

May 19, 1970

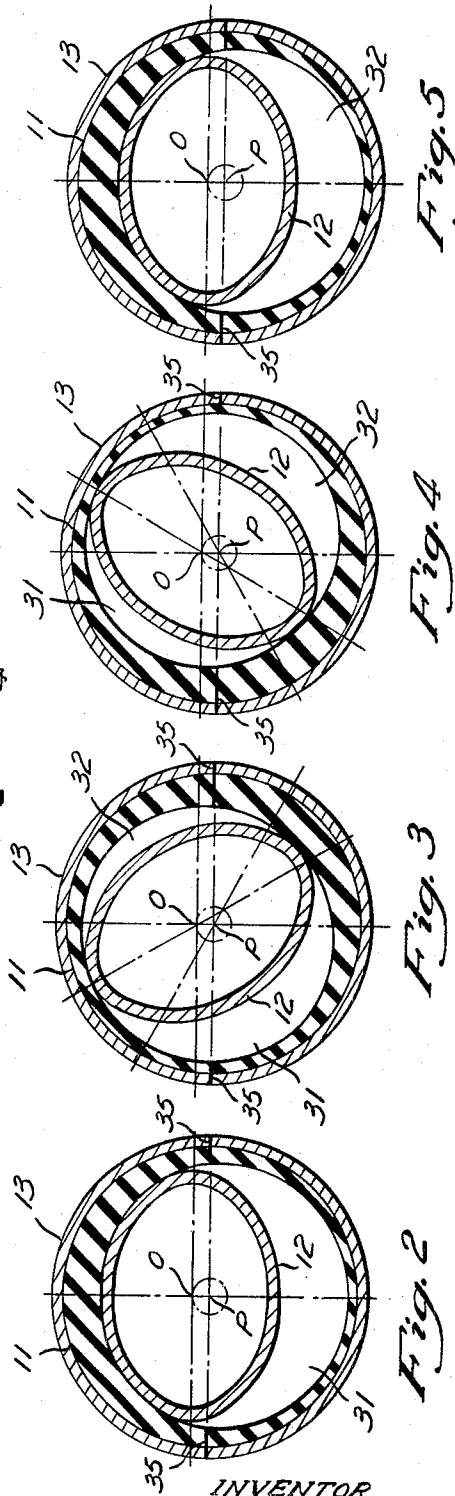
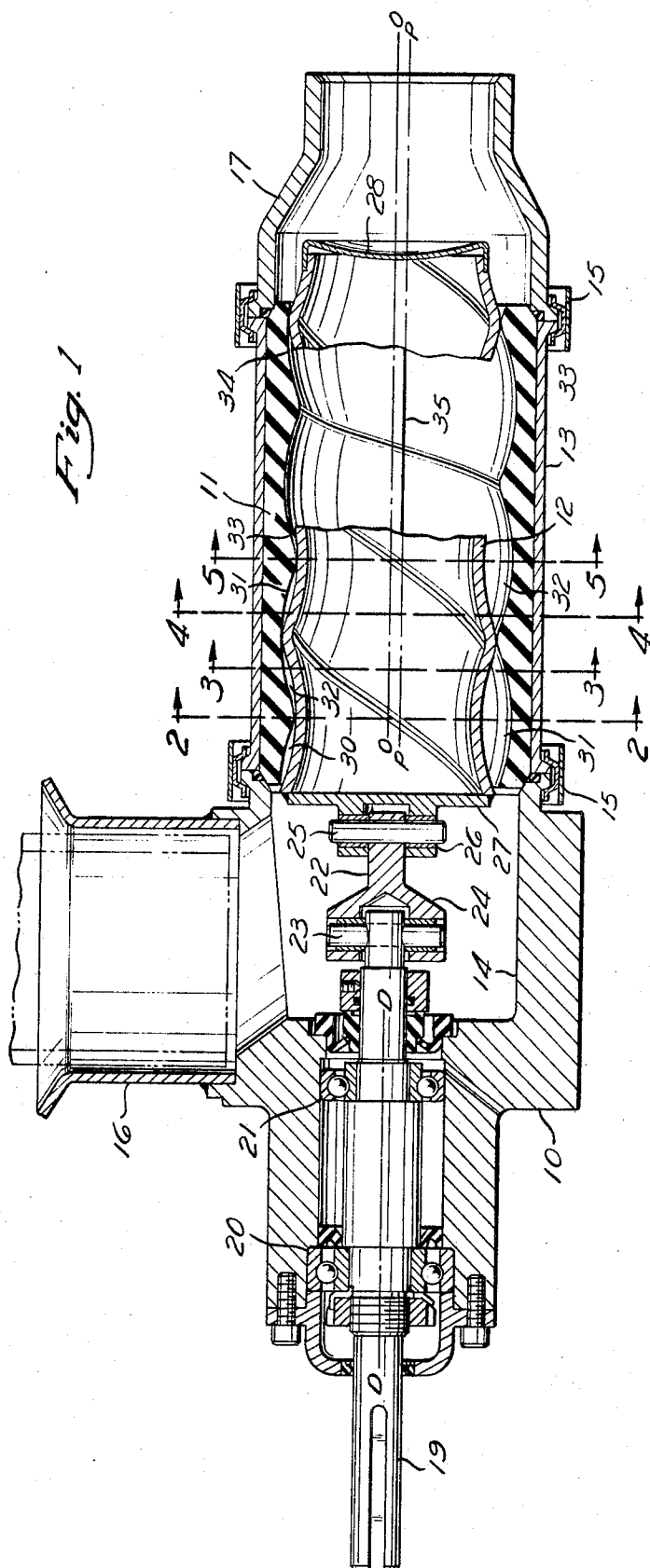
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3,512,904

PROGRESSING CAVITY HELICAL PUMP

Filed May 24, 1968

3 Sheets-Sheet 1



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3 Sheets-Sheet 2

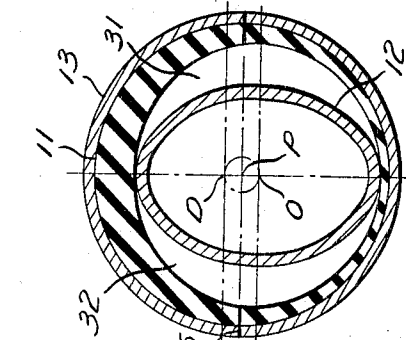
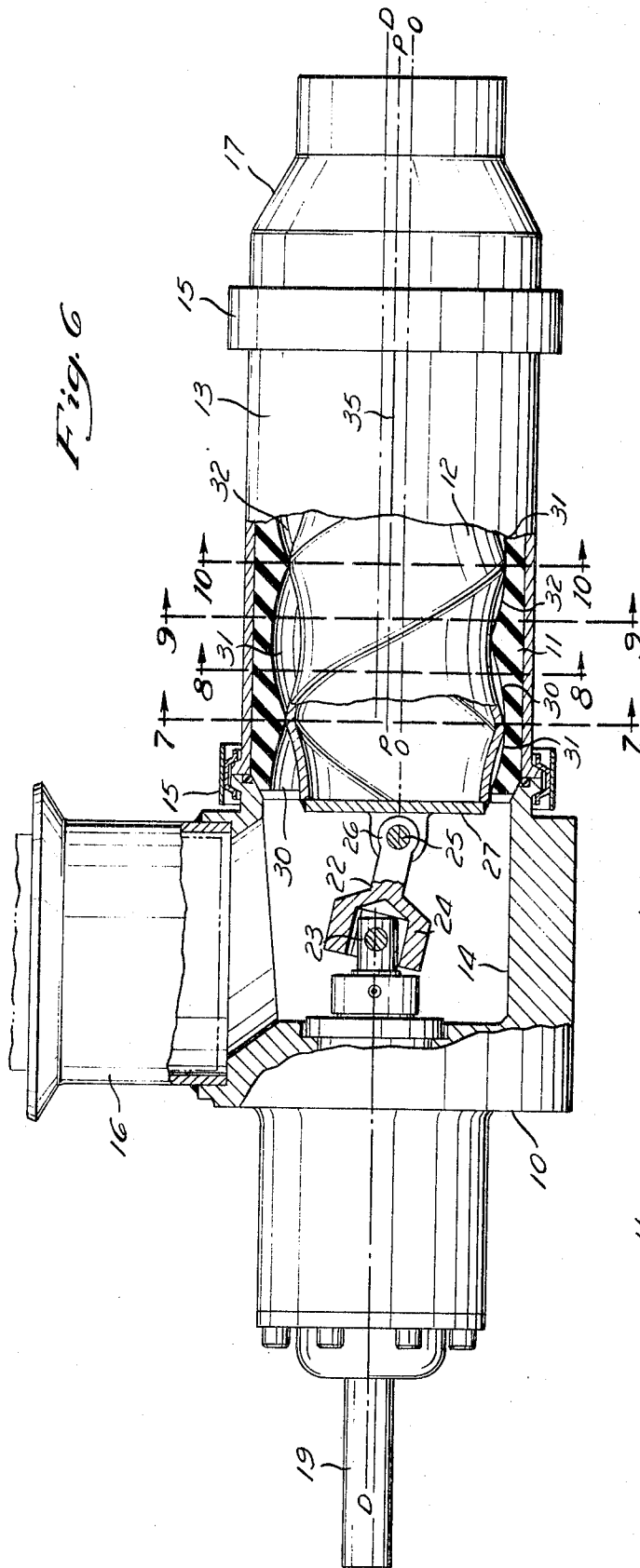


Fig. 10

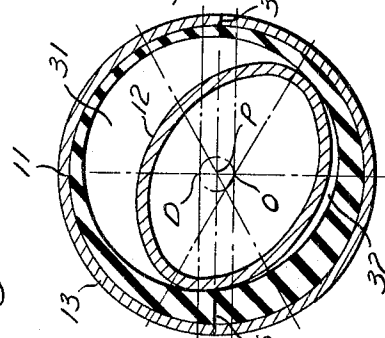


Fig. 6

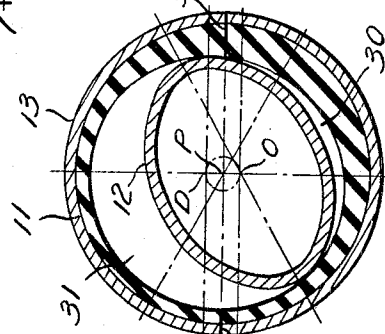


Fig. 8

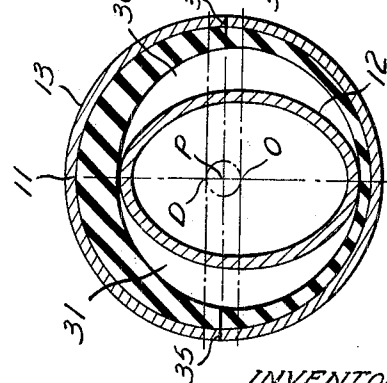


Fig. 7

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3 Sheets-Sheet 3

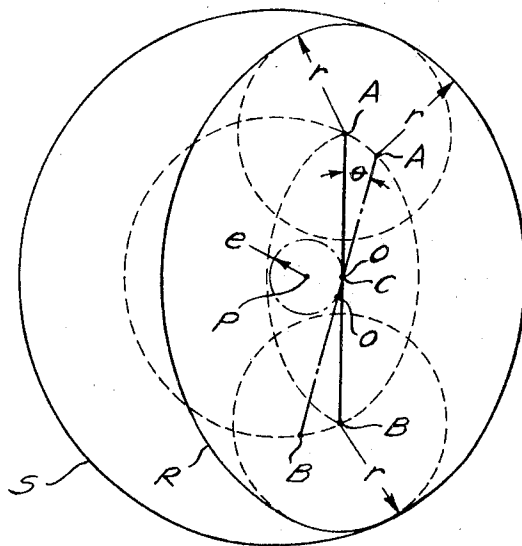


Fig. 11

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PROGRESSING CAVITY HELICAL PUMP

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U.S. Cl. 418—48

7 Claims

ABSTRACT OF THE DISCLOSURE

A progressing cavity, positive displacement, helical pump or motor for handling fluid or comminuted materials. The device forces material axially through helical cavities defined by a stator with a helical interior surface and an eccentric rotor with a helical exterior surface, the rotor being operatively connected through a spindle or hinged joint to a rotary drive.

BACKGROUND OF THE INVENTION

This invention relates to progressing-cavity-type positive displacement helical pumps and motors and especially to planetary rotor type pumps for handling both fluids and comminuted materials such as food products, chemicals, sludge, concrete mix and the like. More particularly the invention relates to an improved planetary rotor and stator design which affords improved sealing of the cavities with reduced wear and which eliminates the need for a universal connection between the rotor and the rotary drive.

Such pumps generally comprise a pair of helical threaded elements in sealing engagement with one another cooperating to produce a series of pumping pockets or cavities which travel axially through the pump from one end to the other. Normally the outer member is a stator with an axial cavity having a helical internal surface and the inner member is a rotor positioned within the stator and having a helical external surface with parts in sealing engagement with the stator to define the helical cavities. In transverse cross section the stator is usually provided with either one lobe more or one lobe less than the rotor, in the latter case the rotor having two or more lobes. Also the longitudinal geometric centerline of the rotor generally translates about an eccentric axis to achieve the pumping action.

Accordingly, the prior art rotors are operatively connected to a rotary drive by a universal connection to accommodate the eccentric translation of the rotor's longitudinal geometric centerline. Normally the centerline translates through 360° at a rate n times the rotation of the rotor where n is the number of lobes on the rotor. In the case where the rotor has one lobe less than the stator the translation is in the direction opposite to rotor rotation, and where the rotor has one lobe more than the stator the translation is in the same direction as rotor rotation.

The shape of the stator in transverse section may be for example, of polar cycloidal form while the rotor may have a generally elliptical or oval form which one lobe more than the stator. A more specific example of a stator cavity transverse sectional form is a polar conchoid which is defined as the locus of the end points of a straight line generatrix when its center point O is translated in a circle while the generatrix pivots about its center point O and continues to intersect an initial reference point on the orbit circle. In polar form the resulting conchoid has the general equation $y = 2e \sin \theta + L$ where y is the distance from the initial tangent reference point of the center O to an end of the generatrix, L is one-half the length of the generatrix,

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e is the orbit radius and θ is the angular position of the generatrix relative to an initial reference position tangent to the circle through which its center translates, the point of tangency being the same as the initial reference point.

A specific example of this type of stator cavity in two dimensional form is disclosed in the U.S. patent to Planche, No. 1,340,625. This type of device uses a stator having a cavity cross section in the form of a polar conchoid and an eccentric two lobe rotor which rotates and translates in an eccentric path within the stator with its end points always in engagement with the stator walls. The width of the rotor is equal to the length of the generatrix of the polar conchoid and the cross section is symmetrical about the generatrix so that the geometrical center translates about a center of eccentricity twice during each full revolution of the rotor. The rotor is connected to a rotary drive by a spindle designed to accommodate the eccentric travel of the rotor.

Another related prior art device in three dimensional form is shown in the U.S. patent to Moineau, No. 1,892,217. This device uses a three dimensional helical rotor and stator cooperating with one another to form sealed helical cavities or pockets which progress axially from one end of the pump to the other as the rotor translates and turns. The rotor has one lobe less than the stator cavity and consequently the center of the rotor translates about a center of eccentricity in a direction opposite to the direction of rotor rotation. The final form of the three dimensional rotor of Moineau is similar to a corkscrew. Accordingly, the rotor shape and the cavity shape are difficult to machine or otherwise fabricate. Furthermore the Moineau rotor must be connected to a rotary drive or rotary prime mover by means of a universal connection in view of the non-planar displacement of the rotor relative to the drive shaft during the pumping operation.

Still another related prior art device is disclosed in the U.S. patent to Payne, No. 3,299,822. The Payne device utilizes a stator having an internal surface with a cross section in the form of a cardioid, and a rotor transverse section of generally elliptical form. In the Payne construction, because of a cusp which engages the rotor either at one lobe or along its side, there is provided, during most of the rotor movement, a three point contact, a cusp always being in contact with the rotor. Due to the cusp or tooth a reduced sealing efficiency results from increased wear concentrated on the cusp. This wear destroys intimate contact between the cusp and the rotor and allows leakage.

Another disadvantage of prior art constructions is the difficulty in cleaning the rotor and stator. In each instance the unit must be disassembled and the rotor completely removed in order to gain access to the cavity forming surfaces. The use of a "split" stator which may be separated and removed from the rotor is not possible because of either the presence of a cusp in some instances (thus requiring a diagonal "split" across a cusp which would quickly be worn to a gap) or the presence of multiple lobes in the stator in other instances (thus requiring a "split" or parting line extending diagonally across the reentrant portions of the lobes where the stator surface would make a sharp angle with the plane of the "split"). Cleaning and disinfecting is particularly important in the handling of foodstuffs where it must be accomplished at intervals as short as every six hours of operation. Also it is desirable to be able to clean the pump without disturbing the piping.

The pump construction of the present invention reduces the disadvantages indicated above and affords other features and advantages not heretofore obtainable.

SUMMARY OF THE INVENTION

It is among the objects of the invention to reduce the wear while improving the sealing efficiency between the stator and rotor of a progressing cavity, planetary rotor, helical pump or motor of the type discussed.

Another object is to eliminate the need for a universal coupling between the eccentric rotor and the rotary drive for the pump or motor.

A further object is to provide a dynamic fluid balance in the pump or motor and thereby to eliminate unbalanced radial forces during operation.

Still another object is to provide a rotary pump or motor of the type discussed wherein the stator may be of split construction to facilitate disassembly without danger of excessive wear resulting at the parting line, so as to accommodate periodic cleaning such as is essential in the case of the handling of foodstuffs.

A still further object is to provide a progressing helical cavity, planetary rotor type pump or motor with a stator cavity of conchoidal transverse sectional form wherein cusps or teeth are eliminated and wear is distributed uniformly over the inner surface of the stator rather than being concentrated on cusps or teeth of the stator.

These and other objects are accomplished by a combined stator and rotor construction comprising a generally tubular stator having an interior helical surface with a transverse section in the form of a first closed plane figure defined by points spaced outwardly a distance r on normal lines from the surface of a polar cycloid having $n-1$ lobes and a generatrix with a center that translates about a center of eccentricity. The interior helical surface is generated by translating the first plane figure along an axis extending perpendicular to the plane thereof through the center of eccentricity while rotating the closed plane figure about the axis. The ratio of the radius of the circumscribed circle of the generatrix to the eccentricity is at least about $n^2:1$. Within the stator cavity is a rotor having a helical surface with a transverse section in the form of a second plane figure of n symmetrical lobes having rounded ends of radius r centered at the end points of the generatrix. The helical surface is generated by translating the second plane figure along a rotor axis through its geometric center at n times the lead that the first plane figure twists about the stator axis. The rotor is turned in the stator by a rotary drive which simultaneously allows translation of the rotor axis about the center of eccentricity P at n times the rate of rotation of the rotor.

In a preferred form the stator cross section is in the form of a polar conchoid and the rotor cross section is in the form of symmetrical quadrants divided by the straight line generatrix and its perpendicular bisector. The sides of the rotor cross section between the rounded ends are formed to match the interior surface of the stator when the circumscribed center of the rotor cross section is located at an initial reference position on the circle through which the center point of the generatrix translates during its generating movement.

According to one aspect of the invention the rotor is a hollow body with a rather thin wall of substantially uniform thickness throughout its length so that the centrifugal force of the rotor about the axis of the rotary drive is about equal and opposite to that of the material in the cavities. Thus the fluid being passed through the pump acts as a counter balancing medium which results in good dynamic balancing of the rotor. Also the connection between the rotary drive and the rotor is preferably in the form of a coupling shaft connected at its ends by parallel hinge pins to the rotary drive shaft on the one hand and the rotor on the other hand. This type of connection is sufficient with rotors and stators embodying the present invention.

As another aspect of the invention, the stator is formed of two matching sections split in an axial plane so that they may be easily removed from the rotor to facilitate

cleaning. This eliminates any need for disconnecting the associated plumbing or disconnecting the rotor from the rotary drive.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a longitudinal section of a progressive cavity pump embodying the invention showing the rotor in an initial reference position;

FIG. 2 is a transverse sectional view taken on the line 2—2 of FIG. 1;

FIG. 3 is a transverse sectional view taken on the line 3—3 of FIG. 1;

FIG. 4 is a transverse sectional view taken on the line 4—4 of FIG. 1;

FIG. 5 is a transverse sectional view taken on the line 5—5 of FIG. 1;

FIG. 6 is a side elevation of the pump of FIG. 1 with parts broken away and shown in section, with the rotor turned 90° from its reference position of FIG. 1;

FIG. 7 is a transverse sectional view taken on the line 7—7 of FIG. 6, which corresponds to line 2—2 of FIG. 1;

FIG. 8 is a transverse sectional view taken on the line 8—8 of FIG. 6, which corresponds to line 3—3 of FIG. 1;

FIG. 9 is a transverse sectional view taken on the line 9—9 of FIG. 6, which corresponds to line 4—4 of FIG. 1;

FIG. 10 is a transverse sectional view taken on the line 10—10 of FIG. 6, which corresponds to line 5—5 of FIG. 1; and

FIG. 11 is a diagrammatic view showing the two dimensional geometric relationships used in generating the stator cavity cross section and the rotor cross section.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring more particularly to the drawings, and especially to FIGS. 1 and 6 there is shown a progressing-cavity rotary pump embodying the invention and particularly adapted for use in pumping foodstuffs such as milk, cottage cheese, pie filling and the like. The pump comprises a pump body 10, a generally tubular stator 11 preferably formed of rubber or other resilient material and a helical rotor 12 received within the stator. The rotor 12 is shown rotated 90° in FIG. 6 from the position shown in FIG. 1 and it will be seen that during rotation the rotor center also translates in a manner to be described in more detail below. The stator 11 is received within a cylindrical metal sleeve 13 which is connected to the pump body 10 at an exit opening of an intake chamber 14 and at the opposite end to a discharge reducer 17. The stator 11 and sleeve 13 are split in a horizontal axial plane into two equal halves and the two halves of the shell 13 are connected along one edge by a hinge (not shown). The halves are clamped together and to the pump body 10 and discharge reducer 17 by ring clamps 15 at each end. With this arrangement the stator 11 and sleeve 13 may be quickly removed from the pump body 10 and rotor 12 for periodic cleaning without disturbing the associated plumbing or the rotary drive unit. Also mounted on the pump body is an inlet pipe 16 which communicates with the intake chamber 14. The material to be pumped is accordingly fed through the inlet pipe 16 in sufficient quantity to supply the pumping capacity of the pump.

Located at the opposite end of the stator 11 and rotor 12 is the discharge reducer 17 through which the material being pumped is fed to its ultimate destination.

The rotor 12 is driven by a drive shaft 19 journaled in bearing units 20 and 21 in the pump housing 10. The connection between the drive shaft 19 and the rotor 12 is in the form of a coupling link 22 which is pivotally connected to the drive shaft by means of a hinge pin 23 extending through the end of the drive shaft 19 and into the bifurcated end 24 of the coupling link 22. The link 22 is pivotally connected to the rotor 12 at its other end by another hinge pin 25 having an axis parallel to the axis of the pin 23 and extending through the end of a cou-

pling link 22 and into bearings 26 located in an end seal 27 secured to the inner end of the rotor 12. The opposite end of the hollow rotor is closed by another end seal 28. The operation of the hinged coupling link 22 and the advantages deriving therefrom are described in greater particularity below.

The stator 11 and rotor 12 define therebetween a series of sealed helical cavities 31, 32, 33, and 34 which progress from the inlet end to the discharge end of the pump during the rotation and translation of the rotor. FIGS. 2 through 5 indicate the relationships between the rotor transverse cross section and the stator transverse cross section at four equally spaced axial positions and the helical twist formed in both the stator and rotor surfaces will be apparent therefrom. It will be seen that the cavities progress from a sealed end to a maximum cross section and then diminish to a sealing point. In the embodiment of the invention illustrated herein the cavities extend two-thirds the length of the rotor and stator or in other words the rotor and stator are one and one-half cavity lengths long. It will be apparent in the embodiment shown that portions of four different cavities will be present in the pump during its operation.

FIGS. 7-10 show the cross sectional relationships at axial positions corresponding to those of FIG. 1 after the rotor has been turned 90°. The progression of the various cavities will be apparent from these views as well as the fact that the rotor translates 180° about its center of eccentricity during the illustrated 90° of rotor rotation about the rotor centerline O—O. Also a new cavity 30 has started to form at the inlet end of the rotor 12.

In order to assure the proper relationship between the rotor 12 and the stator 11 the stator is keyed to the inlet housing 10. This assures that the relationship between the stator centerline P—P and the drive shaft axis D—D will be as shown for example in FIG. 7.

ROTOR AND STATOR GEOMETRY

FIG. 11 will be used to illustrate the various geometrical relationships involved in the construction of the rotor and stator surfaces. The line AB is the generatrix which determines the cross sectional form of both the rotor 12 and stator 11. It is used to generate a conchoid (shown in dashed lines) by the translation of its center O about a center of eccentricity P and simultaneously rotating the generatrix AB about its center O, the angular velocity of rotation being one-half of the velocity of translation and the direction of translation being the same as the direction of rotation. The position shown will be referred to as the reference position of the generatrix AB. During the generating movement of the generatrix the locus of its end points defines a polar conchoid shown in dashed lines, the polar equation of which is $y = 2e \sin \theta + L$, wherein:

y = distance from the center of reference C to any point, A, on the surface of the conchoid (the center of reference C is the point where line AB is perpendicular to a line connecting points O and P and point O is superposed on point C);

e = eccentricity or orbit radius;

θ = angle between line AB when in its reference position and when in its instantaneous position wherein point A is the point on the conchoid described by the equation; and

L = one-half of line AB.

In FIG. 11 there is shown a radius, r , centered on point A and another radius of equal length centered on point B. Thus the conchoid describes the locus of the centers of these two radii as they translate with the generatrix AB. The actual shape of the stator cross-section S thus formed is consequently larger than the conchoid by the radial distance, r , measured normal to the surface of the conchoid.

The rotor cross-section R may be best described with reference to the generatrix AB when in its reference position as shown in FIG. 11 where the geometric center O of

the rotor is instantaneously superimposed on point C. It will be seen that the cross sectional form comprises symmetrical quadrants defined by the generatrix AB as extended at each end by radius (r), and the perpendicular bisector of AB. Each end of the rotor cross section R is rounded by the radius (r) centered at points A and B on the generatrix and the portions between the ends of these radii are shaped so that the rotor fits exactly the inner surface of the stator when, and only when, the rotor is in its reference position shown in FIG. 11. During rotation of the two dimensional rotor, the rotor follows the same path of motion as the generatrix AB in generating the conchoid within the stator cross section S.

This particular stator surface is simpler to generate in production since it allows room for a grinding wheel or rotary cutter of radius, r .

The sides of the new eccentric rotor now fit closely against the stator wall in either reference position AB or the reverse position BA. This reduces the cross sectional area of the cavities to zero at each end. It is obvious, in a two-dimensional motion device, however, that this condition of zero terminal volume is not essential to performance as a pump or expander. In a helical device, however, the side wall of the rotor cross section becomes a sealing line and a close fit is essential to leakage control.

The three-dimensional geometric form of the twisted rotor 12 is created as follows:

We take the eccentric rotor section R and twist it about its center, O, within the conchoidal stator section S axially extended. At the same time we translate the geometric center O about the eccentric center P, so that normal planes passed through the rotor at axial intervals of one pitch length will show the rotor within the stator in exactly the same positions relative to the reference position shown in FIG. 11. This represents 180° of rotation of the rotor section R and 360° of translation of point O around the eccentric circle. The twist about center O is exactly at one-half the rate of translation of O about center P or in other words, the lead of the twist about O is twice as long as the lead of the helix O about P.

In the form, however, the device is useless in a practical sense since it is now locked against motion and the helical rotor cannot be rotated within the stator.

Next we take the eccentric path of motion of center O about center P and impart another helical twist to the entire unit, that is, the axially extended stator section as well as the newly formed helical rotor. This new twist is in a direction opposite to the two initial twists already given the helical rotor and it occurs about centerline, P—P, which is a straight line while centerline O—O has a twist in it centered about P—P as described above. If we consider the two twists already in the helical rotor to be in a counterclockwise direction, the new twist is in a clockwise direction about centerline P—P and it has a lead length equal but opposite in direction to the helical shape of centerline O—O. The result of this rotational twist is that the stator takes on a helical shape since the stator conchoid has unequal radial dimensions with respect to line P—P. Also, we find that the twisted line O—O becomes straight and that the twisted plane AA—BB is untwisted from its counterclockwise direction and re-twisted in a clockwise direction. The lead of the twist of plane AA—BB about the straight centerline O—O is twice as long in a clockwise direction as the lead of the twist in the stator about straight centerline P—P also in a clockwise direction.

Since in any cross section taken along the axial length, the intersection with lines O—O and P—P will occur in the same angular position, it is possible now to rotate the helical rotor about centerline O—O and simultaneously to translate centerline O—O about axis P—P in the same manner as with the two-dimensional device. During rotation of the helical rotor the generatrix AB at any section follows the same path as that in the case of the two-dimensional device described above.

The result of this motion is to cause an axial translation of each cavity 31, 32, 33, and 34 not unlike the pas-

sage of a wave along its path of translation. This wave-like motion is complex since it occurs along a helical path.

Each cavity is sealed by contact between the twisted rotor 12 and the stator inner surface. This contact would occur along lines A—A and B—B if sharp edges were used, however, with the provision of a surface radius centered on lines A—A and B—B according to this invention and as outlined in the description of the two-dimensional device, this contact line occurs between the twisted rotor convex radius and the stator concave radius and furthermore it traverses the entire surface of the radius of the rotor so that rotor wear is uniformly distributed on the rotor radius. At the terminal ends, the cavities are sealed by virtue of the accurate fit between the rotor and stator surfaces. These terminal seal lines of course, travel in wave-like translation as the prescribed relative motion occurs and thus follow the path of the cavities.

This wave-like cavity motion is useful as a pump or as a hydraulic motor since, at the inlet end of such a device the cavity grows to maximum volume as it progresses and then remains at maximum volume while it translates toward the discharge end. The cavity begins to decrease in volume when the leading end passes the discharge edge of the housing. When the trailing edge reaches the discharge end the cavity reaches zero volume and disappears.

By sealing the ends of the cavities in this manner there is created a new family of gear mechanisms based upon high eccentricity ratios where the eccentricity ratio, R_e , is described as the ratio of one-half the length of line A—B to the eccentricity, e , i.e.

$$R_e = \frac{L}{e}$$

It has been found that when this ratio is under 4:1 the inner surface of the stator closest to the orbit center P begins to develop a convex characteristic. A convex surface here would tend to cause the rotor to lock itself to the outer member at the reference position whenever the inner member is made to fit the outer member in the reference position.

Accordingly, the device of this invention will for the most part be restricted to mechanisms wherein the ratio R_e is greater than 3:1 and preferably greater than 4:1.

It is evident that the length of the line $L(1-\cos \phi)$ must be greater than line $e(1-\cos 2\phi)$ to avoid convexity in the outer member at this point, i.e.

$$L(1-\cos \theta) \geq e(1-\cos 2\phi)$$

or

$$\frac{L}{e} \geq \frac{(1-\cos 2\phi)}{1-\cos \theta} \geq 2(1+\cos \phi)$$

where ϕ is the angle of rotation of the generatrix relative to a line which passes through both the orbit center, P, and the initial reference position of O.

The largest value of this ratio occurs at $\phi=0^\circ$ or when $1+\cos \phi=2$ thus

$$R_e \geq 4$$

It should be evident that this same result can be achieved with rotors which have more than 2 lobes. Where the stator has more than one lobe the generatrix becomes a plane figure such as an equilateral triangle (two stator lobes) or other equilateral polygon having a radius of its circumscribed circle L . In these cases the eccentricity ratio will be greater than in the case of a two-lobed rotor. For example $L/e=4, 9, 16$, etc., for one lobe, two lobes or three lobes respectively.

The rotor 12 can be manufactured from steel or aluminum tubing of proper wall thickness by one of the following expansion processes:

- (a) hydraulic tube expansion
- (b) electro-hydraulic, high-velocity tube expansion
- (c) explosive forming
- (d) electro magnetic forming

Previous rotor shapes have not lent themselves to these methods either because of their helical centerlines or because of their restricted cross sectional areas.

HINGED COUPLING

The device described herein lends itself to the use of the simplified type of drive coupling 22 which has flexibility in only one plane as opposed to the full directional flexibility required heretofore. This type of joint will be referred to as a hinge joint.

Referring to FIG. 11 it will be noted that with respect to rotor movement as described above, line AB of the rotor always passes through the reference position C of point O no matter what position the rotor is rotated to.

If a simple hinge pin is connected to the drive shaft 19 centered on the reference position C and a second similar hinge pin is connected on the rotor 12 at point O when point O is at the reference position C, and if the pins of these two joints are aligned parallel to each other and perpendicular to an axial plane through line AB and further if these two joints are connected to each other by a rigid coupling shaft, then the double hinge joint will always have its plane of flexibility parallel to and passing through the line AB no matter which angular position the line AB is rotated into. This simple coupling will then be capable of following and of transmitting torque to the rotor 12.

The use of this simple hinge joint effects substantial savings in the cost of the helical device drive system. A second and equally important advantage is that the journal type bearings 26 may be used with the hinge pin joint. This type of bearing has much greater load carrying capacity than does the modified universal type of flexible coupling where most of the load bearing surface of the journal is cut away to provide the full flexibility needed in this type of joint. Also if desired the rotor can be detachably connected to its hinge pin to permit quick removal for cleaning, since all axial forces are tending to push the rotor against the rotor drive.

DENSITY BALANCED ROTOR

The required orbiting of the rotor 12 has a disadvantageous result in that the centrifugal forces arising from the orbit motion set up vibrations within the pump, or motor frame causing noise and instability and limiting the speed of the device.

The enlarged cross sectional area of the rotor 12 which results from adding the radii at points A and B (FIG. 11) and from expanding the sides of the rotor to fit the stator 11, allows the rotor to be designed with a hollow interior and a relatively thin wall section.

Since this wall is located at a relatively greater distance from the rotor center than the walls of other similar helical gear mechanisms, the torsional stress for a given torque will be substantially less. Furthermore the straight rotor centerline O—O further enhances the torque capacity of the rotor as compared to devices having a rotor which the rotor sections are arranged about a helical centerline.

This greatly enhanced torque capacity allows the wall thickness to be reduced to the point where the rotor density is equal to that of the fluid being pumped or being used to power the motor (assuming that the rotor is empty and sealed at each end). Since the fluid circulates within the outer member at the same average angular velocity as the rotor orbit velocity, the rotor 12 tends to float in the fluid to provide a zero net unbalance force with the fluid itself acting as the counter balance medium.

It will be apparent that pumps or motors of greater axial length having more cavities in series may be used if desired to increase the pressure handling capability.

SPLIT STATOR CONSTRUCTION

As indicated above, the stator 11 and shell 13 are of "split" construction with the "split" 35 lying in an axial plane. This type of construction is possible and feasible only because as indicated in FIGS. 2 to 5 the plane of the "split" 35 intersects the interior helical surface of the stator 11 at approximately right angles throughout the length of the stator. Thus there are no sharp acute angles in the abutting rubber edges along the split line which might be subject to excessive wear.

The elimination of sharp angles at the intersection of the interior surface of the stator and axial planes through the stator is achieved by enlarging the polar conchoid of FIG. 11 (dashed lines) by a distance r and by using a relatively high eccentricity ratio R_e , i.e. at least 3:1 and preferably 4:1 or greater so as to eliminate cusps or teeth. As will be seen from FIG. 11 this substantially "rounds out" the stator cross section as compared with the conchoid from which it is derived.

The two halves of the shell 13 may be hinged together along one split line if desired to assure proper axial alignment with one another when installed. To remove the stator and shell one need merely remove the ring clamps 15 which secure the shell 13 to the pump body 10 and discharge reducer 17, and then separate the halves thus removing them from the rotor.

While the invention has been shown and described with reference to a specific embodiment thereof, this is intended for the purpose of illustration rather than limitation and variations and modifications will become apparent to those skilled in the art within the intended spirit and scope of the invention as herein specifically illustrated and described. Therefore the patent is not to be limited in scope and effect to the preferred form shown herein nor in any other way that is inconsistent with the extent to which the progress in the art has been advanced by the invention.

What is claimed is:

1. A progressing-cavity, positive displacement helical pump comprising a generally tubular stator having an interior helical surface generated by translating a first closed plane figure, defined by points spaced outwardly a distance r on normal lines from a closed polar cycloidal figure having $n-1$ lobes and a generatrix center that translates about a center of eccentricity, along a perpendicular axis through said center of eccentricity while rotating said first plane figure about said axis, the ratio of the radius of the circumscribed circle of the generatrix of said polar cycloidal figure, to the eccentricity being at least about $n^2:1$; a rotor received in said stator and having a helical surface generated by translating a second closed plane figure of n symmetrical lobes having rounded ends of radius r centered at the end points of said generatrix, along a rotor axis perpendicular to said second plane figure at its geometric center, at n times the lead that said first plane figure rotates around said first named axis, and

rotary drive means for turning said rotor in said stator while said rotor axis translates in the same direction about said center of eccentricity at n times the rate of rotation of said rotor.

2. A progressing-cavity, positive displacement helical pump comprising a generally tubular stator having an interior helical surface generated by translating a first closed plane figure defined by points spaced outwardly a distance r on normal lines from a polar conchoid having a straight line generatrix with a center that translates about a center of eccentricity, along a perpendicular axis through said center of eccentricity, while rotating said first plane figure about said axis, the ratio of the radial length of said generatrix to the eccentricity being at least 3:1; a rotor received in said stator and having a helical surface generated by translating a second closed plane figure of symmetrical quadrants divided by said generatrix and its perpendicular bisector, and having rounded ends of radius r centered at the ends of said generatrix, along a rotor axis perpendicular to said second plane figure at its geometric center at twice the lead that said first plane figure rotates around said first named axis, and rotary drive means for turning said rotor in said stator while said rotor axis translates about said center of eccentricity at twice the rate of rotation of said rotor.

3. Apparatus as defined in claim 2 wherein said ratio is at least 4:1.

4. Apparatus as defined in claim 1 wherein said rotor has a uniform wall thickness throughout its length.

5. Apparatus as defined in claim 4 wherein the center of gravity of the rotor and material being pumped, in a radial plane, is at the axis of the rotary drive.

6. Apparatus as defined in claim 2 wherein said rotor is connected to said rotary drive means by a coupling link pivotally connected by a first hinge joint at one end to said rotary drive and pivotally connected by a second hinge joint at the other end to said rotor, said hinge joints having their respective axes parallel to one another.

7. Apparatus as defined in claim 1 wherein said stator is split in an axial plane to form two equal connectible matching halves whereby said stator may be removed from said rotor.

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