will now be described with reference to the accompanying drawing, in which:

Figure 1 shows a vacuum pump having a drag pumping mechanism and a regenerative pumping mechanism.

Referring to Figure 1, a vacuum pump 10 is shown comprising a regenerative pumping mechanism 12 and a drag pumping mechanism 14. The regenerative pumping mechanism 12 comprises a generally disc-shaped member 16 mounted on an axial shaft 18 for rotation relative to a stator 20 of the regenerative pumping mechanism. The drag pumping mechanism 14 comprising a generally cylindrical-shaped member 22 mounted at an outer circumferential portion 24 of the disc-shaped member 16 for rotation about the axial shaft 18 relative to a stator of the drag pumping mechanism. As shown in Figure 1 a portion of the stator of the drag pumping mechanism is formed by stator 20 and another portion of the stator of the drag pumping mechanism is formed by a separate stator part 26. Rotation of the disc-shaped member 16 and the cylindrical-shaped member 22 by the axial drive shaft causes fluid to flow radially inwardly in series through the drag pumping mechanism and the regenerative pumping mechanism. The shaft is driven by a motor 28 and may rotate at speeds of around 40,000 rpm.

The rotor disc-shaped member 16 has a plurality of rotor formations 30 for pumping gas along channels 32. In order not to overcomplicate Figure 1 not all of the formations and channels have been labelled. As described in more detail in the applicant's earlier applications WO2010/133866, WO2010/133867 and WO2010/133868, the contents of which are herein incorporated by reference, the rotor formations 30 are formed by a series of shaped recesses arranged in concentric circles at respective circumferences on the disc-shaped member 16. Three such circumferences are shown in Figure 1, however, greater or fewer numbers can be provided depending on requirements. The concentric circles are aligned with respective circumferential channels formed in the stator 20. The shaped recesses 30 and the stator channels 32 form a gas flow path from an inlet to an outlet of the pumping mechanism so that when the rotor is rotated the shaped recesses generate a gas vortex which flows along the flow path. The stator channels 32 are circumferential throughout most of their extent but comprise a generally straight section for directing gas from one channel to a radially inner channel.

As shown in Figure 1, the disc-shaped member 16 comprises rotor formations 30 on opposing sides. Three arrays of rotor formations are located on an upper side of the disc 16 and three arrays of rotor formations are located on the lower side of the disc 16. The upper and lower rotor formations 30 are co-operable with channels 32 of complementary portions of the stator 20. In Figure 1, the channels 32 located above the disc cooperate with the rotor formations on the upper side of the disc and the channels 32 located below the disc cooperate with the rotor formations 30 on the lower surface of the disc. Therefore, the regenerative pumping mechanism 12 can pump fluid along parallel fluid flow paths on the opposing sides of the disc. The parallel flow paths are shown schematically by arrows 34 pointing radially inwardly, although it will be appreciated that the flow paths are in reality conveyed circumferential around each channel 32 and from one channel to the next inner channel. The parallel flow paths 34 of the regenerative pumping mechanism are symmetrical about a central plane P of the disc 16 such that forces generated during pumping fluid along said parallel flow paths are balanced in the regenerative pumping mechanism.

The generally cylindrical member 22 of the drag pumping mechanism 14 cooperates with the stator 20, 26 to pump fluid along spiral channels formed in either the cylindrical member or the stator. The general arrangement of such a Holweck type pumping mechanism is known to the skilled person. In the arrangement shown in Figure 1, the cylinder 22 comprises a first, outer, cylindrical portion and a second, inner, cylindrical portion extending on opposing axial sides of the cylinder. The outer portion of the cylinder faces the inner portion of stator part 26. The inner portion of the cylinder faces the outer portion of the stator 20. Fluid is pumped in parallel along flow paths shown schematically by arrows 36.

The generally cylindrical member is preferably made form a strong light material such as carbon fibre for reducing inertia about the axial shaft and reducing bending at the axial ends of the cylinder during rotation at speeds of around 40,000 rpm. It will be appreciated that the axial spacing between the rotor and the stator needs to be controlled accurately in order to improve performance and therefore a reduction in bending of the cylinder reduces the required tolerance between the rotor and the stator.

Fluid enters the vacuum pump 10 through inlet 38 and is conveyed along parallel pumping channels 36. The parallel flow paths of the drag pumping mechanism are symmetrical about the central plane P and therefore unlike the earlier patent application, the pressure along the flow paths is generally equal one flow path with the other flow. Therefore, the forces on each side of the drag pumping mechanism balance.

Fluid conveyed from the parallel flow paths of the drag pumping mechanism 14 passes into respective flow paths 34 of the regenerative pumping mechanism 12. Flow paths terminate towards the radial centre of the vacuum pump proximate the axial shaft 18. Fluid conveyed along the flow path 34 above the disc 16 passes through bores 38 extending through the disc. Subsequently fluid passing along both parallel paths 34, 36 is exhausted through outlet 40 typically at atmospheric pressure.

An axial gas bearing arrangement is located at an inner circumference of the generally disc-shaped member 16 for maintaining an axial clearance X between the disc-shaped member and the stator of the regenerative pumping mechanism. The axial gas bearing arrangement comprises first and second axial gas bearings 42, 44 on opposing sides of the generally disc-shaped member. The axial gas bearing arrangement is described in detail in the present applicant's earlier application, however in the earlier application the gas bearing is located at an outer circumference of the disc-shaped member of the regenerative mechanism unlike the present application where it is located at an inner circumference. In the present application, the cylinder 22 of the drag pumping mechanism is located at an outer circumference of the disc 16 proximate the inlet 38 and therefore at low pressure. The gas bearing 42, 44 is therefore located at the inner circumference since gas bearings require pressure close to atmosphere to perform acceptably. In other respects, the present gas bearing is similar to that described in the earlier application and therefore will be described only briefly in this application.

The axial gas bearings 42, 44 comprises a rotor part on the disc and a stator part on the stator 20 located so that gas pumped along the flow paths between the inlet and the outlet can pass between the two parts for controlling the axial clearance X. The gas bearing is beneficial because it allows a small axial running clearance between rotor and stator which is necessary for reducing leakage and producing an efficient small pump. Typical axial clearances achievable in embodiments of the invention are in the range of 10-30 μm and even 10-15 μm. The axial clearance between the rotor and stator of the regenerative pumping mechanism is controlled by the gas bearing, whereas the radial clearance between the rotor and the stator of the drag pumping mechanism is controlled by ball bearings, described in more detail below.

In Figure 1, the axial gas bearing are located on the flow paths between the inlet 38 and the outlet 40 of the pump and therefore it is the pumped gas that forms the gas that supports loading in the bearings. In some pumping applications the pumped gas may contain entrained dirt or dust which can become clogged in the axial gas bearings reducing their efficiency. In a modification of the Figure 1 arrangement, the gas which has been pumped along the flow paths 34, 36 is diverted towards the outlet 40 prior to passing through the axial gas bearings 42, 44 to reduce clogging of the bearings by dirt or dust. The diversion paths may be formed in the rotor and/or stator radially outward from the axial gas bearings. In this case, the axial gas bearings may use ambient gas in the region of the shaft 18 which is typically at atmosphere for supporting loading between the bearing surfaces.

Although an air bearing is able to produce small axial running clearances, air bearings are not well suited to carrying relatively heavy loads. Accordingly, in Figure 1, the flow paths 34 of the regenerative pumping mechanism are symmetrical on each side of the disc 16 relative to the central plane P extending orthogonally to the axial shaft 18. Additionally, the flow paths 36 are symmetrical between an upper portion of the cylinder

22 and a lower portion of the cylinder. Therefore, the forces generated during pumping are generally balanced to such an extent that the air bearing 28 can resist the relatively small and transient loading applied to the bearing.

The gas bearings are located on the atmospheric side of the pumping mechanisms where the pressure of pumped gas is greatest and typically at atmosphere. In Figure 1, the atmospheric side of the pumping mechanisms is at a radially central part of the pump. In the applicant's earlier application, it is indicated that the gas bearing is preferably located at a radially outer part of the pump, where tangential velocity of the rotating disc of the regenerative pumping mechanism is highest. In addition to the pressure of gas in the bearings, the tangential velocity between relatively rotating parts also contributes to the bearing forces which can be generated by the gas bearing. The location of the gas bearing at a radially central part of the pump, where tangential velocity of the disc 16 is lowest, is therefore counter-intuitive. A consequence of locating the gas bearing at radially outer part of the rotating disc in the earlier application is that the low pressure stage(s) of the regenerative pumping mechanism are located at a central part of the mechanism whereas the high pressure stage(s) are located at an outer part of the mechanism. The applicant's have found however that the benefits arising from locating the gas bearing at an outer part of the pump are outweighed by the detrimental effect of locating the low pressure stages towards the centre of the pump and the high pressure stages towards the outer part of the pump. In this regard, low pressure (or high vacuum) stages are required to be relatively large so that they are able to pump a reduced amount of gas at low pressure. Conversely, the high pressure (low vacuum) stages are required to be small because otherwise they would encounter significant gas resistance. In the earlier design the smaller high pressure stages are located at an outer part of the pump where they are rotated with the greatest tangential speed and this higher speed increases gas resistance. Similarly, the low pressure stages are located towards the centre of the pump where they are rotated at the lowest tangential speed and this lower speed reduces the amount of gas that can be pumped or the compression ratio that can be achieved at low pressure. In the present application, the location of the stages enhances rather than detracts from the requirements of the stages at high and low vacuum, since the larger rotor formations 30 of the high vacuum stage are driven at the greatest tangential speed and the smaller rotor formations 30 of the low vacuum stage are driven at the lowest tangential speed. Rotation of the gas bearings 42, 44 at lower speeds is found to produce acceptable bearing forces.

Ball bearings 46, 48 are provided for supporting the drive shaft 18 at end portions thereof. The ball bearings control the radial location of the disc 16 and the cylinder 22. The radial location of the disc relative to the stator is less critical for pumping performance than the relative axial location, since the rotor formations 30 may be slightly radially misaligned with their respective channels 32 without significantly reducing performance. Therefore, even though the ball bearings require greater tolerances and do not fix the relative radial location as accurately as the gas bearing described above, the ball bearings are acceptable. Additionally, the radial location of the cylinder 22 relative to the stator parts is important for the performance of the drag pumping mechanism 14 (typically having a radial spacing of between about 0.1 to 0.5 mm) however this relative location is less critical than the relative axial location of the disc 16 relative to the stator 20 (typically having an axial spacing of 10-20 μm). A back-up bearing (not shown) may be provided in the event of failure of the gas bearing to prevent significant damage to the pump occurring due to a high speed collision of rotor and stator.

The present vacuum pump is configured to pump down from atmosphere to high vacuums in the region of 10^{-3} mbar. When pumping commences, the pressure at the inlet 38 is at atmosphere. The drag pumping mechanism 14 is not efficient at these pressures and therefore pump down from atmosphere is performed primarily by the regenerative pumping mechanism 12. However, the larger upstream stages of the regenerative mechanism are arranged to operate at low pressures but when operating at high pressures they encounter significant resistance to rotation. In the pump shown in Figure 1, a blow-off pathway 50 is provided which can vent to atmosphere through a blow-off valve 52. The blow-off valve 52 selectively opens the fluid path 50 between atmosphere and a stage of the regenerative pumping mechanism inward from the outer circumference for bypassing at least one inner pumping stage from the fluid flow path 34. The blow-off valve may be configured to open the fluid path 50 at pressures above a predetermined pressure and close the path at pressures below the predetermined pressure, preferably with some hysteresis. The switch-over pressure can be determined by those skilled in the art simply by operating the pump and monitoring characteristics such as rotational speed and motor power. The valve may be operably connected to a suitable located pressure sensor for sensing pressure in the pump and initiating opening and closing of the valve. Alternatively, the valve may be arranged mechanically to open and close at the selected pressure. In the arrangement shown, upper and lower bypass flow paths and bypass valve are provided for bypassing one or more pumping stages of the flow paths on both sides of the disc 16. Both upper and lower valves are operated substantially simultaneously for closing and opening so that the flow paths are symmetrical on both side of the disc and the forces balance.

CLAIMS

1. A vacuum pump comprising a regenerative pumping mechanism and a drag pumping mechanism, the regenerative pumping mechanism comprising a generally disc-shaped member mounted on an axial shaft for rotation relative to a stator of the regenerative pumping mechanism, the drag pumping mechanism comprising a generally cylindrical-shaped member mounted at an outer circumferential portion of the disc-shaped member for rotation about the axial shaft relative to a stator of the drag pumping mechanism, rotation of the disc-shaped member and the cylindrical-shaped member by the axial shaft causing fluid to flow radially inwardly in series through the drag pumping mechanism and the regenerative pumping mechanism.

2. A vacuum pump as claimed in claim 1, wherein the generally disc-shaped member comprises rotor formations on opposing sides thereof co-operable with complementary portions of the stator of the regenerative pumping mechanism for pumping fluid along parallel fluid flow paths on said opposed sides.

3. A vacuum pump as claimed in claim 1 or 2, wherein the generally cylindrical-shaped member comprises first and second cylindrical portions extending on opposing axial sides generally disc-shaped member co-operable with complementary portions of the stator of the drag pumping mechanism for pumping fluid along parallel fluid flow paths on said first and second cylindrical portions.

4. A vacuum pump as claimed in claim 2 or 3, wherein the parallel flow paths of the regenerative pumping mechanism are symmetrical about a central plane of the generally disc-shaped member and/or the parallel flow paths of the drag pumping mechanism are symmetrical about said central plane, such that forces generated during pumping fluid along said parallel flow paths are balanced in the regenerative pumping mechanism and/or the drag pumping mechanism.

5. A vacuum pump as claimed in claim 4, comprising an axial gas bearing arrangement located at an inner circumference of the generally disc-shaped member for maintaining an axial clearance between the disc-shaped member and the stator of the regenerative pumping mechanism.

6. A vacuum pump as claimed in any one of the preceding claims, wherein the axial gas bearing arrangement comprises first and second axial gas bearing on opposing sides of the generally disc-shaped member.

7. A vacuum pump as claimed in claim 6, wherein fluid passing along the parallel fluid flow paths is conveyed respectively through the axial gas bearings towards the outlet of the pump.

8. A vacuum pump as claimed in claim 6, wherein fluid passing along the parallel flows paths is diverted along one or more diversions paths in the rotor and/or stator for by-passing the axial gas bearings.

9. A vacuum pump as claimed in any one of the preceding claims, wherein the regenerative pumping mechanism comprises a plurality of pumping stages arranged at respective circumferences of the generally disc-shaped member and the rotor formations of the pumping stages decrease in size from an outer circumference towards an inner circumference.

10. A vacuum pump as claimed in claim 9, comprising a blow-off valve for selectively opening a fluid path between a stage of the regenerative pumping mechanism inward from the outer circumference and atmosphere for bypassing at least one inner pumping stage from the fluid flow path.

11. A vacuum pump as claimed in any one of the preceding claims, wherein generally cylindrical member is made from carbon fibre for reducing inertia about the axial shaft.

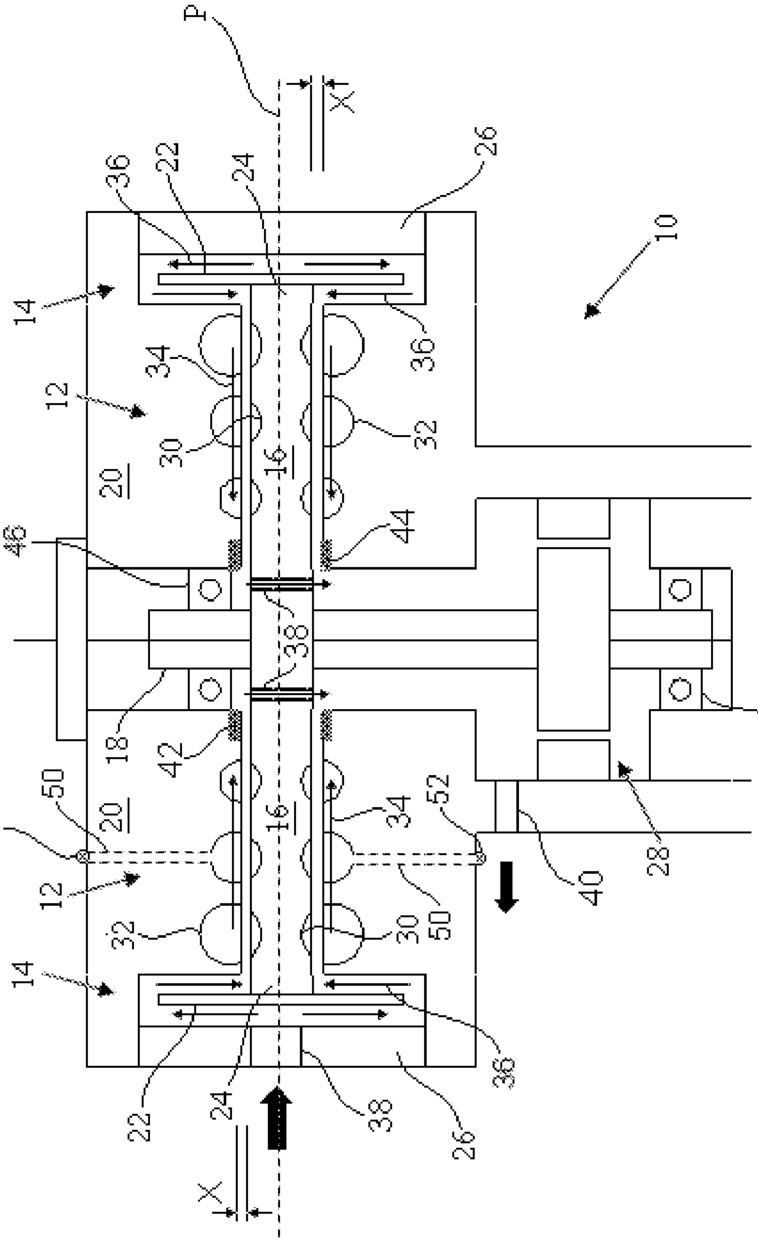


FIG. 1

INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
INV. F04D19/04 F04D23/00 F04D29/057
ADD.

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

B. FIELDS SEARCHED

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

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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A	paragraphs [0014], [0020]; claim 9; figure 1	1

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Form PCT/ISA/210 (continuation of second sheet) (April 2005)

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