

[54] **ROTARY COMPRESSOR-EXPANDER
HAVING SPRING BIASED VANES**

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1971, abandoned.

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418/264; 418/270

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F04C 29/00

[58] **Field of Search**..... 418/8, 13, 152, 178, 235,
418/258, 263, 264, 270, 268, 260-262

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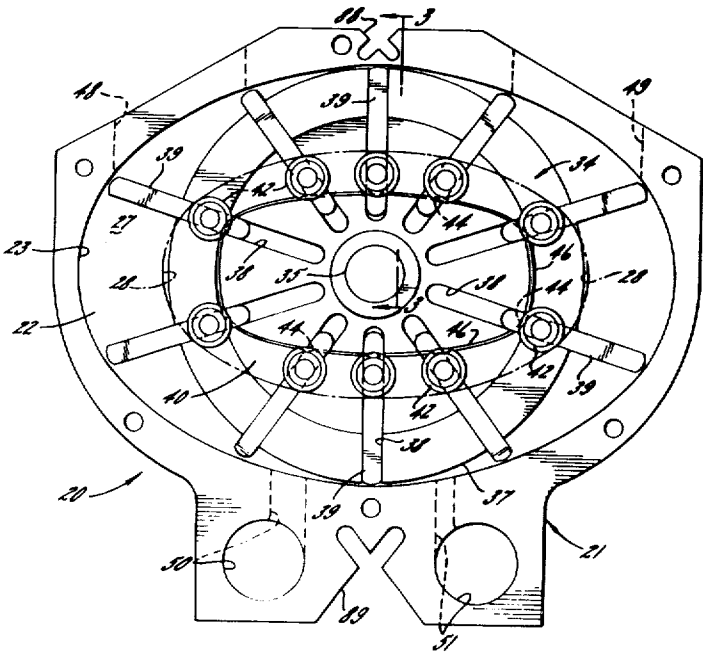
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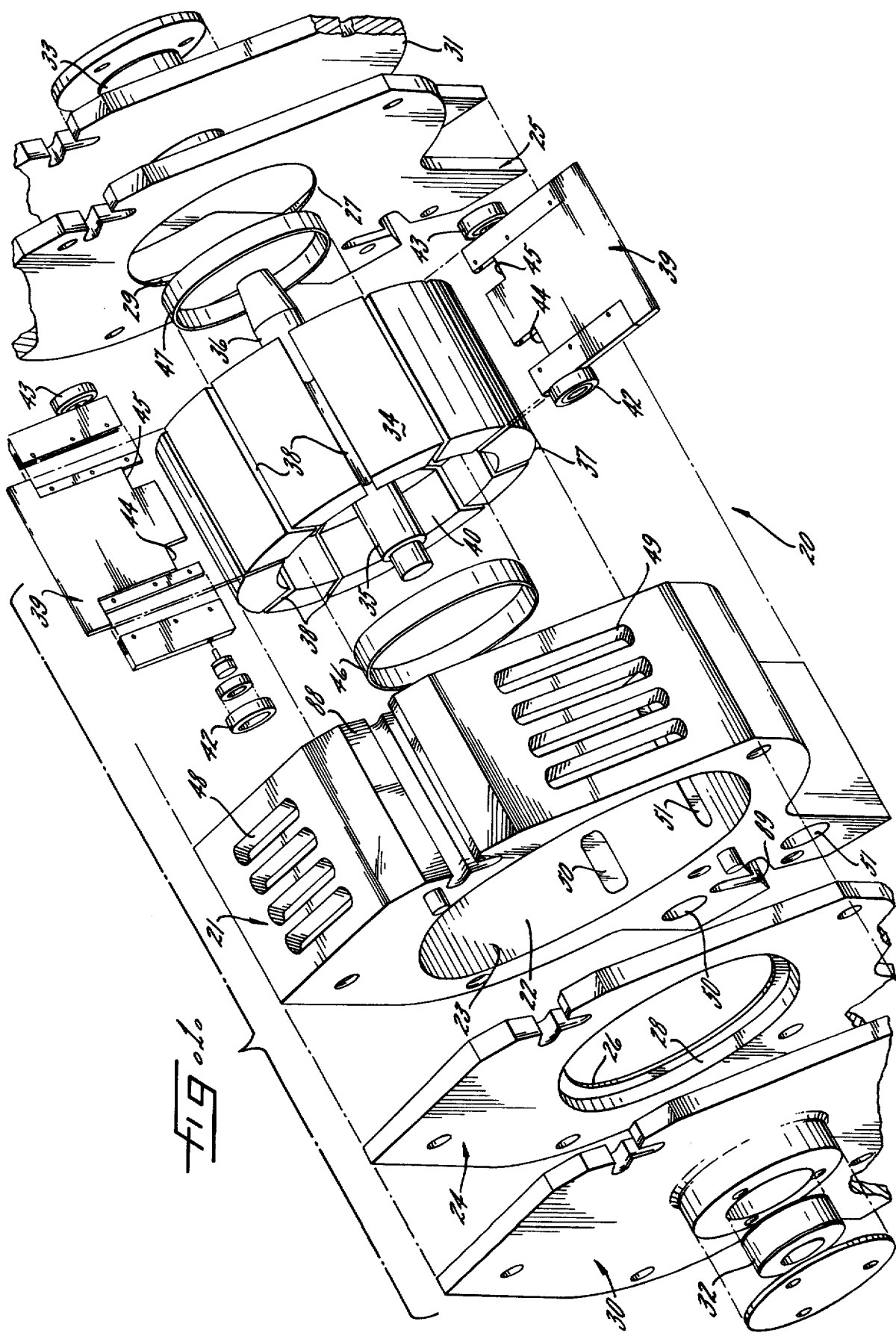
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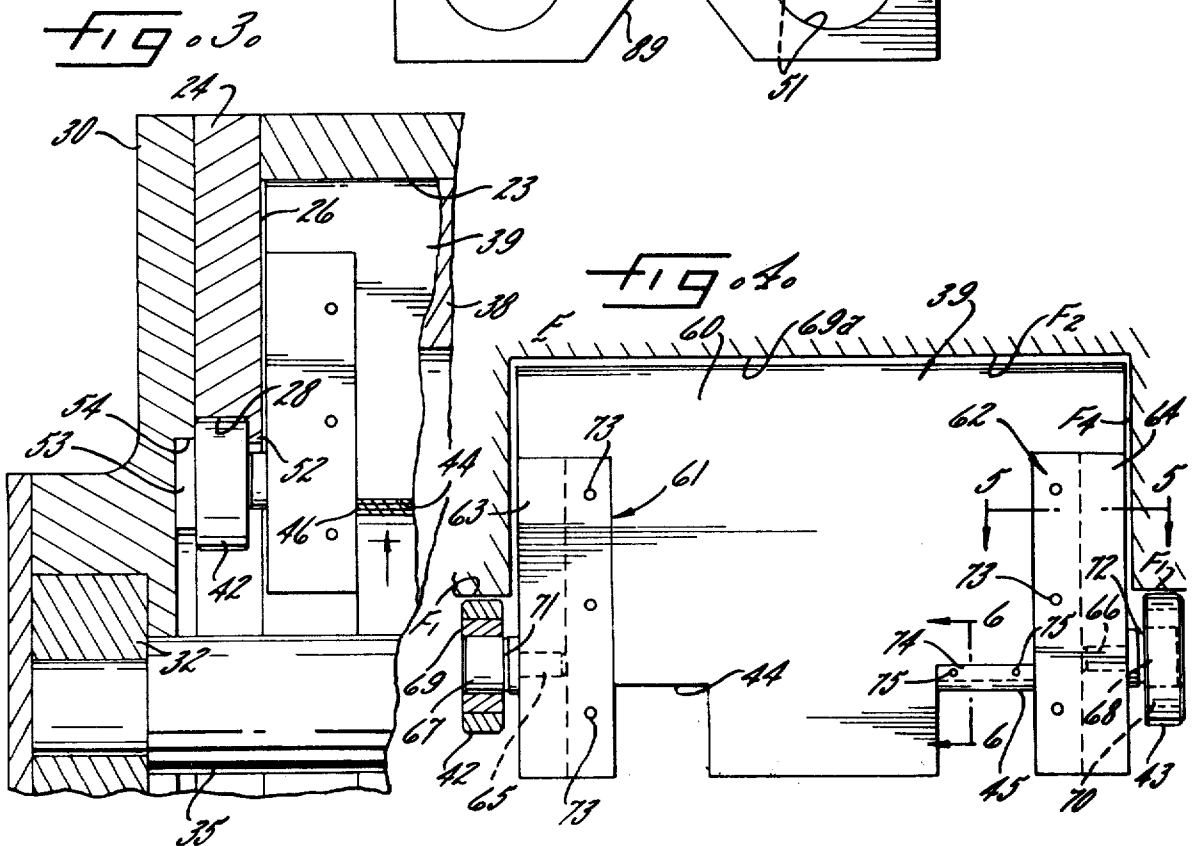
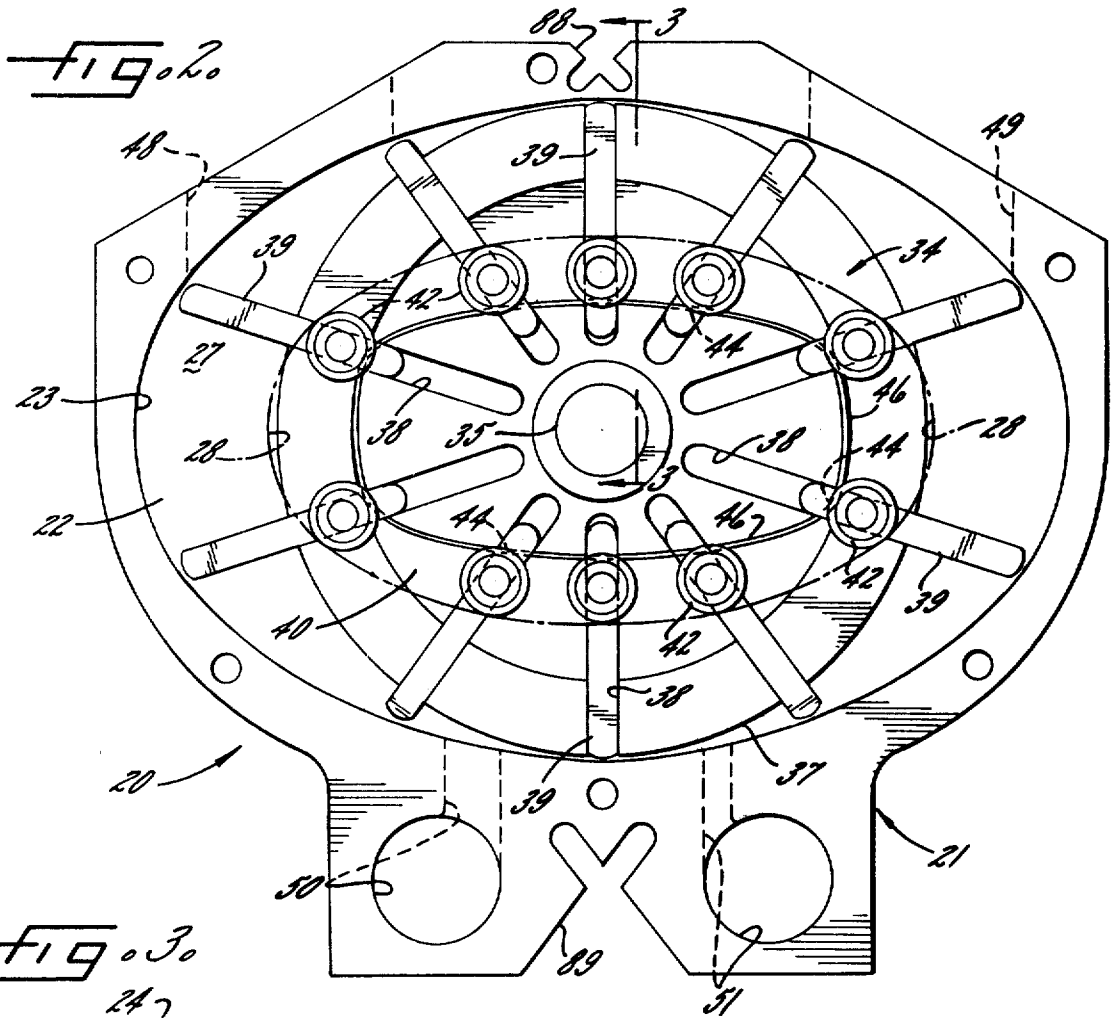
[57] **ABSTRACT**

A rotary unitary compressor-expander for use as a refrigeration device. The unit includes a stator defining a chamber having an oval cross-section and a rotor mounted within the chamber. The rotor contains a plurality of radial vane slots into each of which is inserted a vane which is radially slidable within its slot. Each vane includes, at either edge, a vane pin or stub-shaft on which is rotatably mounted a vane roller. Oval cam tracks are provided at the ends of the stator chamber for engaging the vane rollers. One or more continuous spring bands are contained within the rotor and produce on the vanes an outwardly biasing force which urges the vane rollers into continuous contact with the cam tracks. The cam tracks are so symmetrically sized and positioned with respect to the stator chamber that with the vane rollers thus maintained in contact with the cam tracks, the vane tips are maintained in "clearance" sealing engagement with the wall of the stator chamber.

28 Claims, 15 Drawing Figures







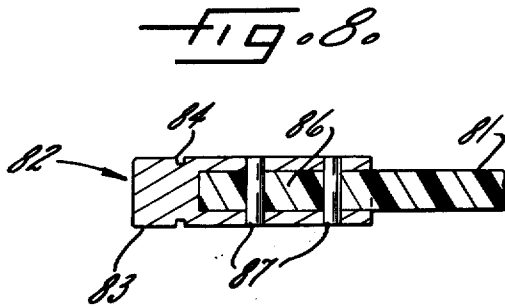
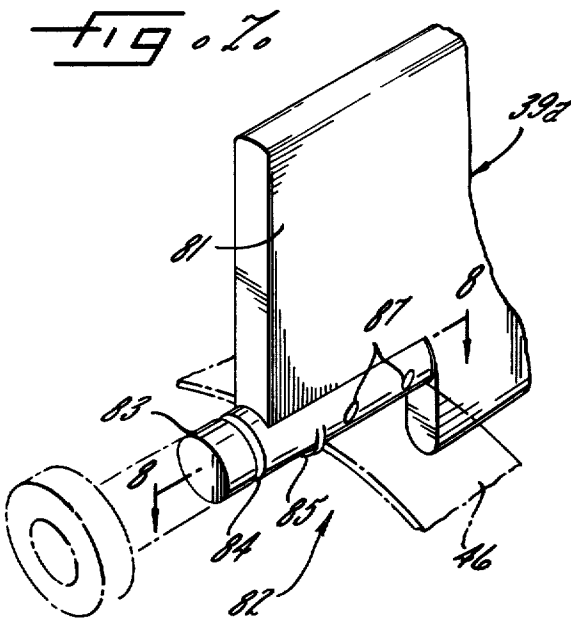
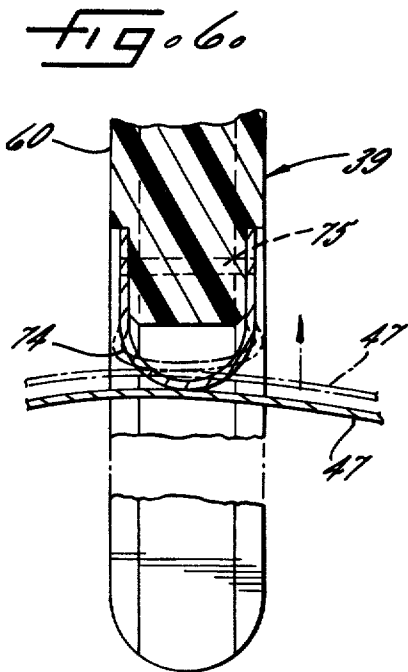
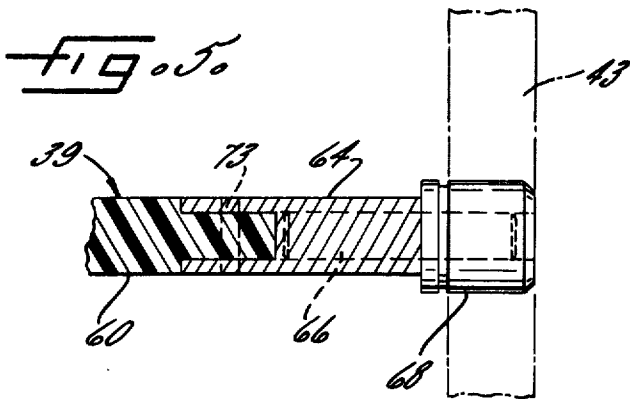


Fig. 9.

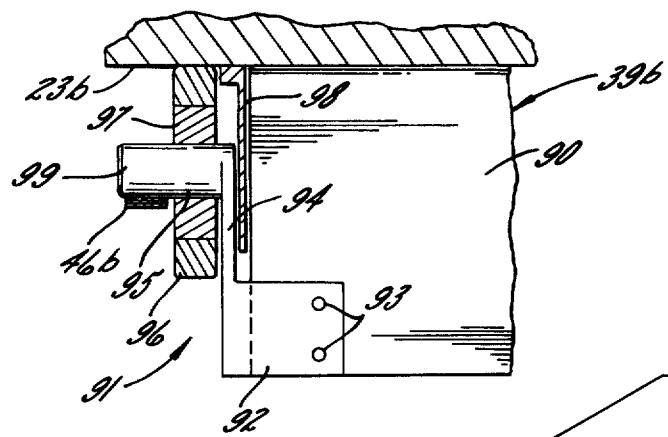


Fig. 10.

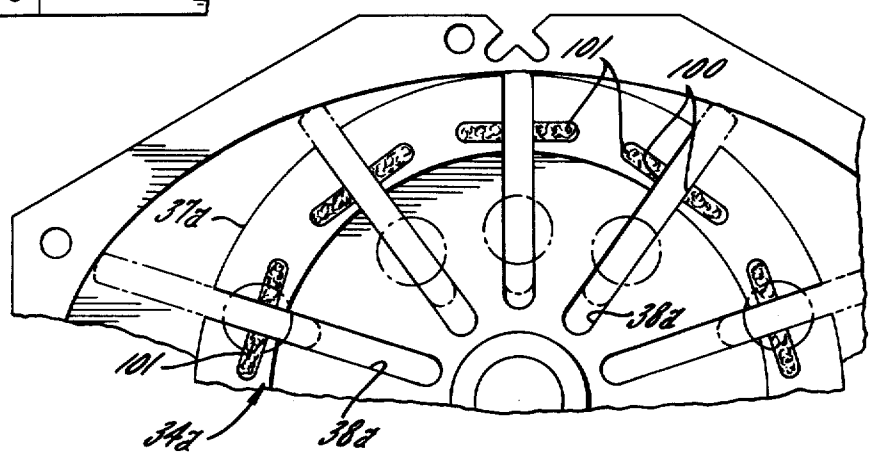
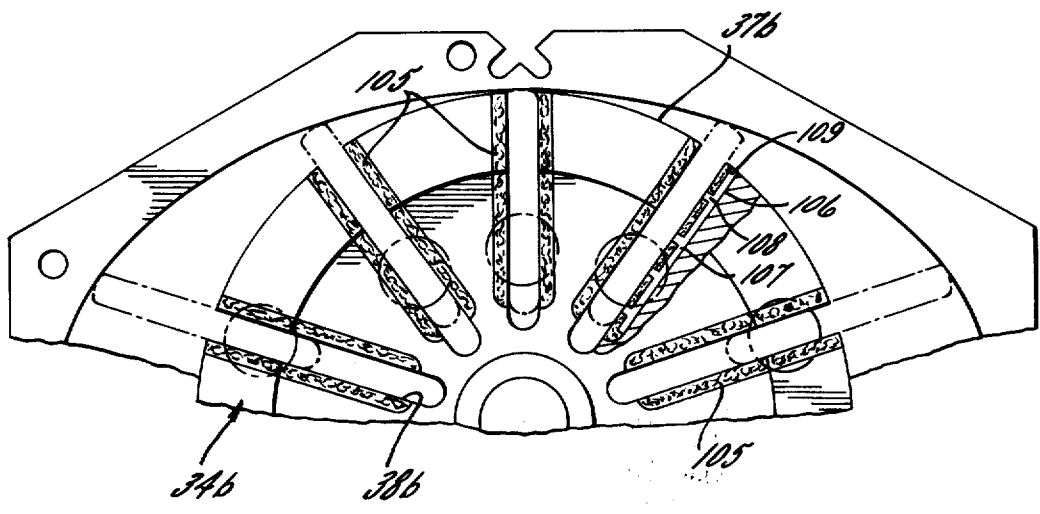
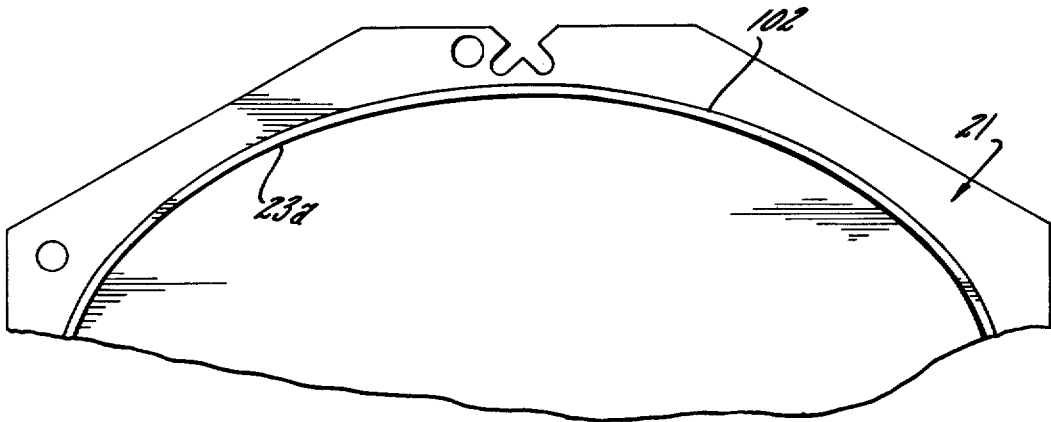
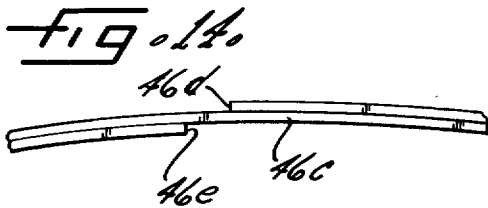
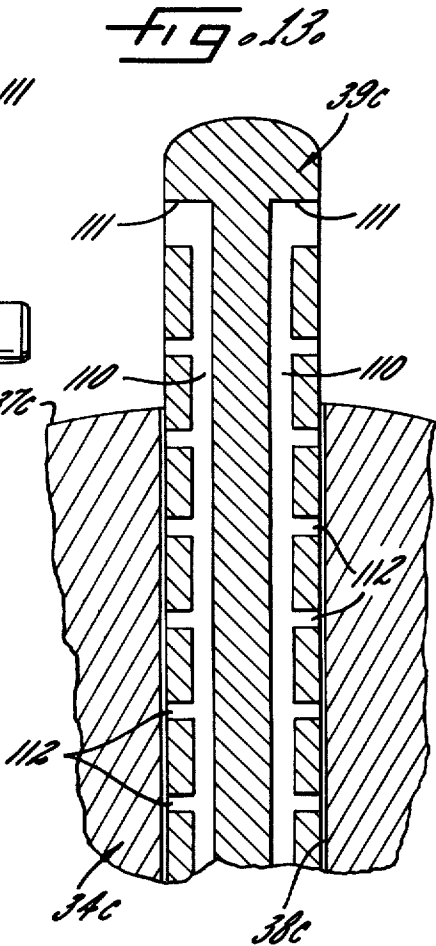
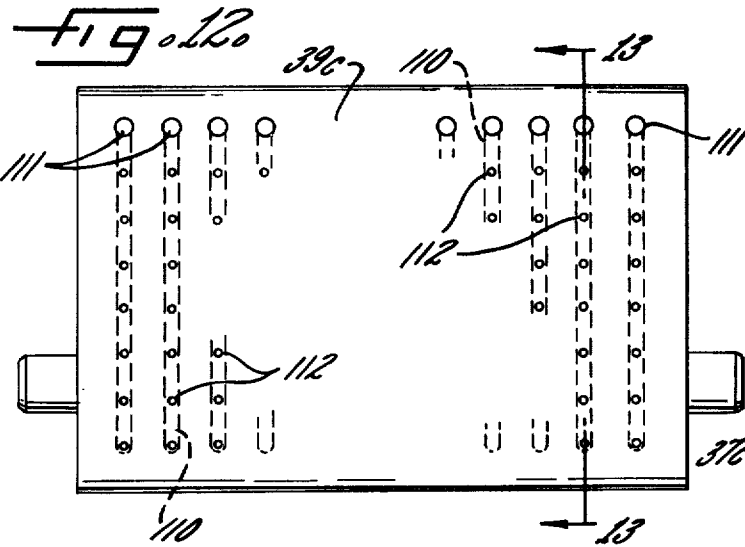


Fig. 11.





ROTARY COMPRESSOR-EXPANDER HAVING SPRING BIASED VANES

The present application is a continuation-in-part of application Ser. No. 197,312 filed on Nov. 10, 1971, and now abandoned.

A rotary unitary compressor-expander of the type disclosed herein is shown in U.S. Pat. No. 3,686,893. However, utilization in areas such as automobile air conditioning requires that the cost of manufacture be minimized while assuring a reasonably long and trouble-free service life. In addition, the various design parameters involved require engineering trade-offs not easily satisfied by methods utilized heretofore. For example, the requirement of maintaining a seal between the vane tip and stator surface is somewhat inconsistent with the requirement of minimum vane tip wear.

It is therefore, an object of this invention to achieve a rotary unitary compressor-expander utilizing materials and methods of manufacture which provide an inexpensive unit having a long useful life. It is a more specific object to provide a unit in which vane tip wear is minimized. It is a still more specific object of this invention to provide a rotary unitary compressor-expander wherein the vane tips are maintained in "clearance" sealing engagement with the stator chamber by the co-operative action between the outwardly biasing force of one or more spring bands acting against the vanes and the positive retractive action of cam tracks disposed to control radial vane travel. In this regard it is an object to provide a unit with greatly enhanced efficiency by eliminating sliding friction between the vane tips and stator wall.

It is a related object of this invention to provide a rotary unitary compressor-expander in which critical tolerances are achieved utilizing efficient and inexpensive methods of construction. In this regard it is an object to provide a composite vane in which the vane-tip-to-vane-pin spacing is achieved by relative adjustment of the component parts before their joinder. It is a more specific object to provide a method of vane assembly that achieves both accuracy and economy.

Other objects and advantages will become apparent from the attached detailed description and upon reference to the drawings in which:

FIG. 1 is an exploded view drawn in perspective of a preferred embodiment of the invention showing its major components.

FIG. 2 is a sectional front view of the compressor-expander with end plate and cam plate removed but showing the position of the cam track.

FIG. 3 is a fragmentary section taken generally along the line 3—3 in FIG. 2 but including the cam plate and end plate, showing the relationship between the vane, its roller, and the cam tracks.

FIG. 4, is a front view of a single vane illustrating the preferred means of vane pin attachment, and also illustrating a secondary springy element.

FIG. 5 is fragmentary section along the line 5—5 of FIG. 4, showing the dove-tailing of the vane pin assembly into the vane.

FIG. 6 is a fragmentary section along the line 6—6 of FIG. 4, illustrating the secondary springy element.

FIG. 7 is a perspective view of a portion of a single vane illustrating an alternative means of attachment of the vane pin to the vane.

FIG. 8 is a fragmentary section taken along the line 8—8 in FIG. 7, showing a single vane pin.

FIG. 9 is a fragmentary front view of a portion of a single vane, illustrating still another method of vane pin attachment.

FIG. 10 is a fragmentary front view of the rotor, illustrating the vane slots and the vane lubrication slots.

FIG. 11 is a fragmentary front view of the rotor illustrating vane slot inserts.

FIG. 12 is a front view of a single vane illustrating means for achieving a gas bearing.

FIG. 13 is a section along the line 13—13 of FIG. 12 showing the internal vane channels and also illustrating the vane within its slot.

FIG. 14 is a fragmentary view of an expansible spring band.

FIG. 15 is a front view of a stator with a graphitic inner liner.

While the invention will be described in connection with certain preferred embodiments, it should be understood that I do not intend to be limited to the particular embodiments shown but intend, on the contrary, to cover the various alternative and equivalent constructions included within the spirit and scope of the appended claims.

Turning now to the drawings and, particularly, to FIGS. 1 and 2, there are illustrated the major components of rotary unitary compressor-expander 20. The unit has a hollow stator member 21 having a central opening 22 defined by wall 23 which is of oval, that is elliptical or near elliptical, cross-section. Mounted at either open end of the stator chamber are cam plates 24 and 25 having inner faces 26 and 27, respectively, partially enclosing the stator chamber. Cam plates 24 and 25 contain cam tracks 28 and 29, respectively which face radially inward. These cam tracks are of oval shape and "geometrically synchronized" to the shape of stator surface 23; the relationship between the two will be more fully discussed below. Enclosing either end of the chamber are end plates 30 and 31 which carry aligned main bearings 32 and 33. Snugly fitted between the cam plates is rotor 34 having a cylindrical outer surface 37 and stub shafts 35 and 36, which engage the main bearings in the end plates. The rotor has machined in it equally spaced radially extending slots 38 which extend the full length of the rotor. It should be noted that in certain applications it may prove desirable to provide vane slots which are slightly inclined from the radial; thus references herein to radial vane slots should be read to include near radial orientation. The slots are occupied by vanes 39. At either end of rotor 34 are hollowed-out annular cavities. Cavity 40 is illustrated in FIG. 1, with the corresponding cavity 41 being a mirror image. Rotatably mounted on each vane at its flat base portion are aligned vane rollers 42 and 43. It is seen that each vane contains spring band notches or recesses 44 and 45. Spring bands 46 and 47 are positioned in the hollowed-out portions 40 and 41 of the rotor to ride within the spring band notches 44 and 45 of all vanes 39. The interrelationship of these elements is shown in FIG. 2. Note that FIG. 2 shows inlet and outlet ports 48 and 49 as well as heat exchanger ports 50 and 51. The construction of and purpose for these ports, as well as the utilization of the rotary unitary compressor-expander in refrigeration, is adequately taught in prior U.S. Pat. No. 3,686,893 therefore, these matters will be dealt with only generally herein.

The function of a rotary unitary compressor-expander, when used in refrigeration, is to accept the fluid to be cooled, compress that fluid in the compression half of the unit, remove the heat of compression in an intercooler and expand the fluid in the expansion half of the unit before discharging it. FIG. 2 illustrates a plurality of individual chambers in which, through rotation of the rotor, the fluid is compressed and expanded. These chambers are defined between any two adjacent vanes 39, rotor surface 37, stator surface 23, and cam plate surfaces 26 and 27. It is seen that to positively define these individual chambers, each vane 39 must be maintained in sealing engagement with stator surface 23, as well as cam surfaces 26 and 27. In accordance with the invention this is accomplished, while preventing any appreciable wear on the tips of the vanes, by the cooperative action of cam tracks 28 and 29, the plurality of vanes 39 with their vane rollers 42 and 43 and spring bands 46 and 47. The cam tracks 28 and 29 are so arranged that with all vane rollers 42 and 43 maintained in contact with those cam tracks, the tips of all vanes are maintained in a positive relation with stator wall 23, with the cam tracks setting the limit of vane travel and serving to positively retract the vanes. When the vane is being extended from its slot, the cam tracks limit the extent of radial travel while during other portions of the cycle the cam tracks positively retract the vane causing it to slide back into its slot. It should be noted that due to the varying angle of presentation of the vane tip to the chamber wall and non-radial (with respect to the rotor) contact of the vane roller with the cam track during parts of the cycle (see FIG. 2), the shape of the cam track does not exactly correspond to the shape of the chamber wall. The term "oval" is a general one intended to take into account such departures from true elliptical shape.

An outwardly biasing force is maintained on the vanes by the spring bands 46 and 47, pressing outwardly against the vanes in their recesses 44 and 45. Thus, while the cam tracks positively limit vane travel and retract the vanes, the spring bands force the vanes outwardly causing the vane rollers to maintain continuous contact with their respective cam tracks. The advantages attendant to this outwardly biasing force generated by the spring band are thereby achieved without the accompanying disadvantage of vane wear which would ultimately defeat the system. That is, without the positive travel limitation and retraction provided by the cam tracks, the spring bands would ultimately wear the vanes, by inward crowding action at the vane tips, to such an extent that the bands could no longer exert an outwardly biasing force on those vanes.

In short, the vane tips in the present construction are guided so close to the chamber wall that they form an effective seal with it, yet the tips "clear" the wall and do not exert pressure against it. Such relationship may be referred to for convenience, as "clearance" sealing engagement; the cam track shape necessary for achieving this engagement may be referred to as geometrically synchronized to the stator shape. The effectiveness of the seal obtained by "clearance" engagement is explained in part by the fact that leakage about the tip of the vane is highly throttled. Due to the high speed of rotation, which may in a typical case be on the order of 1,500 rpm., there is simply not time for any appreciable flow to occur. A further factor is that the differential pressure on opposite sides of a given vane is "in-

cremental," that is stage to stage, rather than "total." There also develops a viscous shear of the clearance gas (fluid between the vane tip and stator wall) which tends to create a non-flowing boundary layer, a mechanism sometimes referred to as visco sealing.

FIG. 3 further illustrates the cooperative action between a vane, its vane roller and the cam track, spring band and stator surface. There is seen spring band 46 riding within its recess 44 and biasing vane 39 outwardly, the biasing force illustrated by the arrow. It is seen that this force causes vane roller 42 to contact cam track 28. Under these conditions, it is seen that the tip of vane 39 is maintained in "clearance" sealing engagement with stator surface 23. The seal between the edge of vane 39 and cam surface 26 is also illustrated.

The structure described above has been found to eliminate the vane tip wear, a major cause of failure in vane-type compressors and expanders, and in addition to greatly improve the mechanical efficiency of the unit. Both of these results derive from the fact that there is no actual contact between the vane tip and the stator surface thus eliminating mechanical friction at the vane tip. In addition, the reduction of drag on the vane tip reduces the cocking moment of the vane in its slot thereby reducing vane to vane slot friction. We have found, both through testing of actual devices and through computer predictions, that utilization of the teachings of our invention can be expected to reduce friction by 80 to 90% over prior art devices.

It is apparent from the foregoing, that the relationship between the cam tracks, stator surface, vane rollers, and vane tips is extremely critical. This situation is further complicated by the fact that these rotary unitary compressor-expanders are intended for mass production, wherein parts should be interchangeable with a minimum of hand fitting. Manufacturing processes (e.g., numerically controlled machining) are available for accurately forming the oval surfaces of the stator chamber and cam tracks. Although these processes could also be applied to the vanes, this would make the completed assembly prohibitively expensive. In addition, it would impose the requirement that the vane be constructed of a material such as steel or aluminum which has good machinability properties.

In the preferred embodiment of our rotary unitary compressor expander, we prefer to use a composite vane illustrated in FIGS. 4, 5 and 6. FIG. 4 shows a composite vane 39 made up of vane body 60 and two vane roller assemblies 61 and 62. In this arrangement, vane body 60 is composed of light, durable plastic material with low thermal conductivity, for example DuPont Vespel SP21. This allows the vane body to be mass produced using fairly liberal tolerances and thereby providing a vane whose major structure is light in weight, has good frictional and thermal properties, is unaffected by the moisture in the fluid being cooled, and is easily and inexpensively fabricated. Each vane roller assembly 61 or 62 is preferably formed on a base 63 or 64 which is essentially a steel bracket. This bracket is drilled to snugly accept an attachment pin 65 or 66 on which vane pin 67 or 68 is tightly pressed, thereby joining the vane pin to its bracket. In the preferred embodiment, the vane pins 67 and 68 which serve as stubshafts for the rollers, are of metal or other durable material machined and hardened to act as inner races for bearings 69 and 70. The outer race of each bearing is snugly pressed into vane roller 42 or 43,

and the bearings have a close fit, so that when the bearing is assembled on its inner race, the roller is rotatably mounted free of play on its vane bracket. In addition, each vane pin 67 or 68 is provided with groove 71 or 72 which helps to retard the flow of lubricant away from the vane roller. It should be noted at this point that while the vane roller arrangement described above provides several desirable features, if economy is the major consideration the vane rollers can be replaced by cam followers, properly contoured and fixed to the vane stub shafts thereby eliminating both the vane rollers and their bearings.

As described above, the relationship between the vane roller and vane tip is an extremely critical one. I have found that in order to provide extended life in a vane with 1.936 inch spacing between the vane pin center and the vane tip, the preferable tolerance is $+0.0000 - 0.0005$ inches. The composite vane described above provides an extremely practical means of maintaining this critical tolerance while utilizing components manufactured to liberal tolerances. This is achieved by designing the vane body and vane pin assemblies such that their relative position is adjustable prior to joinder, and permanently joining these components while they are held in an assembly fixture or jig. FIG. 5 illustrates the means by which the vane body is joined to the vane pin assembly. It is seen that the vane body 60 dovetails into the vane pin assembly bracket 64. In practice, cement is applied to the mating portions of vane pin brackets 63 and 64 and vane body 60. They are dove-tailed and placed in an assembly fixture diagrammatically illustrated at F in FIG. 4. With the rollers bottomed on surfaces F1, the vane body 60 is "extended" on the fixture to engage the surface F2, thereby establishing a fitted position. If desired, the fixture end walls F3, F4 may be set at a reference spacing for gauging purposes. With the parts held in extended position, holes are drilled through the brackets 63 and 64 and the vane body 60, and pins 73 are pressed snugly into place. The end result is a relatively light and inexpensive composite vane, wherein the critical dimension is maintained from vane to vane throughout an entire production run and which insures a close running fit between each vane and the wall of the chamber.

An additional feature which can be incorporated into composite vane 39 is illustrated in FIGS. 4 and 6. It has been found that in rotary compressor-expanders utilizing ovals in which the ratio between the major and minor axes is relatively large, there may arise conditions wherein additional vane biasing range is required to supplement the range of the spring band. To this end, the vanes can be provided with secondary springy element 74 illustrated in spring band recess 45 on FIG. 4. This springy element is preferably made of spring steel and secured to the vane by press pins 75. Its function is illustrated in FIG. 6 which shows a vane 39 with attached secondary springy element 74. The spring band 47 is shown in engagement with this springy secondary element. In the normal condition, the secondary springy element assumes the position shown by the dashed lines. This is the condition wherein the spring band 47 has sufficient range to cause the vane rollers to contact the cam track as described above. However, in conditions when the range of the spring band is insufficient, the secondary springy element expands as shown in the solid lines to provide additional takeup. It should be noted that this function could also be accom-

plished by a rubbery secondary element attached to or dove-tailed into the vane in the spring band recesses 44 and 45.

FIGS. 7 and 8 show an alternative composite vane construction distinguished by extreme simplicity. Here a composite vane 39a has a vane body 81 constructed substantially as described above. A vane pin assembly 82 (FIG. 8) is formed from a length of steel rod having a portion of its surface 83 machined and hardened as described above to act as the inner race for the vane roller bearing. In addition, lubrication retaining groove 84 is also provided. A slot 86 for accepting the base of vane body 81 is formed in the vane pin as shown. Referring back to FIG. 7, the method of engagement between the vane pin assembly 82 and the vane body 81 is illustrated. In a manner similar to that described above, the relative position between these elements is adjusted in an assembly fixture before holes are drilled through the vane pin assembly and the vane body and press pin 87 are inserted. In addition, retainer 85 is positioned as shown, in order to prevent outward movement of the spring bands 46 and 47. In addition to providing the advantages of the composite vane described above, this method also provides a steel surface for co-acting with the spring band thereby to minimize wear.

One further embodiment of vane construction is illustrated with reference to FIG. 9. There a portion of a composite vane 39b is shown whose major structural element is a substantially rectangular vane body 90. Vane pin assembly 91 is attached to this vane body via bracket 92 which is positioned and pinned with pins 93. Attached to bracket 92 is offset member 94 to which vane pin 95 is attached as shown. Vane roller 96 and its bearing 97 are mounted on the vane pin, the roller 96 being of large diameter such that when assembled as illustrated, the surface of the roller and the vane tip are in alignment and will simultaneously contact stator surface 23b as illustrated. This results in a rotary unitary compressor-expander wherein the separate cam tracks are eliminated. As extension of the stator chamber acts as the cam track, thus eliminating the need for separate cam plates. It is seen that a space is provided between the offset member 94 and the edge of the vane. This is to allow insertion in the stator chamber of a sealing fence 98 to maintain sealing engagement with the edges of the vanes. Offset member 94 allows full vane travel without interfering with this sealing fence. This embodiment also illustrates use of an extension 99 on vane pin 95. This extension is provided to coact with the spring band since the vane illustrated here is not provided with spring band recesses. The spring band is thus placed outboard of the rotor as illustrated at 46b eliminating the need to form hollows in the rotor to accommodate the bands. It should be noted that although this outboard spring band has only been illustrated with reference to this particular embodiment, it is a feature which can be incorporated into any of the previous embodiments.

In addition to eliminating vane tip wear and improving mechanical efficiency, a further desirable feature in providing a long life unit is proper lubrication. Main rotor bearings 32 and 33 are lubricated in the normal manner. Referring briefly to FIG. 3, the means for lubricating the vane rollers is illustrated. There is shown a portion of a continuous oval slot 54 similar in shape to the cam track 28 cut in end plate 30. In this slot is disposed a lubrication retaining wick 53. This wick

maintains a source of lubricant for the vane roller bearings and also for the vane roller itself. In addition, the function of lubrication retaining grooves 71 and 72 in the vane pins in restraining the flow of lubricant away from the vane rollers has been described. Lubrication retaining fence 52 further helps maintain the lubricant as necessary in this area.

Referring now to FIG. 10 the means for lubricating the vanes and vane slots is shown. A fragment of rotor 34a with its numerous vane slots 38a is shown in end view. It is seen that intersecting each vane slot are lubrication slots 100. Inserted in these lubrication slots are lubrication retaining wicks 101 which maintain a source of lubricant for the vanes and vane slots.

An alternative means for reducing friction between the vane and its slot is shown in FIG. 11. There a fragment of rotor 34b is again shown in end view. This embodiment is similar to FIG. 10 except that the lubrication slots are removed and the vane slots 38b are enlarged to accept inserts 105. These inserts are bonded to their enlarged slots thereby to provide a composite vane slot. The inserts are made of a material with a low coefficient of friction such as DuPont Vespel SP21 thereby providing a freely sliding assembly. In addition a gas bearing effect can be achieved by modifying the vane slot inserts as shown by insert 106 in FIG. 11 which is cut away to illustrate one of a plurality of internal channels 107. These internal channels communicate to the vane slot through ports 108. In form they are similar to the vane channels illustrated in FIGS. 12 and 13 (to be described below) however they differ in that the channels communicate through ports 109 with the compressor-expander chambers. It is seen that a small portion of the pressurized fluid in the individual chamber is forced through port 109 into channel 107 and through ports 108 into the vane slot creating a cushion of air between the vane and its slot. As the inserts are bonded to the rotor the channels can be formed of grooves on the side of insert 106 which will mate with the rotor. It is obvious that using these means, channels cannot be provided in portions of the insert corresponding to the hollowed out portions of the rotor, therefore it is preferable to utilize these means with rotors having no internal spring band cavities.

An extremely durable unit is achieved by utilizing inserts made of steel, having internal rows of aligned roller bearings. The rollers are arranged so that their axes are perpendicular to the direction of vane travel, and so that the roller surfaces barely project into the vane slots.

A vane to vane-slot gas bearing is provided by the means illustrated in FIGS. 12 and 13. There is shown a modified vane 39c adapted to be used in a unit wherein the spring bands are positioned outboard of the rotor thereby to allow use of a rotor without hollows to accommodate the spring band. It should be noted that the vane pins are shown diagrammatically as any of the above described means of attachment can be used. As illustrated, the vane is provided with numerous internal channels 110, communicating with the vane surface via numerous ports 111 and 112. These channels and ports are disposed to allow passage of the fluid being cooled. FIG. 13 illustrates a vane 39c inserted in its vane slot 38c in the rotor. It is seen that the position of the vane in its slot causes some of the ports 112 to be enclosed within the vane slot while other of

the ports 111 are above the rotor surface 37c. Thus a portion of the fluid within the individual compressor or expander cavities is forced through ports 111, through channels 110 and through ports 112 creating a cushion between the vane and its slot thus providing a gas bearing effect. It should be noted that in the illustrated embodiment a set of channels is provided on either side of the vane; but the passage on either side of the vane are not connected thereby preventing pressure leakage between adjacent chambers.

Although the function of the spring band has been described above, the actual structure has not been dealt with in detail. In its simplest embodiment, each band is a continuous loop of spring steel. The loop is so sized that when it is positioned in the spring band recesses of its associated vanes, as illustrated in FIG. 2, (or against its vane pin extension if a spring band is used which is outboard of the rotor) it assumes an oval shape similar to the shape of the stator surface and cam tracks and forces all vane rollers into contact with the cam tracks. Rotation of the rotor causes the band to generally rotate with the rotor and its vanes while maintaining its oval profile, thereby maintaining a biasing force on all of the vanes. In a preferred embodiment, each band is composed of a laminate consisting of several loops of band material nested together to form a composite band. Such arrangement allows the use of relatively thin, individual layers which will be subject to comparatively lower stresses while still providing the necessary total biasing force. In addition, we have found it useful to provide a teflon coating on the spring bands to minimize wear on the band and its associated slots. When using multiple nested bands, this teflon coating allows the layers to slip on each other assuring equalized distribution of force to the vanes.

One further embodiment of spring band construction should be discussed. As noted above, when using rotary unitary compressor-expanders with elongated ovals, there may arise conditions wherein the biasing force generated by the spring band 46 and 47 must be supplemented by means such as the secondary springy element 74 of FIG. 6. The need for these secondary springy elements may be eliminated by providing a spring band which is truly expansible, a fragment of which is illustrated in FIG. 14. To that end, a spring band is used which is formed from a single multi-wrapped band 46c of relatively thin band material with free ends 46d, and 46e and outwardly sprung. Such band, teflon coated, is free to expand and contract providing a continuous biasing force to all vanes even in greatly elongated oval configuration and with greater available takeup, if necessary, for wear.

While the preferred form of the invention contemplates use of a continuous spring band, it will be apparent to one skilled in the art that the invention, in certain of its aspects, is not limited to use of the spring band and that, if desired, individual springs associated with each vane may be used to bias such vanes outwardly with respect to the rotor. In this case, just as in those described above, the vanes do not press against the inner wall of the chamber but they are, indeed, prevented from doing so by the engagement of the vane rollers with their respective cam tracks.

In the preferred embodiment of the rotary unitary compressor-expander described above, it was stated that the stator surface and cam tracks must be machined with great accuracy. In addition, means for

manufacturing identical vanes are disclosed. We have found that these accurately manufactured vanes can be used in a modified construction to allow more liberal tolerances to be used in forming the stator surface. It should be appreciated that the distance between the cam track and stator surface as measured along any radial line extending from the rotor center is fixed. This distance is a function of vane-pin-to-vane-tip spacing. In accordance with this aspect of the invention, the cam tracks are accurately machined as described above and the required surface finish provided. However, the stator chamber is formed using more liberal tolerances with minimal attention given to surface finish. The main requirement in forming the stator chamber is that the opening be slightly larger than the design size as dictated by the cam tracks and vanes. The curved wall of the chamber is then coated with a layer of graphite material uniformly distributed in a binder which forms a stator chamber which is slightly smaller than the design size. A usable graphite material is a carbon graphite mixture combined with an epoxy binder. When the unit is assembled, the spring bands will bias the vane tips into contact with the chamber liner which will, in turn, prevent the vane rollers from contacting their cam tracks. The rotor is then rotated during a "run-in" period which results in the vanes wearing away the comparatively softer graphitic surface until the vane rollers come into contact their cam tracks. As all the vanes have identical vane pin to vane tip spacing, it is seen that the rotor surface thus formed yields the required clearance sealing engagement between all vane tips and the rotor surface through all positions of rotor rotation. The result is a graphitic liner illustrated as 102 in FIG. 15 formed within the stator chamber. The liner material may be cast in place, if desired, followed by "run-in."

The graphitic liner discussed above in addition to reducing the precision machining required provides an additional benefit. It has an important effect in maintaining the efficiency of the rotary unitary compressor-expander by reason of thermal management. It will be appreciated that the fluid being cooled undergoes significant changes in temperature during a cycle. In general direct heat transfer through the device should be minimized so that the heat generated in the compression process is not conducted via the machine elements and transferred back to the cooled fluid resulting from the expansion process. Stated simply, it is important to prevent the hot (or compression) side of the unit from transferring heat to the cold (or expansion) side so that the expansion process can be performed adiabatically. The graphitic liner 102 (FIG. 15) has an important role in preventing this unwanted heat transfer as it has low coefficient of thermal conductivity. This liner thereby retards heat transfer to the stator housing 21a which acts as a conductive path. It should be appreciated that what is required for efficient thermal management is an effective thermal block between the compression side and the expansion side of the device. This can be achieved in addition to the graphitic liner described above by thermal blockages between the two halves of the stator such as the slots illustrated as 88 and 89 on FIGS. 1 and 2 which decrease the area for heat conduction. Also, as described above the individual vanes are made of a plastic material with a low coefficient of thermal conductivity thereby yielding an efficient thermal block between adjacent cavities and preventing

them from transferring appreciable heat during a rotational cycle. In addition, the surface of the rotor may be coated with insulating material between the vanes.

Throughout this description the material to be refrigerated has been referred to interchangeably as fluid or air. While air is the preferred medium, it will be understood that the device disclosed is applicable to compressible fluids in general.

We claim as our invention:

1. A rotary unitary compressor-expander for use in a refrigeration device comprising in combination, a stator including a hollow member enclosed by respective end members defining a chamber having a wall of oval cross section, a rotor rotatably mounted in axial position in the stator chamber, the rotor having a plurality of equally spaced radial vane slots, a plurality of vanes snugly slideable in the respective vane slots, each of said vanes having a base portion and having a radially presented vane tip, the base portion having aligned axially extending stubshafts fitted with cam followers, a continuous inwardly facing cam track at each end of the stator chamber for engaging the respective cam followers on each of the vanes, spring band biasing means operatively associated with the vanes for urging the vanes radially outwardly to keep the cam followers thereon biased against the cam tracks, said cam tracks being of oval configuration geometrically synchronized to the oval wall of the chamber so that the tips of said vanes are maintained in continuous clearance sealing engagement with the wall, the cam tracks serving to resist the biasing force and to positively retract the vanes inwardly during portion of the rotational cycle thereby to avoid crowding, with resultant wear and friction at the tips of the vanes.
2. A rotary unitary compressor-expander for use in a refrigeration device comprising in combination, a stator including a hollow member enclosed by respective end members defining a chamber having a wall of oval cross section, a rotor rotatably mounted in axial position in the stator chamber, the rotor having a plurality of equally spaced radial vane slots, a plurality of vanes snugly slideable in the respective vane slots, each of said vanes having a flat base portion and having a radially presented vane tip, the base portion having aligned axially extending stubshafts, closely fitted rollers on the stubshafts, a continuous inwardly facing cam track in each of the end members for engaging the respective rollers on each of the vanes, continuous spring band means arranged to press outwardly on the vanes to bias the vanes and to keep the rollers thereon biased radially outwardly against the cam tracks, said tracks being of oval configuration and so symmetrically sized and positioned with respect to the oval wall of the chamber that the tips of said vanes are maintained in continuous clearance sealing engagement with such wall, the cam tracks serving to resist the biasing force and to positively retract the vanes inwardly during portions of the rotational cycle thereby to avoid crowding with resultant wear and friction at the tips of the vanes.
3. A rotary unitary compressor-expander for use in a refrigeration device comprising in combination, a stator including a hollow member enclosed by respective end members defining a chamber having a wall of oval cross section, a hollow rotor rotatably mounted in axial position in the stator chamber, the rotor having a plurality of equally spaced radial vane slots, a plurality of vanes snugly slideable in the respective vane slots, each

of said vanes having a flat base portion with spaced notches formed therein and having a radially presented vane tip, the base portion having aligned axially extending stubshafts, closely fitted rollers on the stubshafts, a continuous inwardly facing cam track in each of the end members for engaging the respective rollers on each of the vanes, a pair of continuous spring bands axially spaced in the hollow of the rotor and arranged to press outwardly in the notches of the vanes to keep the rollers thereon biased radially outwards against the cam tracks, said cam tracks being of oval configuration and so symmetrically sized and positioned with respect to the oval wall of chamber that the tips of said vanes are maintained in continuous clearance sealing engagement with the wall of the chamber while prevented from contacting such wall, thereby to minimize friction, reducing wear and increasing efficiency.

4. A rotary unitary compressor-expander for use in a refrigeration device comprising in combination, a stator including a hollow member enclosed by respective end members defining a chamber having a wall of oval cross section, a rotor rotatably mounted in axial position in the stator chamber, the rotor having a plurality of equally spaced radial vane slots, a plurality of vanes snugly slideable in the respective vane slots, each of said vanes having a flat base portion and having a radially presented vane tip, the base portion having aligned axially extending stubshafts, closely fitted rollers on the stubshafts, a continuous inwardly facing cam track at each end of the stator chamber for engaging the respective rollers on each of the vanes, means including a resilient spring band arranged to press outwardly on the vanes to bias the vanes and to keep the rollers thereon biased radially outwardly against the cam tracks, said cam tracks being of oval configuration and so symmetrically sized and positioned with respect to the oval chamber that the tips of said vanes are maintained in continuous clearance sealing engagement with the wall, the cam tracks serving to resist the biasing force and to positively retract the vanes inwardly during portions of the rotational cycle thereby to minimize wear and friction at the tips of the vanes, the band being of laminated construction formed of a thin helically wound strip with unsecured ends and outwardly sprung to take up radial movement of the vane.

5. A rotary unitary compressor-expander for use in a refrigeration device comprising in combination, a stator including a hollow member enclosed by respective end members defining a chamber having a wall of oval cross section, a rotor rotatably mounted in axial position in the stator chamber, the rotor having a plurality of equally spaced radial vane slots, a plurality of vanes snugly slideable in the respective vane slots, each of said vanes having a base portion and having a radially presented vane tip, the base portion having aligned axially extending stubshafts, closely fitted rollers on the stubshafts, a continuous inwardly facing cam track at each end of the stator chamber for engaging the respective rollers on each of the vanes, spring band biasing means operatively associated with the vanes for urging the vanes radially outwardly to keep the rollers thereon biased against the cam tracks, said cam tracks being of oval configuration and geometrically synchronized to the oval wall of the chamber so that the tips of said vanes are maintained in continuous clearance sealing engagement with such wall, the cam tracks serving to resist the biasing force and to positively retract the

vanes inwardly during portions of the rotational cycle thereby to avoid crowding, with resultant wear and friction at the tips of the vanes.

6. The combination as claimed in claim 5 in which each vane is of composite construction including a flat vane body of light plastic having brackets thereon for mounting the aligned stubshafts, the brackets being radially moveable on the vane body into fitted position of precise dimension between the stubshafts and the tip of the vane thereby to insure a close running fit between the tips of all the vanes and the oval wall of the chamber, the brackets having means for fixing the same in fitted positions.

7. The combination as claimed in claim 6 in which the biasing means comprises a pair of continuous spring bands, and the stubshafts include respective stubshaft extensions for coacting with the spring bands whereby said bands are positioned outboard of the rotor.

8. The combination as claimed in claim 1 in which each vane is of composite construction including a flat vane body of light plastic and including brackets mounting the stubshafts, said stubshafts being of durable material and extending in axial alignment from the brackets, the brackets having grooves mating with the respective lateral edges of the vane body to provide relative radial sliding movement and with the brackets being pinned to the vane body in a fitted position in which there exists a precise radial dimension between the stubshafts and the tip of the vane.

9. The combination as claimed in claim 8 in which the biasing means comprises a pair of continuous spring bands, and the stubshafts include respective stubshaft extensions for coacting with the spring bands whereby said bands are positioned outboard of the rotor.

10. The combination as claimed in claim 5 in which the portion of each vane slot engaged with the vane includes insert members fixed to the rotor for providing a smooth surface to contact the vanes thereby reducing vane to vane slot friction.

11. The combination as claimed in claim 10 in which the insert members include a pattern of radially extending channels terminating in a pattern of ports at the engaged surfaces and in which means are provided for supplying to the channels a portion of the air compressed in the chambers thereby to establish a film or air at the engaged surfaces for lubricating the same.

12. The combination as claimed in claim 5 in which the biasing means includes a pair of continuous spring bands arranged to press outwardly on the vanes.

13. The combination as claimed in claim 12 in which each vane is provided with a resilient cushion mounted thereon at the region of engagement between the vane and the band to thereby increase the range of resilient follow up action of the vane.

14. The combination as claimed in claim 12 in which each vane is of composite construction including a flat vane body of light plastic the stubshafts being of elongated construction including a slotted extension portion mating with the base portion of the vane body, the extension portion being pinned to the vane body in a fitted position in which there exists a precise radial dimension between the stubshafts and the tip of the vane, the extension portions of the stubshafts engaging the spring bands thereby to minimize wear.

15. The combination as claimed in claim 14 in which the portion of each vane engaged with the vane slot includes a plurality of radially extending internal chan-

nels terminating in a pattern of ports at the engaged surfaces and in which means are provided for continuously supplying to the channels a portion of the air compressed in the chambers thereby to establish a film of air at the engaged surfaces for lubricating the same.

16. The combination as claimed in claim 15 in which each vane includes a plurality of radially extending channels including a pattern of ports in both the portion of the vane engaged with the vane slot and the portion of the vane extending into the chamber so that a portion of air compressed in the chamber flows through the channel to the vane slot thereby to establish a film of air at the engaged surfaces for lubricating the same.

17. The combination as claimed in claim 14 in which rotation of the rotor in a given direction defines a compression half and an expansion half of the compressor-expander and the stator includes thermal blocking means interposed between the halves of the stator to retard heat transfer through the stator between the compression and expansion sides to more nearly approach the efficiency of adiabatic expansion on the expansion side.

18. The combination as claimed in claim 17 in which the vanes are formed of a plastic material having thermal insulating properties.

19. The combination as claimed in claim 17 in which the thermal blocking means comprises slots formed in the exterior of the stator to decrease the area for heat transfer between said halves through the stator.

20. The combination as claimed in claim 1 in which the stubshafts are formed separately from the vane which carries them and in which means are provided for precisely locating the radial position of the stubshafts with respect to the tip of the vane thereby to insure a close running fit between the tips of all the vanes and the oval wall of the chamber.

21. The combination as claimed in claim 20 in which the biasing means comprises a pair of continuous spring bands, and the stubshafts include respective stubshaft

extensions for coacting with the spring bands whereby said bands are positioned outboard of the rotor.

22. The combination as claimed in claim 20 further including a lubrication retaining force extending inwardly from each cam track toward the respective stubshafts and interposed between the vane brackets and the vane rollers.

23. The combination as claimed in claim 4 in which the cam tracks comprise an extension of the oval wall of the stator chamber.

24. The combination as claimed in claim 23 in which stationary fences are provided at the ends of the stator between the vanes and the respective rollers thereon for sealing engagement with the lateral edges of the vanes.

25. The combination claimed in claim 20 in which the stator chamber is of enlarged size to produce a gap between the oval wall and the vane tips when the rollers are biased against the cam tracks, the wall of chamber being coated with a layer of graphitic material uniformly distributed in a binder to close said gap, said graphite material being softer than the material comprising the tips of the vanes so as to undergo intentional wear during run-in and until the rollers are freely seated on the cam tracks thereby to provide the clearance sealing engagement between the tips of the vanes and the coated wall.

26. The combination as claimed in claim 25 in which the inner wall of the stator is coated with a layer of material having thermal insulating as well as lubricating properties thereby to further enhance the adiabatic nature of the expansion.

27. The combination as claimed in claim 26 in which the layer of insulating and lubricating material consists of graphitic material uniformly distributed in an insulating binder.

28. The combination as claimed in claim 27 in which the insulating binder is an epoxy resin.

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