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Driver et al.

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(54) **ROTARY POSITIVE-DISPLACEMENT FLUID MACHINES**

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(73) Assignee: **Driver Technology Limited**, Leicestershire (GB)

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(51) **Int. Cl.**[7] **F01C 1/44**
(52) **U.S. Cl.** **418/265**
(58) **Field of Search** 418/265

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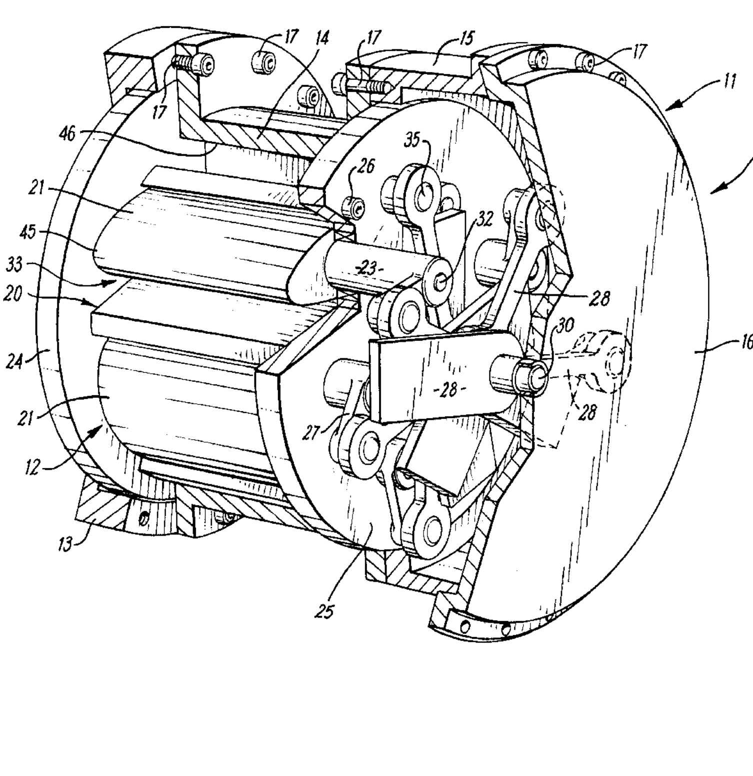
Primary Examiner—John J. Vrablik
(74) *Attorney, Agent, or Firm*—Morgan, Lewis & Bockius LLP

(57) **ABSTRACT**

A rotary positive-displacement fluid machine comprising a rotor eccentrically mounted in a casing for rotation about an axis, the rotor having recesses respectively receiving vanes which oscillate in the recesses as the rotor rotates. Each vane is connected by a crank to an arm for oscillation about a vane axis which is located inwards of the outer extremity of the tip which itself has a clearance fit within the casing. The tip of each vane is preferably curved about an axis parallel to the respective vane axis. The machine may be connected to the crankshaft of an internal combustion engine and driven by the pressure difference between the ambient air and that at the engine inlet manifold. Alternatively, the device may be operated as a heat pump.

14 Claims, 6 Drawing Sheets



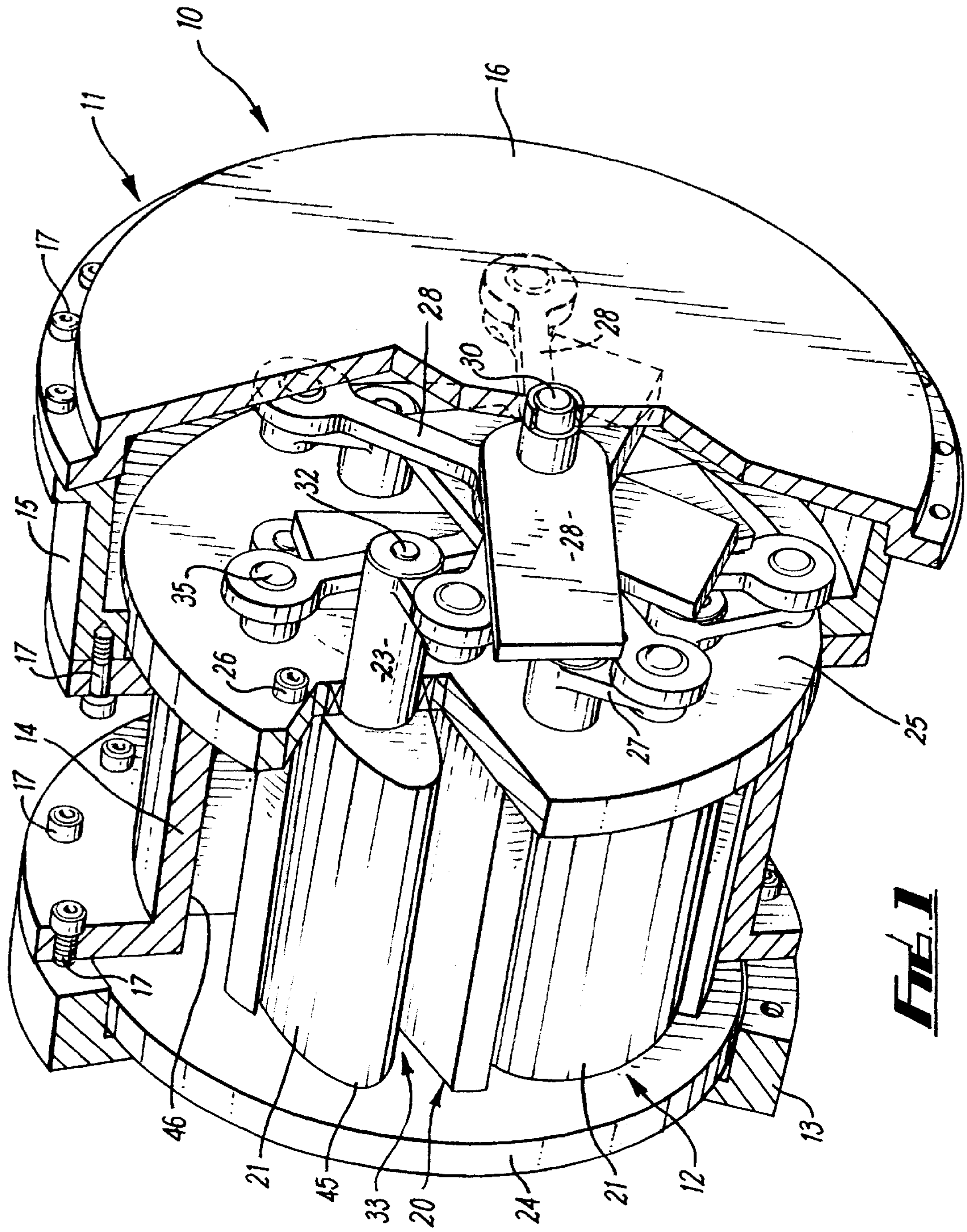
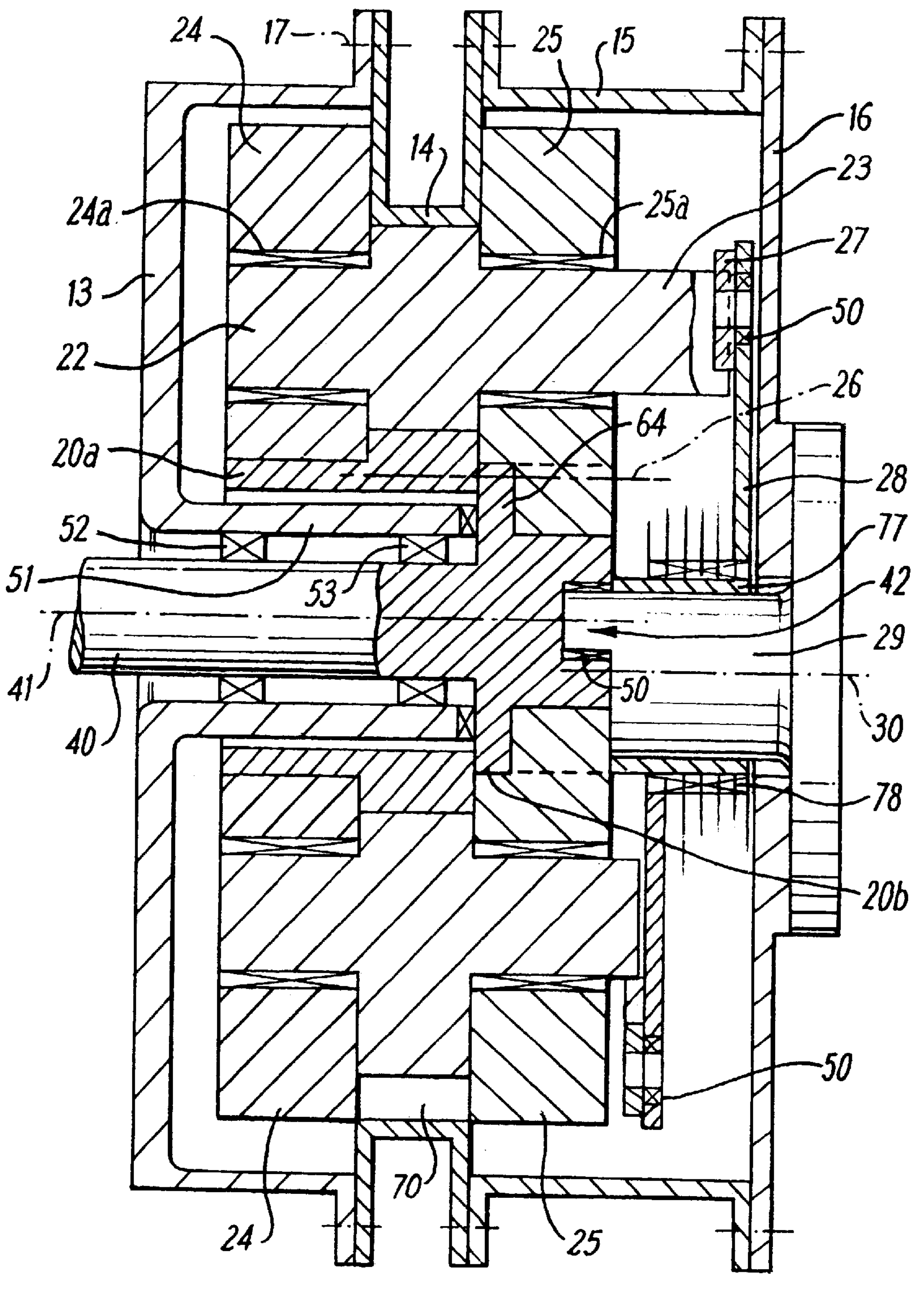


FIG. 1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17
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16
14
23
24a
25a
27
13
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22
26
64
20a
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77
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42
53
29
41
50
30
40
78
20b
50
24
70
25

FIG. 2

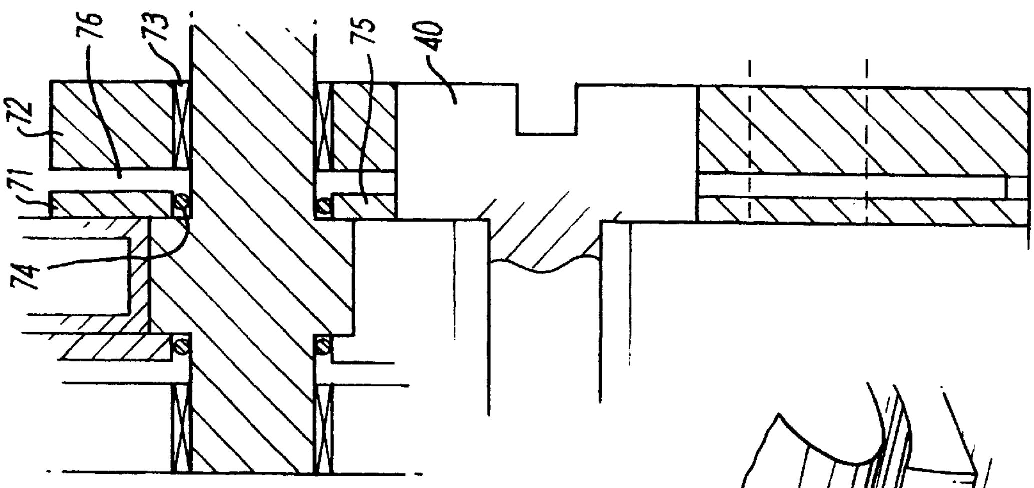

FIG. 8

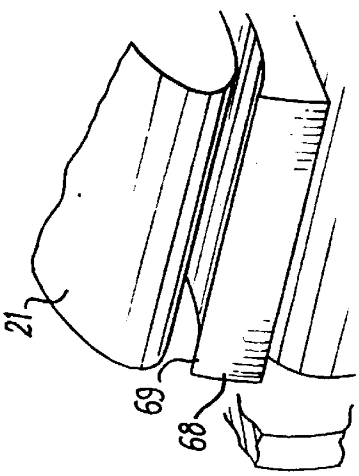

FIG. 7

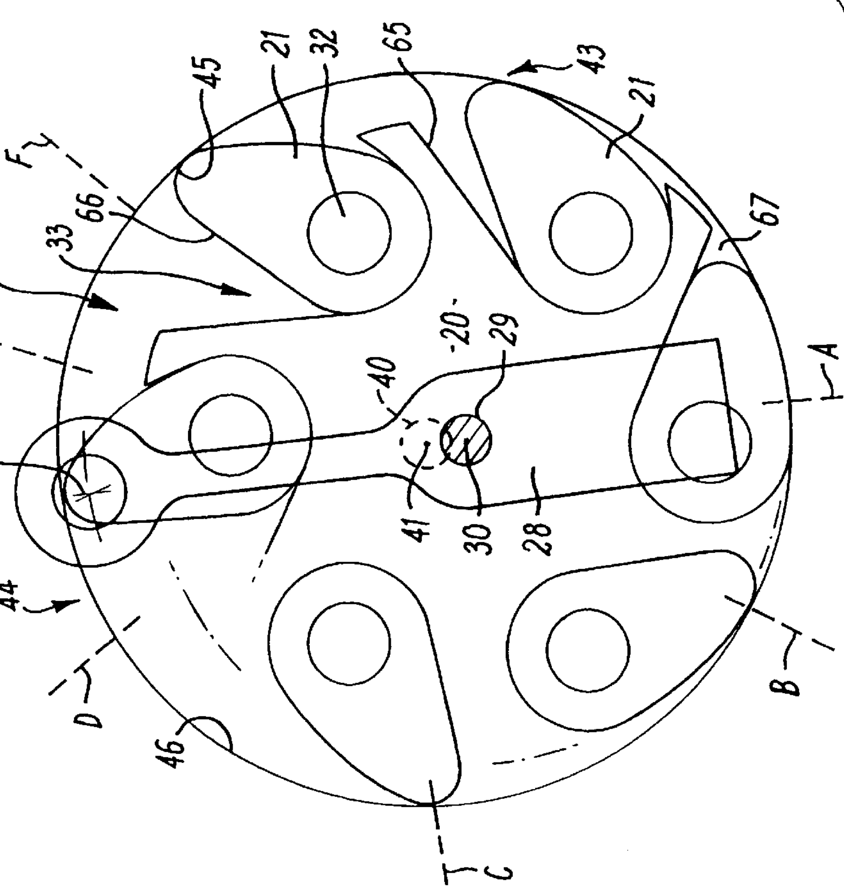

FIG. 3

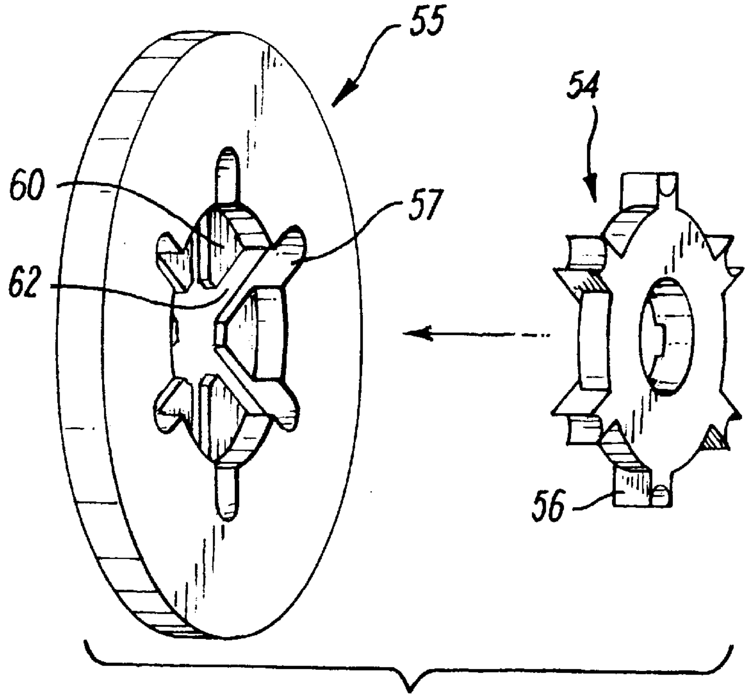

FIG. 4

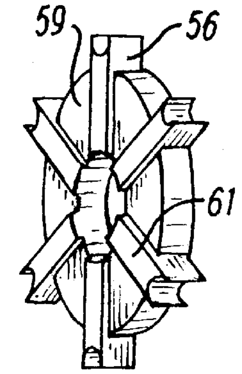

FIG. 5

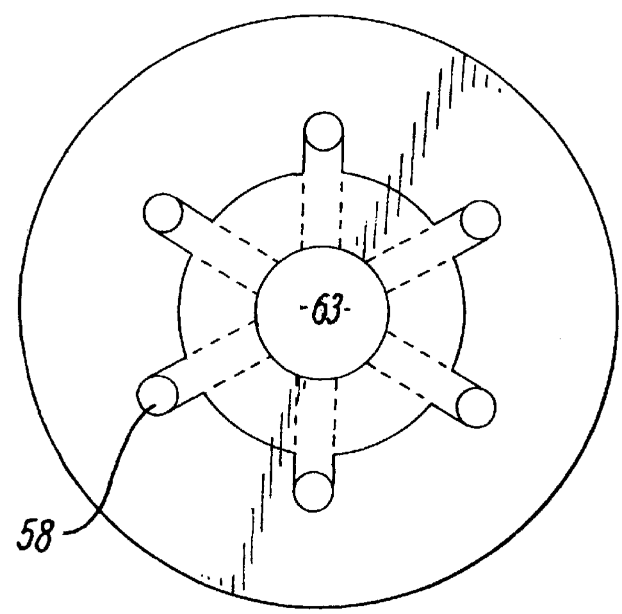

FIG. 6

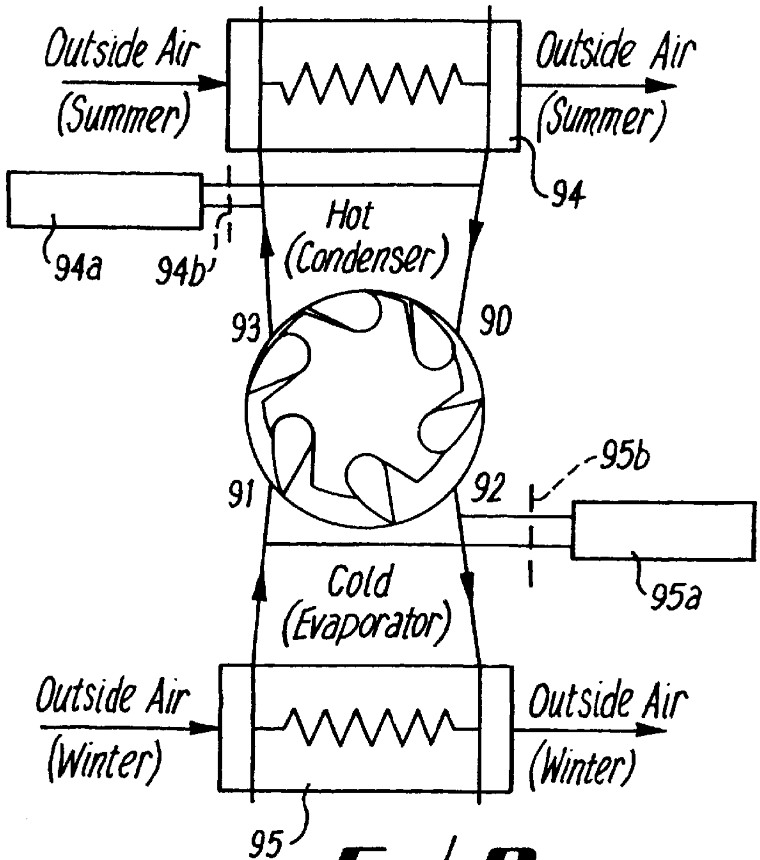
Outside Air
(Summer)
Outside Air
(Summer)
94
94a
94b'
Hot
(Condenser)
93
90
91
92
95b
95a
Cold
(Evaporator)
Outside Air
(Winter)
Outside Air
(Winter)
95

FIG. 9

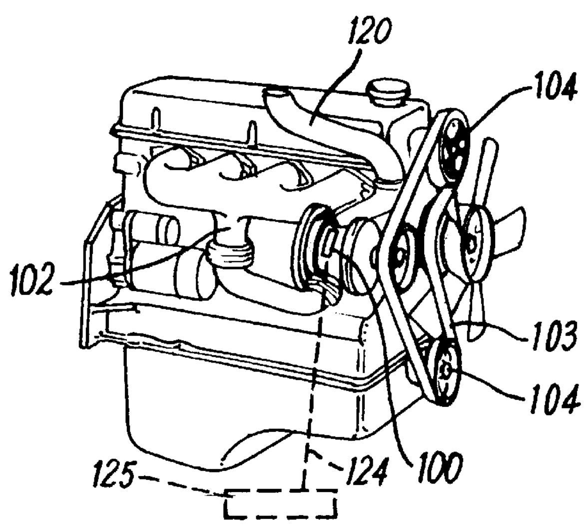
120
104
102
103
104
125
124
100

FIG. 10

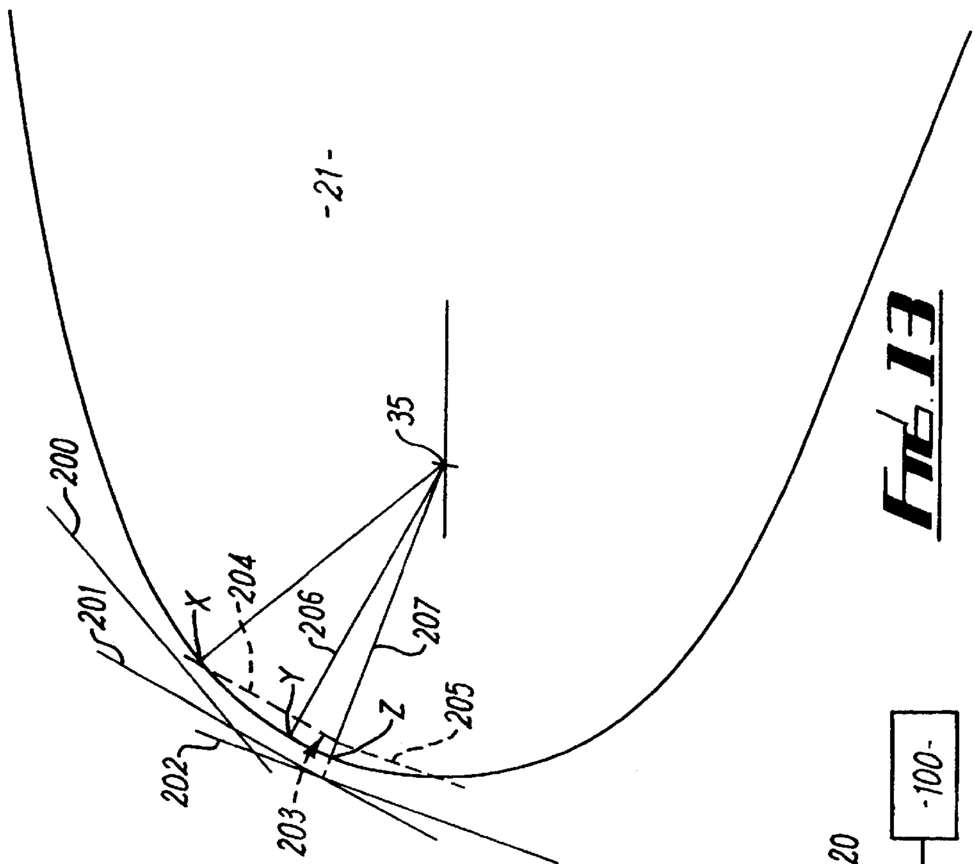

FIG. 13

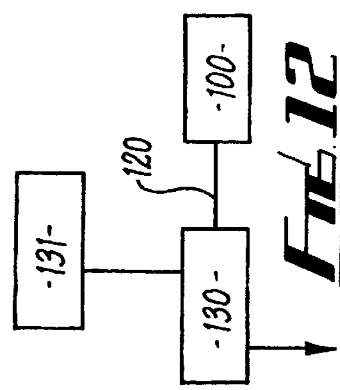

FIG. 12

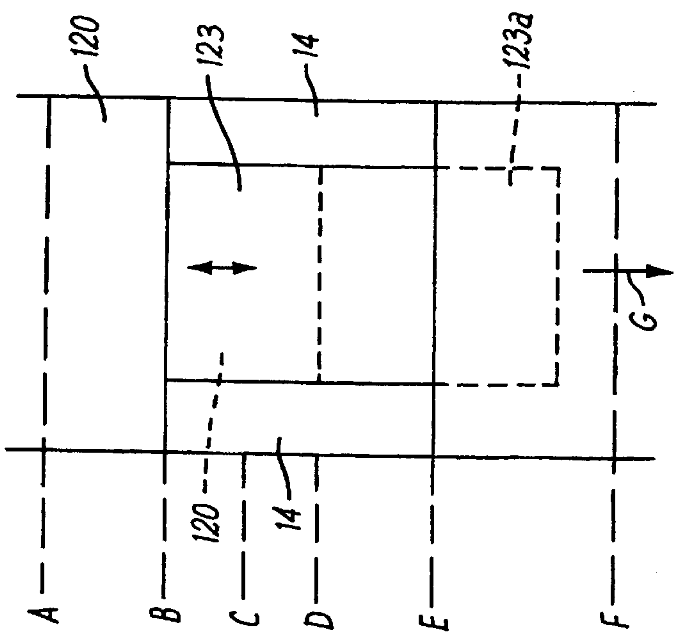

FIG. 11

ROTARY POSITIVE-DISPLACEMENT FLUID MACHINES

THIS INVENTION relates to rotary positive-displacement fluid machines.

Such as machine is described in patent specification WO 96/39571 in which a rotor is eccentrically mounted in a casing for rotation about an axis the rotor having recesses respectively receiving vanes which oscillate in the recesses as the rotor rotates, each vane being connected by a crank to an arm for oscillation thereon about a vane axis, which arm can oscillate about an axis offset from the rotor axis. The vane axis coincides with the radial inner surface of the casing thus to pivot about the vane tip on a axis which coincides with the radial inner surface of the casing.

According to the present invention there is provided a rotary positive-displacement fluid machine comprising a rotor eccentrically mounted in a casing for rotation about an axis, the rotor having recesses respectively receiving vanes which oscillate in the recesses as the rotor rotates, each vane being connected by a crank to an arm for oscillation thereon about a vane axis, which arm can oscillate about an axis offset from the rotor axis, characterised in that the vane axis is located radially inwards of the radial inner surface of the casing.

The vane tip may be curved about said vane axis. The profile of the curved tip of each vane may be modified to a more flattened shape to ensure clearance from the radial inner surface of the casing at high rotor speeds. The modified profile may comprise one or more flats.

The invention may be performed in various ways and one specific embodiment with possible modifications will now be described by way of example with reference to the accompanying drawings, somewhat diagrammatic, in which:

FIG. **1** is a perspective view part cut away of a rotary machine;

FIG. **2** is a schematic section of a machine;

FIG. **3** is a schematic axial view of a rotor;

FIG. **4** is an exploded perspective view of a rotor disc;

FIG. **5** is a perspective view of part of the disc;

FIG. **6** is an axial view of the disc;

FIG. **7** shows a modification;

FIG. **8** shows another modification;

FIG. **9** illustrates a heat pump; and

FIG. **10** shows an engine;

FIG. **11** shows a control plate;

FIG. **12** is a flow diagram; and

FIG. **13** is an enlarged view of part of a modified rotor vane.

A rotary positive-displacement fluid machine **10** has an outer stator assembly **11** within which can rotate an eccentrically mounted rotor assembly **12**. The stator assembly **11** has a first end plate **13**, a two-part radially stepped casing part **14, 15** and a second end plate **16**, the assembly being held together by bolts **17**, with fluid-tight seals as appropriate (not shown), and providing an expansion/compression chamber **70**.

The rotor assembly **12** comprises a rotor **20** with angularly spaced peripheral recesses **33** receiving respective vanes **21**. Each vane **21** is integral with end shafts **22, 23** mounted respectively for rotation (oscillation) about axis **32** on bearings **24***a,* **25***a* in a first rotor disc **24** and a second rotor disc **25** secured to the rotor **20** by bolts **26** (only one shown). The shafts **23** are pivotally connected by respective integral crank arms **27** to oscillating arms or spokes **28** which can oscillate (about an axis **30**) on a common shaft **29** which is fixed in the second end plate **16**.

The arms **28** rotate with the rotor and also oscillate on the shaft **29**. The arms **27** oscillate about axes **35**.

A drive shaft **40** with an axis **41** offset from the axis **30** is held by bolts **26** to the rotor assembly.

With this arrangement, the vanes **21** oscillate about axes **32** in the recesses **33** to produce a compression region **43** and an expansion region **44** with the outer surface **45** of the vanes **21** disposed with very small clearance with respect to the inner surface **46** of the casing **14**.

The vane surfaces **45** are machined to maximum tolerance and the vane surface has a very small running clearance with surface **46**.

Suitable bearings **50** are provided as required.

In the present case the rotor assembly **12** is supported on the drive shaft **40**.

The end wall **13** is extended axially at **51** its central region towards the end wall **16** with interposed bearings **52, 53**. The pressure load on the rotor assembly is thus largely taken on bearings **52, 53** so as to be axially distributed rather than being cantilevered at an end of the drive shaft.

The drive shaft **40** is received at **42** in the shaft **29** which improves balance and the shaft **29** is thus supported at both its ends and has less bending load than a cantilevered shaft and can thus be smaller, reducing weight. The shaft **29** can be integral with plate **16**. The shafts **29, 40** can be assembled by relative axial movement.

This feature can be used in machines with vanes which slide radially in and out in the rotor.

In the present case the axes **35** of relative angular movement between the arms **27** and **28** are radially inwards of the casing surface **46** and of the outer surfaces or tips **45** of the vanes, which are curved about or around the axes **35** (part-circular).

Compared with an arrangement in which the axis **35** is coincident with the surface **46** and the surface **45** is effectively an edge about which the vane **21** pivots as it rotates in the casing, the present arrangement provides a curved surface for the vane tip which rolls as the vane is oscillated about axis **35** thus reducing tip wear. The curved vane tip is easier to make, is stronger, and improves maintenance of tip clearance. The lengths of arms **27** and **28** are also less thus reducing weight and providing for a smaller overall machine diameter.

For ease of manufacture and assembly the rotor disc **25** is formed from two parts **54, 55** FIG. **4** which are assembled by relative axial movement. The part **54** has radial portions **56** with concave ends which are received in radial recesses **57** in part **55** to form apertures **58** for the shafts **23** and have recesses **59** in one face which receive projections **60** of part **55** with ribs **61** received in slot **62** between projections **60,** the whole providing aperture **63** for rotor portion **20**a. The shafts **23** are placed in apertures **58** in part **55** before the part **54** is moved axially into position. In this case the rotor surf ace **20***b* FIG. **2** can extend the axial extent of disc **25**. If the rotor is cut away to provide flange **64** the part **55** has an end recess for receipt of flange **64** on shaft **40**.

Rotor disc **24** can be made as two pieces formed by a circular split line passing through apertures in disc **24** for receiving shafts **22** and assembled by relative axial movement.

One wall surface **65** (the trailing surface) of the recess **33** generally conforms to a surface **66** of the respective vane **21** and the curved surface **45** means that at one limit of the oscillating movement of the vane **21** there will be a small volume **67** FIG. **3** not occupied by the vane. As shown in FIG. **7** this can be reduced by appropriately shaping the rotor portion **68** at **69**. This reduces loss of compression.

As shown in FIG. **8**, one way of sealing the expansion/compression chamber **70** against entry of lubricating oil is to split the discs **24**, **25** into two axially spaced parts **71**, **72** bolted together at their radial outer ends and provide bearing **73** for part **72** and seal **74** for part **71** engaging a ring **75** on the shaft **40**. The gap **76** between parts **71**, **72** can act as an air vent and oil drain. In this case the parts **71**, **72** can each be in two parts connected by a circular face passing through apertures **58**, and the arrangement of FIG. **6** is not needed.

A close sleeve **77** FIG. **2** can be located on shaft **29** between part **16** and disc **25** and the arms **28** can oscillate on the sleeve **77** with interposed bearings **78**. This distributes the radial loading along the sleeve (the radial loading on arms **28** varies as they rotate). The sleeve **77** rotates at a speed between the rotor speed and the oscillation speed of the arms **28**.

In one example, FIG. **9**, the device is used as a heat pump. Angularly spaced inlet ports **90**, **91** and outlet ports **92**, **93** communicate with the interior **70** of the casing. Radiators **94** and **94***a* are selectively connectable by switching **94***b* to ports **90**, **93**; and radiators **95**, **95***a* are selectively connectable by switching **95***b* to ports **91**, **92**. Fluid is circulated in a closed circuit. Radiators **94***a* and **95***a* are inside the house and radiators **94**, **95** are outside the house.

In summer, radiators **94***a*, **95** are not used. Hot fluid leaving port **93** is cooled in radiator **94** by outside air and further cooled fluid leaving port **92** cools radiator **95***a*.

In winter radiators **94** and **95***a* are not used; cold air leaving port **92** is heated in radiator **95** by outside (less cold) ambient air, and the heated fluid from port **93** heats the house via radiator **94***a*.

If the device is used for example as a throttle loss recovery turbine in an internal combustion engine **131** (FIGS. **10** and **12**) the device **100** replaces a butterfly valve between the air intake **120** and the inlet manifold **102**, being driven by the pressure difference between ambient and the inlet manifold which is at a pressure less than ambient and thus driving belt **103** and crankshaft pulleys **104** to put energy into the crankshaft.

In this case, as rotor speed increases, the fluid mass flow is increased. For example as shown in FIGS. **3** and **11**, an angularly extending air inlet port **120** is formed in casing **14**, and angularly slidable in the casing to enlarge or reduce the angular extent of the inlet port is a plate **123** which can move from its position illustrated with full lines in FIG. **11**, at idling speed to a position **123***a* illustrated with dotted lines at maximum rotor speed (full throttle). At idling speed the air inlet port **120** extends from A to B in FIGS. **3** and **11**, but plate **123** moves to position **123***a* at full throttle thus to extend the air inlet to position D. The flow to the engine inlet manifold, shown at G, is via a port which is open between positions E and A. The distance between consecutive or adjacent vanes **21** thus defining the extent of chambers **70**, illustrated diagrammatically by B to C and D to E in FIG. **3**. The movement of the plate **123** can be controlled by mechanism **124** (for example a cable) in response to movement of an engine accelerator pedal **125** (FIG. **10**).

In a modification shown in FIG. **12**, some of the exhaust gas passing through an exhaust pipe **130** from the internal combustion engine **131** is passed to the air inlet **120** of the rotary device **100** and is thus then fed back to the engine air inlet to reduce the nitric oxide content of the exhaust gas passing to atmosphere. The pressure of this exhaust gas is normally less than or equal to that of the ambient air.

FIG. **13** shows another arrangement intended for use at high speeds. Point X indicates the point of the tip which is closest to the casing when the vane is closed up (compartment at least volume); point Z indicates the point of the tip which is closest to the casing when the vane is fully open (compartment at maximum volume); and point Y is between points X and Z.

Lines **200**, **201**, **202** are tangents to the casing surface opposite points X, Y, Z respectively.

As the vane tip pivots during operation, the part of the vane tip closest to the internal surface of the casing moves from point X to point Z. Between point Y and Z the mechanism stresses are at their highest and the normal tip clearance (calculated at X) reduces. Typically the linkage mechanism between the vane and the drive shaft, which causes the vane to oscillate, stretches and/or twists (including bearings, crank arm) and the tip clearance is reduced. If the reduction is greater than the available clearance, this will produce tip-rub.

At high speeds e.g. 6000 rpm there is a relatively large tip movement between points Y and Z. To prevent a heavy rub on the tip, the tip profile is modified to a more flattened shape as shown by the broken line **203**. This may follow the curvature of the casing at every increment, or for practical purposes, the line **203** could be two flats **204**, **205** machined on the tip at right angles to the radii **206**, **207** at points Y and Z respectively.

What is claimed is:

1. A rotary positive-displacement fluid machine comprising:

casing having an inner surface; and

a rotor disposed within the casing and rotatable about a first axis, the rotor including:

a plurality of recesses;

a plurality of vanes, each one of the plurality of vanes being received in a corresponding one of the plurality of recesses, each one of the plurality of vanes oscillating about a corresponding second axis as the rotor rotates about the first axis, each corresponding second axis being located between the first axis and the inner surface of the casing, and each one of the plurality of vanes having a respective shaft extending along the respective second axis;

a plurality of cranks, each one of the plurality of cranks being operatively coupled to a corresponding one of the plurality of vanes;

a plurality of arms, each one of the plurality of arms being operatively coupled to a corresponding one of the plurality of cranks at a respective third axis, and each of the plurality of arms oscillating about a fourth axis that is offset from the first axis of the rotor; and

first and second rotor end members supporting the plurality of vanes for oscillation about each respective second axis, the first rotor end member including a first part and a second part, the second part being positioned between the first part and the plurality of vanes, the first and second parts being adapted to be assembled by relative axial movement, and the first rotor end member including:

a bearing between the first part and the vane shaft; and

a seal between the second part and the vane shaft.

2. A rotary positive-displacement fluid machine according to claim **1**, wherein the first part is fastened to the second part.

3. A rotary positive-displacement fluid machine according to claim **2**, wherein the first and second parts define a passage that allows fluid communication to each vane shaft.

4. A rotary positive-displacement fluid machine according to claim **1**, wherein each one of the plurality of vanes comprises a tip including at least one arcuate segment with respect to a respective third axis.

5. A rotary positive-displacement fluid machine according to claim **4**, wherein the tip further comprises at least one linear segment tangent to the respective third axis.

6. A rotary positive-displacement fluid machine comprising:

a casing having an inner surface, a fluid inlet port, and a fluid outlet port, a size of the fluid inlet port being automatically adjustable according to changes in fluid mass flow; and

a rotor disposed within the casing and rotatable about a first axis, the rotor including:

a plurality of recesses;

a plurality of vanes, each one of the plurality of vanes being received in a corresponding one of the plurality of recesses, each one of the plurality of vanes oscillating about a corresponding second axis as the rotor rotates about the first axis, each corresponding second axis being located between the first axis and the inner surface of the casing, and each pair of adjacent ones of the plurality of vanes partially defining a respective chamber that serves repeatedly and alternately as a compression chamber and as an expansion chamber;

a plurality of cranks, each one of the plurality of cranks being operatively coupled to a corresponding one of the plurality of vanes; and

a plurality of arms, each one of the plurality of arms being operatively coupled to a corresponding one of the plurality of cranks at a respective third axis, and each of the plurality of arms oscillating about a fourth axis that is offset from the first axis of the rotor.

7. A rotary positive-displacement fluid machine according to claim **6**, wherein the rotor further comprises at least one rotor end member supporting the plurality of vanes for oscillation about each respective second axis, the at least one rotor end member including a first part and a second part, and the first and second parts being adapted to be assembled by relative axial movement.

8. A rotary positive-displacement fluid machine according to claim **7**, wherein the first part is fastened to the second part.

9. A rotary positive-displacement fluid machine according to claim **7**, wherein the first part is received within the second part.

10. A rotary positive-displacement fluid machine according to claim **6**, wherein each one of the plurality of vanes comprises a tip including at least one arcuate segment with respect to a respective third axis.

11. A rotary positive-displacement fluid machine according to claim **10**, wherein the tip further comprises at least one linear segment tangent to the respective third axis.

12. A rotary positive-displacement fluid machine comprising:

a casing having an inner surface; and

a rotor disposed within the casing and rotatable about a first axis, the rotor including:

a plurality of recesses;

a plurality of vanes, each one of the plurality of vanes being received in a corresponding one of the plurality of recesses, each one of the plurality of vanes oscillating about a corresponding second axis as the rotor rotates about the first axis, each corresponding second axis being located between the first axis and the inner surface of the casing, and each one of the plurality of vanes having a curved vane tip including a more flattened shape to ensure clearance from the casing at high rotor speeds;

a plurality of cranks, each one of the plurality of cranks being operatively coupled to a corresponding one of the plurality of vanes; and

a plurality of arms, each one of the plurality of arms being operatively coupled to a corresponding one of the plurality of cranks at a respective third axis, and each of the plurality of arms oscillating about a fourth axis that is offset from the first axis of the rotor.

13. A rotary positive-displacement fluid machine according to claim **12**, wherein the flattened section comprises one or more flats.

14. A rotary positive-displacement fluid machine according to claim **12**, wherein the rotor further comprises at least one rotor end member supporting the plurality of vanes for oscillation about each respective second axis, the at least one rotor end member including a first part and a second part, and the first and second parts being adapted to be assembled by relative axial movement.

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