United States Patent [19]

Foster

[11] **3,813,191**

[45] **May 28, 1974**

[54] **ROTARY VANE DEVICE FOR COMPRESSOR, MOTOR OR ENGINE**

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[21] Appl. No.: **350,632**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 268,866, May 1, 1972, Pat. No. 3,747,573, which is a continuation of Ser. No. 41,008, May 22, 1970.

[52] **U.S. Cl.** **417/406,** 417/348

[51] **Int. Cl.** **F04b 17/00**

[58] **Field of Search** 417/406, 348

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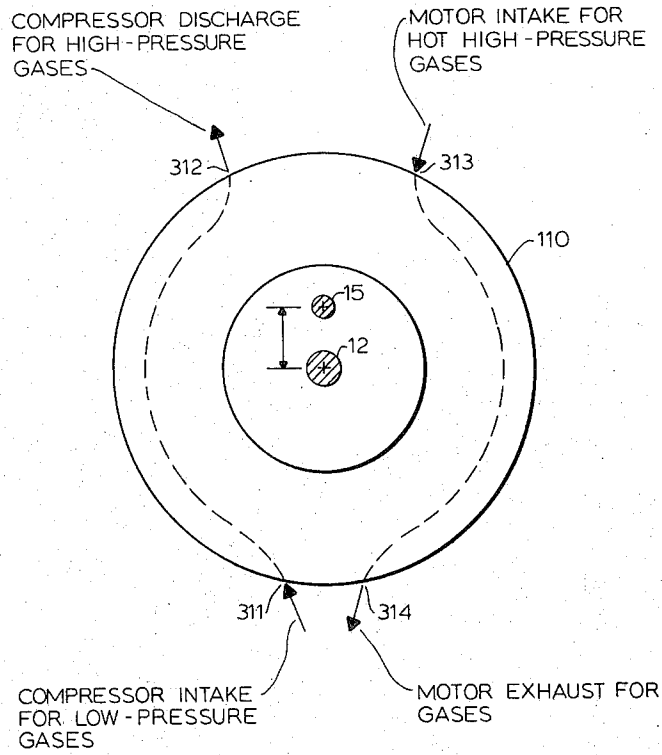
Primary Examiner—C. J. Husar

Attorney, Agent, or Firm—Owen, Wickersham & Erickson

[57] **ABSTRACT**

An integral vane compressor and vane motor. At least three vanes are pinned to a central hub and extend through respective slots in a generally cylindrical drum with its axis parallel to and displaced radially from that of said hub, the slots guiding the radial position of the vanes. Synchronizing means, such as a gear train, cause the hub and drum to rotate in the same direction and at the same speed, with the vanes reciprocating and oscillating in the guide slots. A housing encloses the vanes and cooperates with them and the drum to provide a series of working spaces, one for each vane to compress or expand a fluid. Intake and exhaust ports lead fluid into and from the working spaces.

2 Claims, 9 Drawing Figures



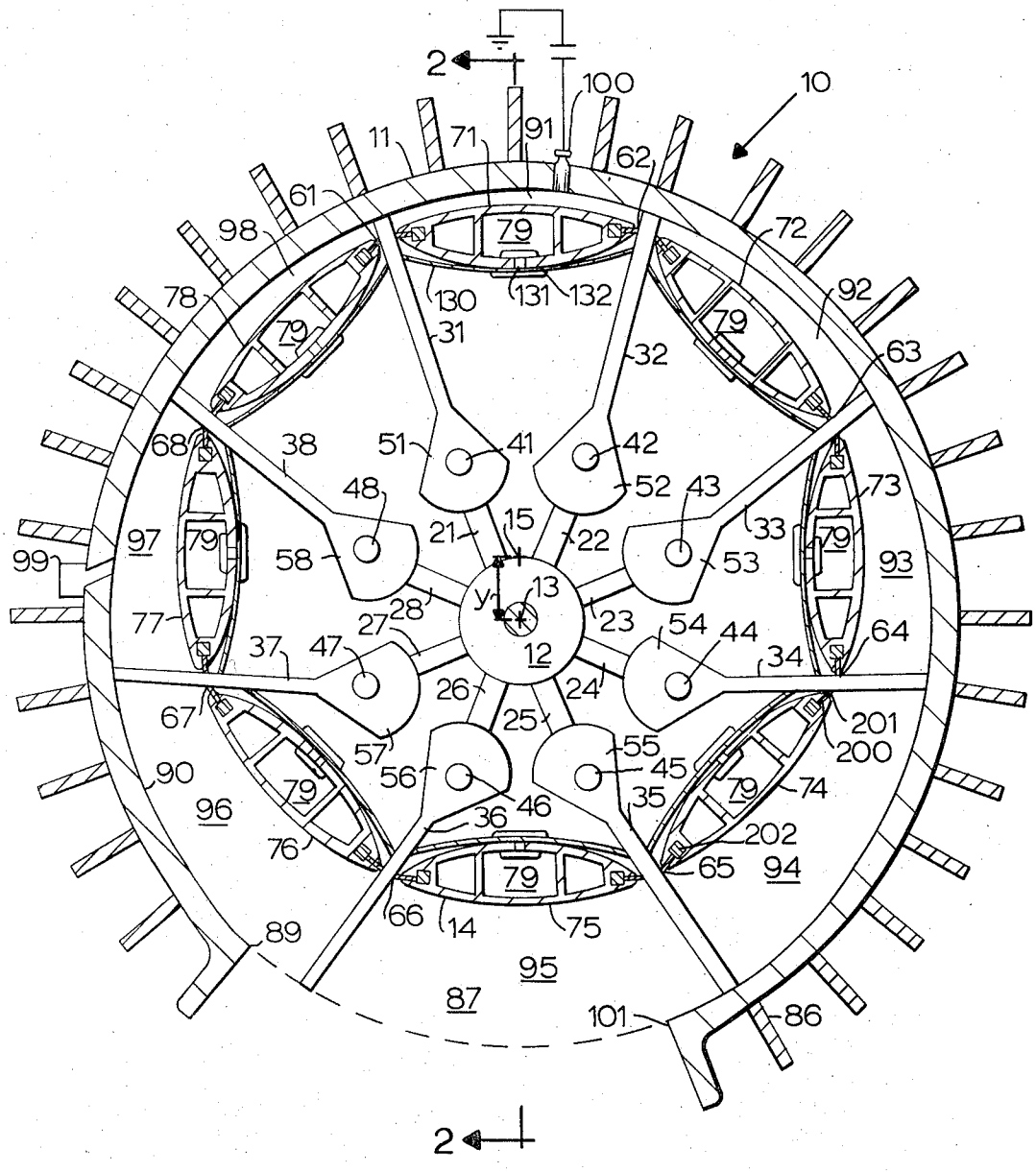

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FIG. 1

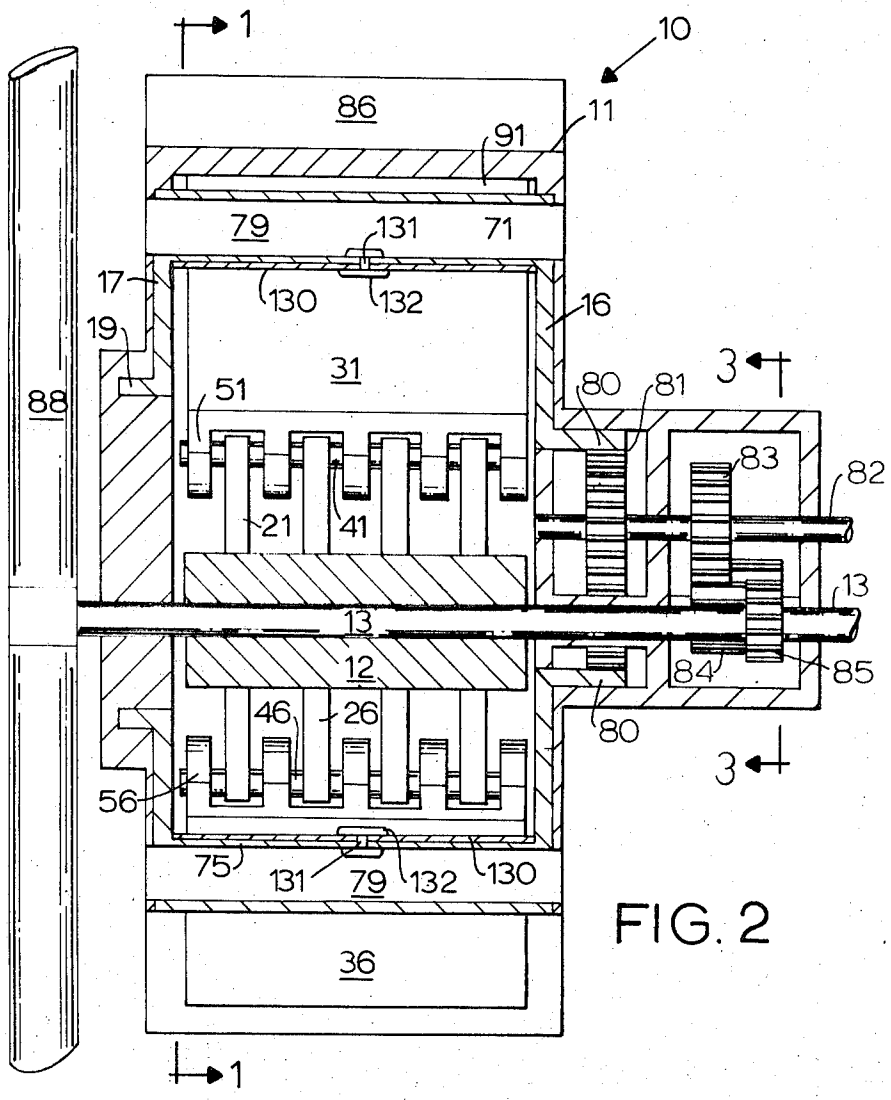

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FIG. 2

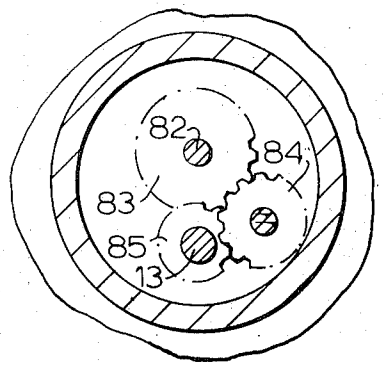

82
84
83
85
13

FIG. 3

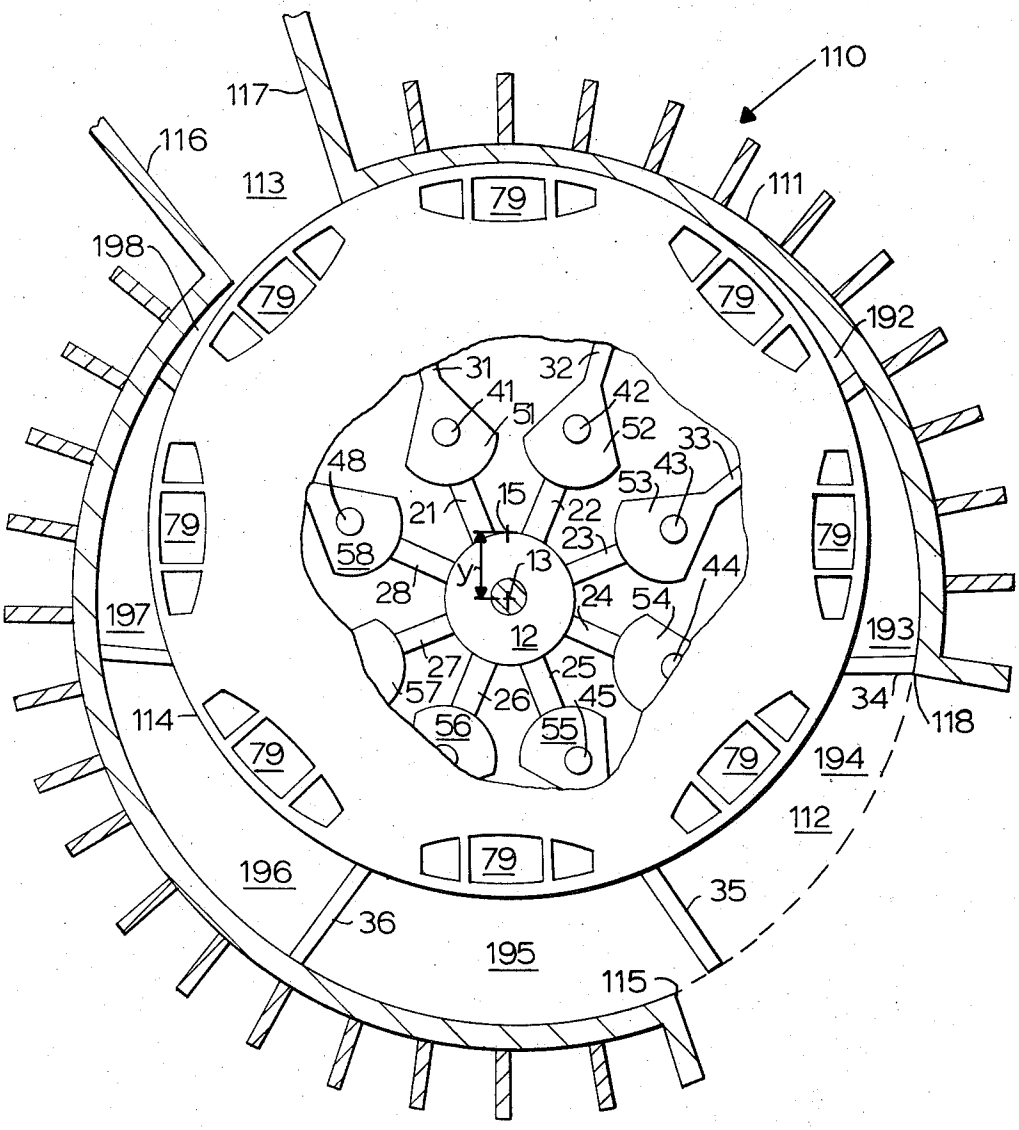

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FIG. 4

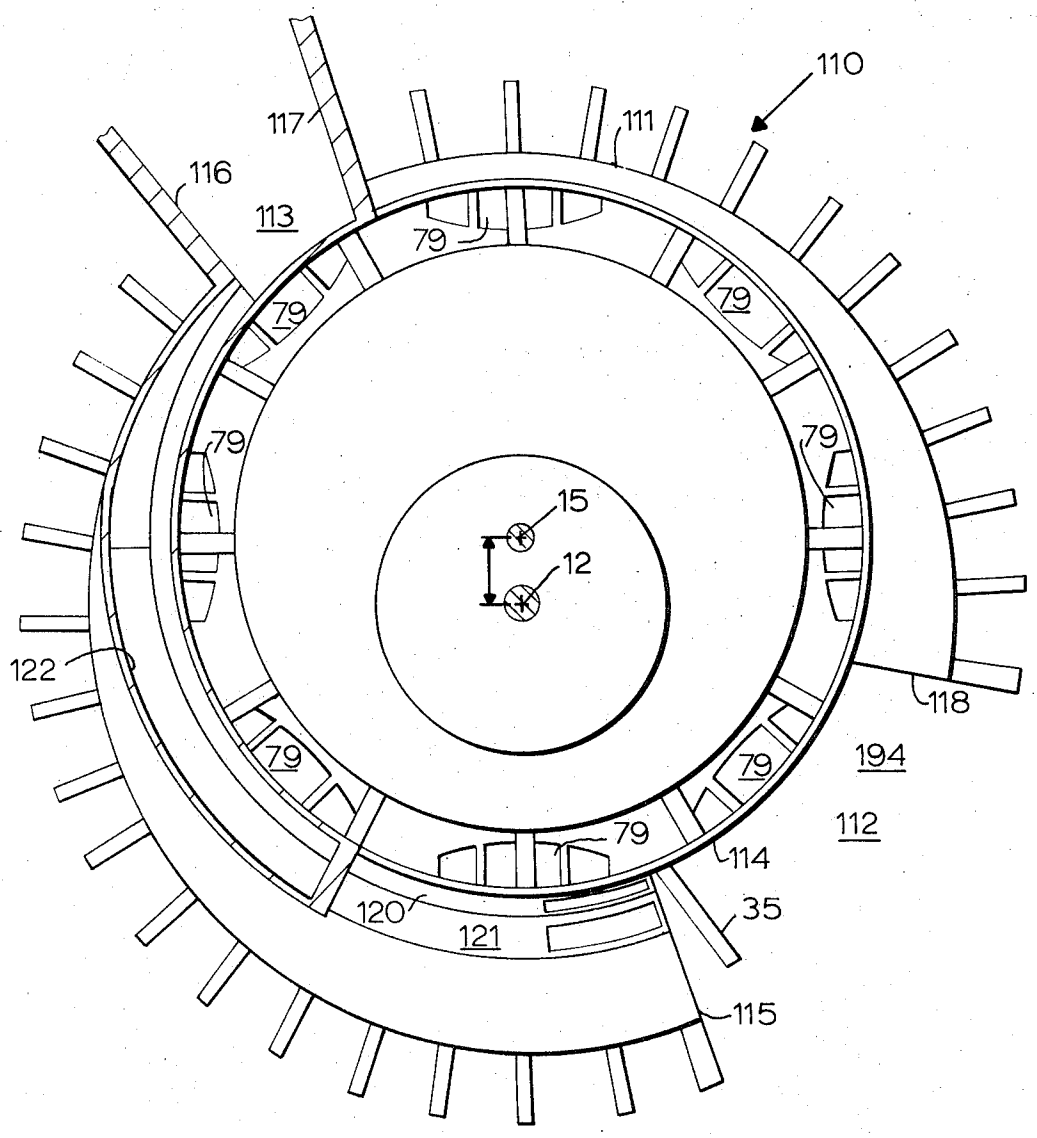

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FIG. 5

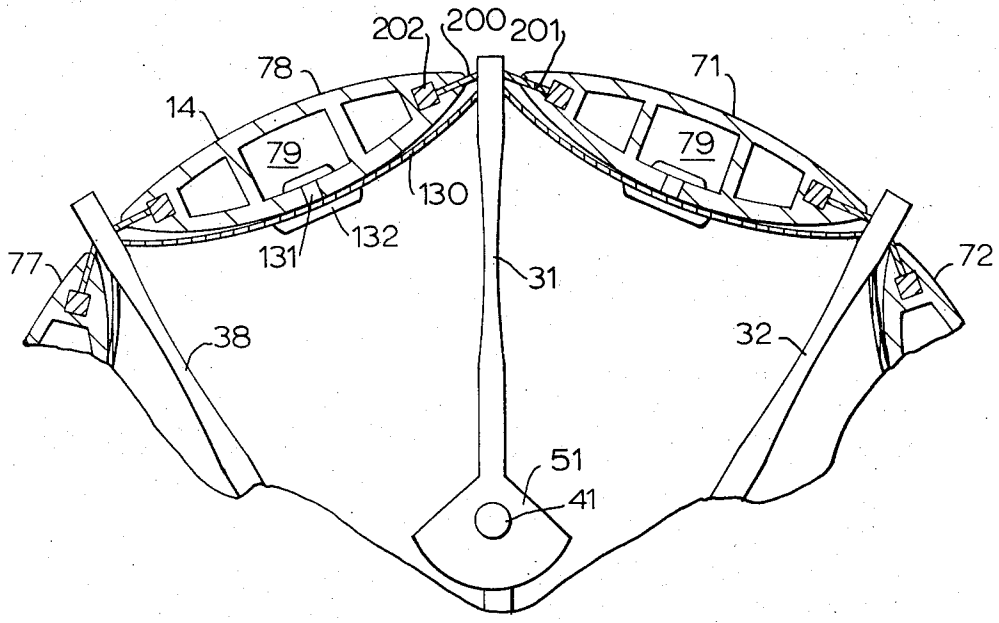
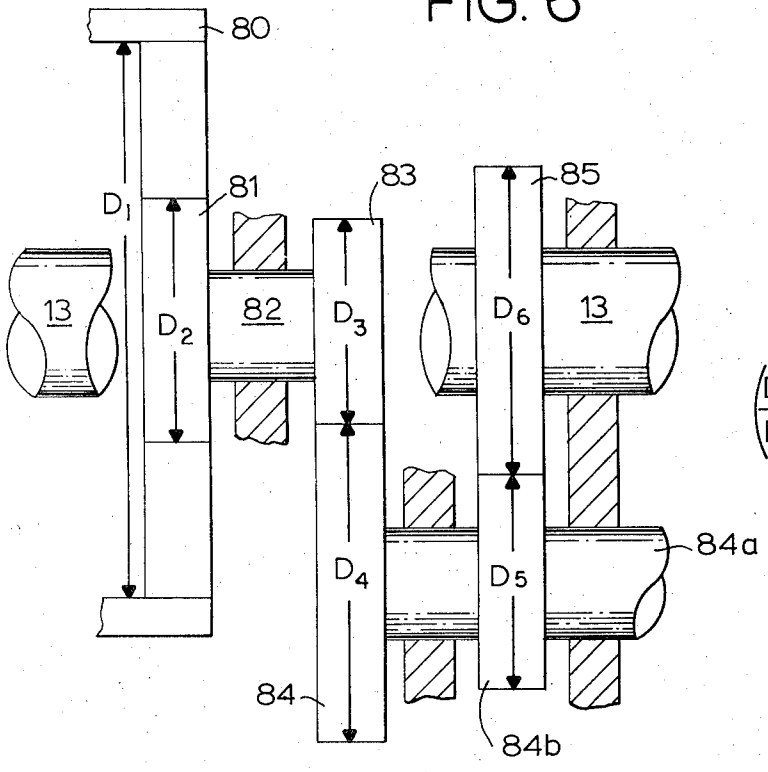


FIG. 6



$$\left(\frac{D_1}{D_2}\right)\left(\frac{D_3}{D_4}\right)\left(\frac{D_5}{D_6}\right)=1$$

FIG. 7

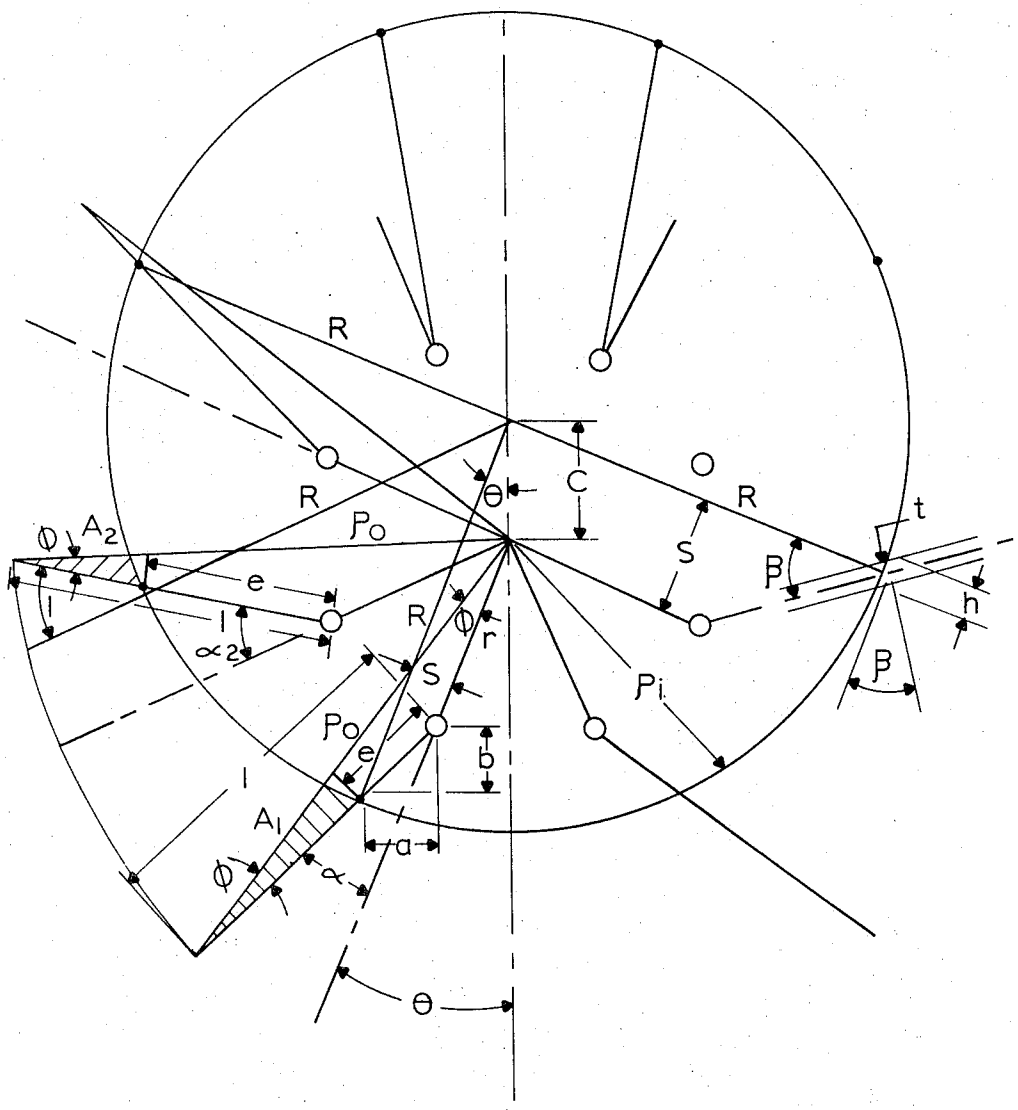


FIG. 8

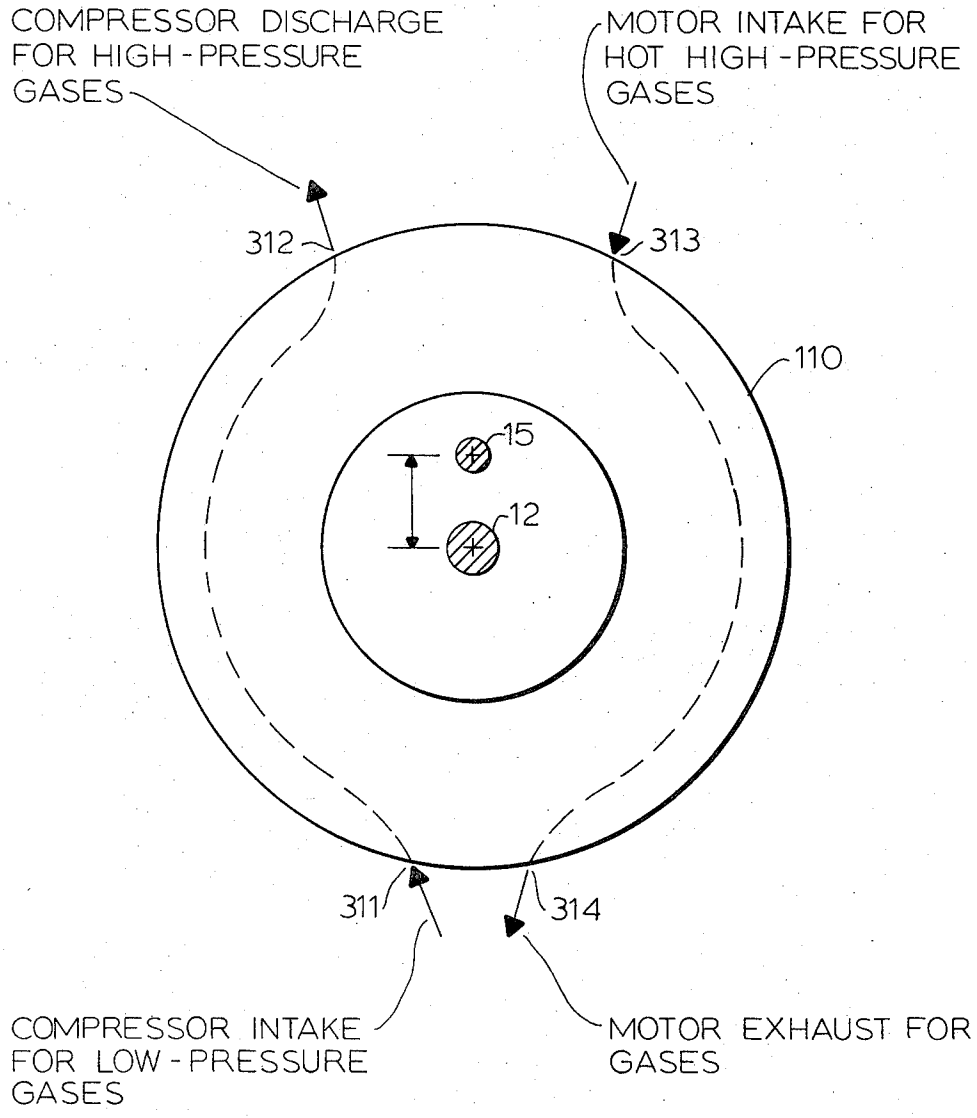

COMPRESSOR DISCHARGE FOR HIGH-PRESSURE GASES
MOTOR INTAKE FOR HOT HIGH-PRESSURE GASES
312
313
110
15
12
311
314
COMPRESSOR INTAKE FOR LOW-PRESSURE GASES
MOTOR EXHAUST FOR GASES

FIG. 9

ROTARY VANE DEVICE FOR COMPRESSOR, MOTOR OR ENGINE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of application Ser. No. 248,866 filed May 1, 1972, now U.S. Pat. No. 3,747,573 which was a continuation of application Ser. No. 41,008 filed May 22, 1970.

BACKGROUND AND SUMMARY OF THE INVENTION

This invention relates to an integral vane compressor and vane motor.

A feature of the rotary vane device of this invention is that the vanes are pinned to a central hub-shaft, and it has a separate circular drum to help transmit torque through the vanes and to guide the radial direction of the vanes. The vanes are pinned at their centers of gravity to the central hub-shaft, so that they can oscillate back and forth as the central hub-shaft rotates; as a result, the mechanism is kept in dynamic balance. The central hub shaft supports the full centrifugal pull of the vanes; consequently, they have no friction drag at their tips where they nearly (but not quite) touch the housing.

The central hub-shaft and the circular drum both rotate at the same speed and in the same direction, but the center of rotation of the circular drum is offset from the center of rotation of the central hub-shaft. The radius of the circular drum is smaller than the radial distance from the hub center to the tips of the extended vanes in every position of their rotation. The circular drum preferably has equally spaced axial slots at its outer periphery, one for each vane; these axial slots are preferably just big enough so that the vanes are forced to oscillate and reciprocate in them as the drum and shaft rotate. As the shaft and drum rotate and the vanes are forced to rotate and oscillate, their tips form a circumscribed surface.

The housing of my new rotary vane device is slightly larger than the circumscribed surface of the vanes; thus there is no friction between the vanes and the housing. The housing may be provided with an intake port and an exhaust port. The space bounded between two adjacent vanes, the cylindrical surface of the drum between these vanes, and the cylindrical and disc surfaces of the housing constitutes the working space. There may be three or more working spaces in each device, and the volume of each working space varies as the drum and the hub-shaft rotate in the stationary housing. For example, the maximum volume of this working space is 180° out of phase with its minimum volume.

In the compressor portion, the intake port is closed by a rotary vane just after the working space is largest; as the vanes and drum rotate, decreasing the volume of the working space, they give an isentropic compression of the trapped gases. The compressed gases are then forced out of the working space through a discharge port located where the working space is smallest.

In the motor portion, used to expand compressed gases for useful work, the intake port is opened where the working space is smallest, and it may have an adjustable device to regulate the shut-off point of the intake port. When the prescribed amount of compressed gas is in the working space, the vanes trap this compressed gas and expand it until the working space is at its largest volume; then the exhaust port opens to exhaust low pressure gases as the working space becomes smaller.

The integral vane compressor and vane motor have a compressor intake port for low pressure gases, a compressor discharge port for high-pressure gases, a motor intake port for hot high-pressure gases and a motor exhaust port for exhaust gases. The compressor intake port and the motor exhaust port may connect to the same working space. A blower may be used to force a fresh charge into the intake port. A jet pump action of the exhaust gases flowing out and the fresh charge flowing in may exhaust, charge, and scavenge the common working space for the intake and exhaust ports. This integral vane compressor and vane motor may be used similar to a turbocharger. Also, it may be used similar to a gas turbine, wherein the compressor and motor use the same wheel. The working spaces for the vane motor may expand to a larger volume than the intake volume for the vane compressor; thus the device will generate shaft power similar to a gas turbine. As an alternate design the working spaces for the vane motor may expand to a volume equal to or only slightly larger than the intake volume for the compressor; in this case the vane device acts like a turbo-charger or a gas turbine gas generator which may supply gases to a free-running gas turbine.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a view in section (which may be considered as taken along the line 1—1 in FIG. 2) normal to the rotating shaft for the hub and drum, of a rotary vane device embodying the principles of the invention, when employed as an internal combustion engine.

FIG. 2 is a fragmentary view in section taken along the line 2—2 in FIG. 1 showing a gear box for synchronizing the shaft and the drum of the engine of FIG. 1.

FIG. 3 is a view in section taken along the line 3—3 in FIG. 2, showing the end view of the gears.

FIG. 4 is a fragmentary view in section of a modified form of the device that may be used as a compressor or a motor, depending on whether the hub-shaft and the drum rotate clockwise, when it acts as a compressor, or counterclockwise, when it acts as a motor or steam engine.

FIG. 5 is an end view in section of the engine of FIG. 4 showing the adjustable sliding circular valve for regulating the cutoff point for steam or compressed gas expansion in the vane motor.

FIG. 6 is a fragmentary detail view of a portion of the motor, showing a spring seal ring to contain the lubricating oil inside the drum.

FIG. 7 is a fragmentary enlarged view, partly diagrammatic, of the gear box with part of the hub shaft broken away to show parts otherwise obscured.

FIG. 8 is a diagram relative to the geometry of the vanes, hub, and drum as they rotate.

FIG. 9 is a block flow diagram showing how the rotary vane device may be used as an integral vane compressor and vane motor.

DESCRIPTION OF THE PARTS AND THEIR OPERATION

The vane engine 10 of FIGS. 1 to 3 comprises a gen-

erally cylindrical housing **11**. A hub-shaft **12** rotates about a center line **13**, having its bearings on or supported by the housing **11** (FIG. 2). In the design shown, the hub-shaft **12** has eight equally spaced piano hinges **21, 22, 23, 24, 25, 26, 27, 28**, (which may be pinned at the ends only or as shown) and eight vanes **31, 32, 33, 34, 35, 36, 37**, and **38** are pinned at their center of gravity to respective piano hinge points **21, 22, 23, 24, 25, 26, 27**, and **28** by means of shafts **41, 42, 43, 44, 45, 46, 47**, and **48**. Each of the vanes **31, 32, 33, 34, 35, 36, 37, 38** may have a counter mass **51, 52, 53, 54, 55, 56, 57, 58**, so that as the vanes oscillate about their respective shafts **41, 42, 43, 44, 45, 46, 47, 48**, the hub-shaft **12** remains in dynamic balance as it rotates. Although eight vanes are shown in FIG. **1**, any number of equally spaced vanes greater than three may be used.

A drum **14** rotates about a center line **15** which is displaced from the hub center line **13** by the distance *y*. The drum **14** has its bearing on the housing **11**. The drum **14** and the hub-shaft **12** are synchronized to rotate in the same direction and at the same rotating speed. The drum **14** has slots **61, 62, 63, 64, 65, 66, 67, 68** at its outer diameter, and these slots are just large enough for the corresponding vanes **31, 32, 33, 34, 35, 36, 37, 38** to slide and oscillate in as the hub-shaft **12** and the drum **14** rotate. Between adjacent axial slots **61, 62, 63, 64, 65, 66, 67, 68** there may be gusseted arch or beam sections **71, 72, 73, 74, 75, 76, 77, 78** with cooling ports or tubes **79**. The drum **14** may have discs **16** and **17** (FIG. 2) at its ends for supporting the gusseted arc sections **71, 72, 73, 74, 75, 76, 77, 78**. The discs **16** and **17** also support the bearings **18** and **19** for the drum **14** on the housing **11**. The disc **16** may also be provided with an internal gear **80** (FIG. 3).

The mechanism for synchronizing the hub-shaft **12** and the drum **14** may comprise the internal gear **80** and a meshing spur gear **81**, which is keyed to a shaft **82** that has its bearings on the housing **11**. Also keyed to shaft **82** is a second spur gear **83**. The spur gear **83** may be meshed with a pinion gear **84**, which is also meshed to a third spur gear **85**, or, as shown in FIG. **7**, the gear **84** is keyed to a shaft **84***a* that also carries a gear **84***b* meshed to the gear **85**. The spur gear **85** is keyed to the hub-shaft **12**. The pinion gear **84** has its shaft bearings on the housing **11**. The pitch diameter and teeth of the gears **80, 81, 83, 84**, and **85** are prescribed so that the hub-shaft **12** and the drum **14** are synchronized to rotate in the same direction and at the same rotating speed.

As shown in FIG. **7**, the gears have the following pitch diameters:

gear	diameter
80	D_1
81	D_2
83	D_3
84	D_4
84*b*	D_5
85	D_6

and the pitch diameters are related so that

$$D_1/D_2 \times D_3/D_4 \times D_5D_6 = 1.$$

Power may be transmitted through the shaft **12** or the shaft **82** or both of them. The housing **11** may be provided with cooling fins **86**.

For the engine device of FIG. **1**, the housing **11** may be provided with an intake scavenging and exhaust port **87**. A fan **88**, which is keyed to the hub-shaft **12**, may be used to blow a fresh charge of air through the open port **87** to help scavenge the expanded gases out of the exhaust, to cool the vanes **31, 32, 33, 34, 35, 36, 37**, and **38** and to cool the outer surface of each drum beam section **71, 72, 73, 74, 75, 76, 77, 78** when it is at the port **87**. Also, the fan air flows past the cooling fins **86** to cool the engine housing **11** and blows air through the cooling passages **79** between the gussets and the arcuate segments in the beam elements **71, 72, 73, 74, 75, 76, 77**, and **78**.

The hub-shaft **12** rotates clockwise, and when, for example, the vane **36** moves past the position **89** of the housing **11**, a fresh charge is trapped in a working space **96** bounded by the adjacent vanes **36** and **37**, the outer surface of the beam element **76**, and the inner surface **90** of the housing **11** between the tips of the vanes **36, 37** and side disc section of the housing **2**. Each of the adjacent vanes **31, 32, 33, 34, 35, 36, 37, 38** has a working space **91, 92, 93, 94, 95, 96, 97, 98**. (For a three vane engine there would be three working spaces; for every vane, no matter how many, there is a corresponding working space.) A fuel injector **99** may inject fuel into each working space **91, 92, 93, 94, 95, 96, 97, 98**, in turn as it moves past it.

As the hub-shaft **12** and the drum **14** move clockwise, they force the vanes **31, 32, 33, 34, 35, 36, 37, 38** to follow a prescribed movement and the working space **91, 92, 93, 94, 95, 96, 97, 98** becomes smaller, thus compressing the gases trapped in it in a manner approaching isentropic compression. When each space is in the top position (where the space **91** is in FIG. **1**), it has been reduced to its smallest volume, and a spark ignition system **100** is timed to explode the fuel in the space **91** and heat it substantially by a constant volume process to increase its pressure and force the vanes to turn the hub-shaft **12** clockwise, so the hot gases will expand and do work on the engine shaft. When the vanes **31**, etc., reach the position **101** of the housing **11**, the hot expanded gases in the space **91**, etc., are exhausted centrifugally by the centrifugal action of rotation. Also, the fan **88** forces exhaust gases to flow axially out of the port **87**.

In FIGS. **4** and **5** the rotary vane compressor or motor **110** has most of the same parts as the engine **10** and are given the same reference numerals. The basic differences are that the fuel injector **99** and the spark ignition system **100** are eliminated, and in place of the common exhaust, scavenging, and intake port **87** shown for the engine **10**, the housing **111** of the compressor or motor **110** has an intake port **112** separate from the discharge port **113**, and these ports **112** and **113** are located diametrically opposite each other. Also, the vanes **31, 32, 33, 34, 35, 36**, and **37** are practically inside the drum **114**, when its respective working space **191, 192, 193, 194, 195, 196, 197, 198** is at its minimum volume, which is equal to the working tolerances between the housing **111** and the drum **114** multiplied by the vane width.

When operating as a vane compressor **110**, the intake port **112** is closed as the vane **31, 32**, etc., is forced past the edge **115** of the port **112** by means of clockwise rotation of hub-shaft **12** and the drum **114**. The working space **191,192**, etc., may be close to its largest volume just after the vane **31, 32**, etc., closes the intake port

112 at the station 115. As the compressor rotates clockwise, the working space 191, 192, etc., is reduced, and the trapped gases are compressed approximately adiabatically until the vanes 31, 32, etc., move past the station 116 in the housing 111 to open the space 191, 192, etc., to the discharge port 113. The compressed gases are preferably forced out of the space 191, 192, etc., through the discharge port 113 into a compressed gas accumulator (not shown). When the vanes 31, 32, etc., rotate past a station 117, a small volume of compressed gas is trapped in the space 191, 192, etc., this trapped compressed gas expands approximately isentropically and does work on the vanes 31, 32, etc., as the space 191, 192, etc., increases. When the vanes 31, 32, etc., pass a station 118, the compressed gas in the space 191, 192, etc., is substantially equal to the pressure of the gas in the intake port 112. In order to increase the volumetric efficiency of the compressor, the volume of space 191, 192, etc., as the vane 31, 32, etc., moves past the station 117 should be kept to a minimum.

When the device 110 is operation as a vane motor or steam engine, the motor turns in a counterclockwise direction. Compressed gas or steam, etc., flows from the accumulator, not shown, through the port 113, which is now the intake port, into the working space 191, 192, etc. After the vanes 31, 32, etc., move past the station 116, the compressed gases are trapped in the working space 191, 192, etc. As the motor rotates counterclockwise, the working space 191, 192, etc., increases in volume and the compressed gases expand approximately isentropically to do work on the vanes 31, 32, etc., until they move past the station 115 to open port 112, which is now the exhaust port. When the exhaust port 112 is open, the pressure in the working spaces 191, 192, etc., is substantially the same as the gases in the exhaust port 112, except when the cutoff point is increased. After the vane 31, 32, etc., moves past the station 118, gases are trapped in the space 191, 192, etc.; this trapped gas is approximately isentropically compressed back to the pressure in the accumulator as the working space 191, 192, etc., is reduced. In order to increase the efficiency of the motor, the mass of gas which is compressed back to the accumulator pressure is designed to be a minimum. When the 31, 32, etc., rotates past the station 117, the compressed gases are returned back to the intake port 112 to be combined with more compressed gases for another expansion work cycle.

In order to increase the motor torque per revolution an arcuate cutoff valve 120 (FIG. 5) may be turned counterclockwise to give the desired cutoff volume 191, 192, etc. For full admission, an arcuate valve 121 may be turned counterclockwise. The compressed gases flow axially from a chamber 122 through the arc ports into the working spaces 191, 192, etc.

In order to contain lubricating oil inside the drum 14 or 114, leaf spring scrapers 130 (FIG. 6) may be used to scrape the oil of the vanes 31, 32, etc., and keep it inside the drum 14 for lubricating the pivot shafts 41, 42, 43, 44, 45, 46, 47, 48, the bearings for the hub-shaft 12 and the bearings 18 and 19 for the drum 14. The scrapers 130 may be secured to each bridge section 71, 72, 73, 74, 75, 76, 77, 78, by means of screws 131 and a nut plate 132 or a quick disconnect clamp. The beam section 14 has an arcuate surface for the spring 130 to follow as it flexes; so it will have fatigue stresses which are below the endurance limit of the spring steel 130. As the vanes 31, 32, etc., reciprocate and oscillate in the slots 61, 62, etc., the leaf spring 130 scrapes the excess lubricating oil of the vanes 31, 32, etc., so it will be contained inside the drum 14; just sufficient oil is left on the vane 31, 32, etc., to lubricate the rubbing surface between the vanes 31, 32, etc., and the slots 61, 62, etc.

In order to limit the flow of compressed gas into the drum 14 to a minimum, seal bars 200 may be provided in axial slots 201 in the ends of the beam arcs 71, etc., that bear on the vanes 31 to 38. Metal springs 202 or other fluid pressure means may be used to keep the seal bars 200 tight against the vanes, and the bars 200 fit snugly in the axial slots 201, thus a minimum flow of compressed gas passes from the working space 91–98 into the drum 14.

The geometry of the rotary vanes is illustrated in FIG. 8. When a vane 31 is in its zero θ position, the radial line R from the centerline of the drum 14 passes through the centerline of the hub-shaft 12 and through the pivot point of this vane 31. This radial line R also passes through the centerline of the vane 31 and is collinear with the radial line r from the centerline of the hub-shaft 12. Thus, the angle α between the centerline of the vane 31 and the radial line r is also zero when $\theta = 0$. $P_o = r + l = P_o$ maximum.

As the hub-shaft 11 and the drum 14 rotate clockwise, the angle α increases, and the blade tip leads the rotor, and the radial lines r and R remain parallel to each other. The vane 31 (whose length is l) bears on the drum 14 (R) at a distance e from the pivot point. Thus, the tip of the vane l will be at a radial distance P_o from the centerline of the hub. As the vane rotates from its $\theta = 0$ position to its $\theta = 90° = \pi/2$ radians position, the angle α increases and reaches a maximum when $\theta = 90°$; likewise, the radial distance P_o is a minimum when $\theta = 90°$.

As the vane rotates past its $\theta = 90°$ position, the angle α decreases, and the radial distance P_o increases until $\theta = 180° = \pi$ radians, where $P_o = r + l = P_o$ maximum again, and where $\alpha = 0$ again.

As the vane rotates past its $\theta = 180°$ position, the angle α becomes negative, and the vane tip lags behind the rotor. The radial lines r and R remain parallel to each other, and the radial distance P_o from the hub centerline to the tip of the vane l again decreases until the vane reaches its $\theta = 270°$ position, where P_o is at its minimum radial position again and the angle α is at its negative maximum.

As the vane rotates past its $\theta = 270° = 3\pi/2$ position, the angle α decreases and the radial distance P_o increases until $\theta = 360° = 2\pi$ radians, where $P_o = r + l = P_o$ maximum again, and $\alpha = 0$ again. The cycle for one vane is then completed and will be repeated.

All of the vanes 32, 33, 34, 35, 36, 37, 38, undergo the same cycle as the vane 31. If there are n vanes, they may be placed $2\pi/n$ radians apart, so that there will be equal working spaces between vanes.

The surface which the vane tips circumscribe as they rotate and oscillate about the hub shaft can be derived mathematically; they can be written in polar coordinates with the origin at the centerline of the hub-shaft 12. For a prescribed design, the only variable is the angle θ. The angle θ is zero when a radial line drawn from the centerline of the drum first passes through the centerline of the hub shaft then through the pivot point

of the vane and through the centerline of the vane. The vane is in its straight line extended position at $\theta = 0$ and $P_o = r_1 + l_1$, which is at its largest radius.

The fixed parameters for a prescribed design are:

c = the distance between the centerlines of the drum and the hub shaft.

h = the width of the slot in which the vane reciprocates and oscillates.

l = the length of the vane from its pivot point to its extended position.

r = the radial distance from the hub centerline to the vane pivot point, and

R = the radius of the drum where the drum bears on the vane.

The variable parameters are:

e = the distance from the vane pivot point to its slot bearing point at R.

t = the thickness of the vane at e.

P_o = the radius from the hub centerline to the vane tip.

θ = the angle of the hub and drum measured from the radial line drawn from the drum centerline to the centerline of the hub shaft.

The equation for the radius of the circumscribed surface of the vane tip with its origin at the hub centerline is:

$$P_o = \sqrt{r^2 + l^2 + 2rl\sqrt{1.0 - \frac{c^2 \sin^2 \theta}{(R-r)^2 + 2c(R-r)\cos\theta + c^2}}}$$

The equation for the distance from the vane pivot point to the point where the drum bears on the drum is:

$$e = \sqrt{(R-r)^2 - 2(R-r)\,c\cos\theta + c^2}$$

The equation for the thickness of the vane is:

$$t = h\cos\left\{\sin^{-1}\left[\frac{c\sin\theta}{\sqrt{(R-r)^2 - 2c(R-r\cos\theta + c^2}}\right]\right\}$$

These equations may be derived as follows:

The distance s between the parallel radial lines R and r at angle θ:

$$s = c\sin\theta. \tag{1}$$

The chord segment distance a for the vane contact at radius R to the vane pivot point at r:

$$a = (R-r)\sin\theta \tag{2}$$

The minimum distance b from the vane pivot point to the chord, a line normal to the chord:

$$b = (R-r)\cos\theta - c \tag{3}$$

The hypotenuse e of the triangle abe:

$$e^2 = a^2 + b^2 = (R-r)^2(\sin^2\theta + \cos^2\theta) - 2(R-r)\,c\cos\theta + c^2 \tag{4}$$

$$e = \sqrt{(R-r)^2 - 2(R-r)\,c\cos\theta + c^2}$$

This gives the second equation shown above.

The sine of the angle α between the radial line r and the vane centerline l:

$$\sin\alpha = s/e = c\sin\theta / \sqrt{(R-r)^2 - 2(R-r)\,c\cos\theta + c^2} \tag{5}$$

The cosine law is used to get the radius of curvature P_1 of the surface circumscribed by the vane with respect to the star shaft centerline.

$$\cos\alpha = \sqrt{1-\sin^2\alpha}$$

$$P_o^2 = r^2 + l^2 - 2rl\cos(\pi-\alpha)$$

$$= r^2 + l^2 + 2rl\cos\alpha$$

$$P_o = \sqrt{r^2 + l^2 + 2rl\sqrt{1.0 - \frac{c^2\sin^2\theta}{(R-r)^2 + 2c(R-r)\cos\theta + c^2}}} \tag{6}$$

which is the first equation given above.

The angle β between the vane and the radial line R:

$$\sin\beta = s/e = c\sin\theta / \sqrt{(R-r)^2 - 2c(R-r)\cos\theta + c^2} \tag{7}$$

For a constant slot h in the drum at radius R, to determine the vane thickness t with respect to the distance e from the vane pivot point, so that it will fit snugly in h:

$$t = h\cos\beta = h\cos\left\{\sin^{-1}\left[\frac{c\sin\theta}{\sqrt{(R-r)^2 - 2c(R-r)\cos\theta + c^2}}\right]\right\} \tag{8}$$

For the radius of curvature of the drum circle with respect to the centerline of the star shaft center, the cosine law is again used:

$$P_i = \sqrt{R^2 + c^2 - 2Rc\cos\theta} \tag{9}$$

The angle ϕ between the radial line P and the centerline to the vane l is obtained by the sine law.

$$r/\sin\phi = P_o/\sin(\pi-\alpha)$$

$$= P_o/\sin\alpha$$

$$\sin\phi = r/P_o\sin\alpha$$

The area A_1 at θ_x:

$$A_1 \approx \tfrac{1}{2}(l-e_x)^2(r/P_o)\sin\alpha_x\,[1-(r/P_o)\sin\alpha_x\tan\alpha_x] \tag{10}$$

The area $A_{x'}$ of the working space for n vanes of constant thickness t:

$$\theta_{x'} = \theta_x + 2\pi/n \tag{11}$$

$$A_w=\left\{1/2\int_{\theta_x}^{\theta_x+\frac{2\pi}{n}}(P_o^2-P_1^2)d\theta-lt-\frac{t}{2}(e_x+e_x')\right.$$
$$+1/2(l-e_x)^2\frac{r}{p}\sin\alpha_1\left[1-\left(\frac{r}{P_{o_x}}\right)\sin\alpha_x\tan\alpha_x\right]$$
$$\left.-1/2(l-P_{x'})^2\frac{r}{P_{o_{x'}}}\sin\alpha_2\left[1-\left(\frac{r}{P_{o_{x'}}}\right)\sin\alpha_{x'}\tan\alpha_{x'}\right]\right\}$$
(12)

The working space or working volume is V_w = the working area times the width of the vane s.

$$V_w=A_wS$$
(13)

An integral vane compressor and vane motor **30** is shown in FIG. **9**. It has a compressor intake port **311**, a compressor exhaust port **312**, a motor intake port **313**, and a motor exhaust port **314**.

The compressor intake port **311** to each working space is closed by a vane after that working space achieves its largest volume, low pressure gas being compressed in that working space as it is made smaller. The compressed gas, after it has been compressed to a desired pressure level, is discharged through the compressor exhaust **312**, the compressor exhaust port **312** being passed by the vane just before the working space achieves its smallest volume.

The vane then opens the working space to high pressure gas flowing into the motor intake port **313** just after the working space passes its smallest volume. The motor intake port **313** remains open until the space between the vanes is at a prescribed value, then the next vane moving to close the working space off from the intake port **313** traps compressed gas in the working space. The working space increases in volume, and the compressed gas expands to do work on the vanes and members rotating therwith until the working space is near its largest volume; then the working space is opened by a vane to the motor exhaust port **314**, so that the expanded gases are exhausted. The momentum of the hot gases forces them to flow out radially and tangentially, or flow out in radial and tangential directions, while a fan or other device scavenges the hot gases, axially or otherwise, so that a fresh charge is blown into the working space where it enters the compressor intake port **311**.

To those skilled in the art to which this invention relates, many changes in construction and widely differing embodiments and applications of the invention will suggest themselves without departing from the spirit and scope of the invention. The disclosures and the description herein are purely illustrative and are not intended to be in any sense limiting.

I claim:

1. An integral vane compressor and vane motor having compressor intake port means and exhaust port means and motor intake port means and exhaust port means, comprising:

a rotating central hub having a series of vane pivot points spaced therearound at equal radii from the center of the hub,

at least three vanes, each pinned at its center of gravity to said hub at a said pivot point,

a generally cylindrical drum with its axis parallel to and displaced radially from that of said hub, said drum having a separate slot for each vane through which the vane extends, for guiding the radial position of each said vane,

synchronizing means mechanically linking said hub and said drum so that they rotate in the same direction and at the same rotating speed, so that said vanes reciprocate and oscillate in said guide slots as the hub and drum rotate,

a housing enclosing said vanes and cooperating with said vanes and said drum to provide a series of working spaces, one for each said vane to compress or expand a fluid, and

intake and exhaust port means for leading fluid into and from said working spaces,

said compressor intake port means to each working space being closed by a said vane after that working space achieves its largest volume, low pressure gas being compressed in said working space as it is made smaller, the compressed gas, after it has been compressed to a desired pressure level, being discharged through said compressor exhaust port means,

said compressor exhaust port means being passed by said vane just before said working space achieves its smallest volume,

said vane then opening said working space to high pressure gas flowing into said motor intake port means just after said working space passes its smallest volume, said motor intake port means remaining open until the space between said vanes is at a prescribed value, then the next said vane moving to close said working space off from said intake port means and to trap compressed gas in said working space,

said working space increasing in volume and said compressed gas expanding to do work on the vanes and members rotating therewith until said working space is near its largest volume,

then said working space being opened by a said vane to said motor exhaust port means, so that said expanded gases are exhausted;

the centrifugal force of the hot gases forcing them to flow out radially and

a fan for scavenging said hot gases axially so that a fresh charge is blown into the working space where it enters said compressor intake port means.

2. An integral vane compressor and vane motor having compressor intake port means and exhaust port means and motor intake port means and exhaust port means, comprising:

a rotating central hub having a series of vane pivot points spaced therearound at equal radii from the center of the hub,

at least three vanes, each pinned at its center of gravity to said hub at a said pivot point,

a generally cylindrical drum with its axis parallel to and displaced radially from that of said hub, said drum having a separate slot for each vane through which the vane extends, for guiding the radial position of each said vane,

synchronizing means mechanically linking said hub and said drum so that they rotate in the same direction and at the same rotating speed, so that said

vanes reciprocate and oscillate in said guide slots as the hub and drum rotate,

a housing enclosing said vanes and cooperating with said vanes and said drum to provide a series of working spaces, one for each said vane to compress or expand a fluid, and

intake and exhaust port means for leading fluid into and from said working spaces,

said compressor intake port means to each working space being closed by a said vane after that working space achieves its largest volume, low pressure gas being compressed in said working space as it is made smaller, the compressed gas, after it has been compressed to a desired pressure level, being discharged through said compressor exhaust port means,

said compressor exhaust port means being passed by said vane just before said working space achieves its smallest volume,

said vane then opening said working space to high pressure gas flowing into said motor intake port means just after said working space passes its smallest volume, said motor intake port means remaining open until the space between said vanes is at a prescribed value, then the next said vane moving to close said working space off from said intake port means and to trap compressed gas in said working space,

said working space increasing in volume and said compressed gas expanding to do work on the vanes and members rotating therewith until said working space is near its largest volume,

then said working space being opened by a said vane to said motor exhaust port means, so that said expanded gases are exhausted;

the momentum of the hot gases forcing them to flow out in a radial and tangential direction, and

means for scavenging said hot gases so that a fresh charge is blown into the working space where it enters said compressor intake port means.

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