

[54] SEGMENTED STATOR FOR PROGRESSIVE CAVITY TRANSDUCER 2,898,087 8/1959 Clark 418/48
3,208,391 9/1965 Lindberg..... 418/48

[75] Inventor: John E. Tschirky, Long Beach, Calif.

Primary Examiner—C. J. Husar

[73] Assignee: Smith International, Inc., Newport Beach, Calif.

Assistant Examiner—Leonard Smith

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[21] Appl. No.: 433,540

[57] ABSTRACT

[52] U.S. Cl. 418/48

[51] Int. Cl.²..... F01C 5/04; F03C 3/00

[58] Field of Search 175/107; 418/48, 55, 216, 418/220, 5

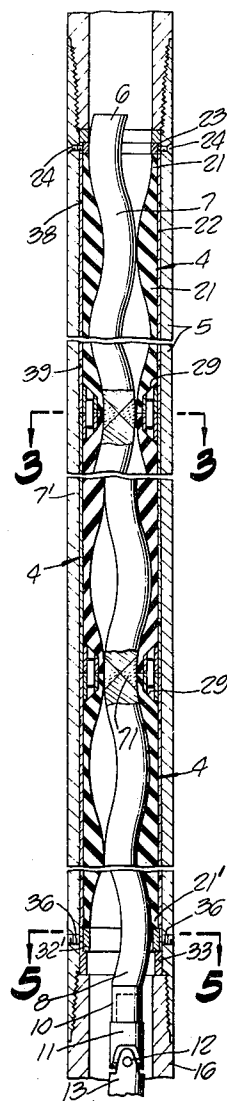
This invention relates to progressing cavity fluid motors with multiple segmented stator elements connected in series to provide a fluid passageway from the input to initial stator of the series to the terminal stator of the series; the rotor elements in each stator are connected together for simultaneous rotation.

[56] References Cited

UNITED STATES PATENTS

2,505,136 4/1950 Moineau..... 418/5

22 Claims, 18 Drawing Figures



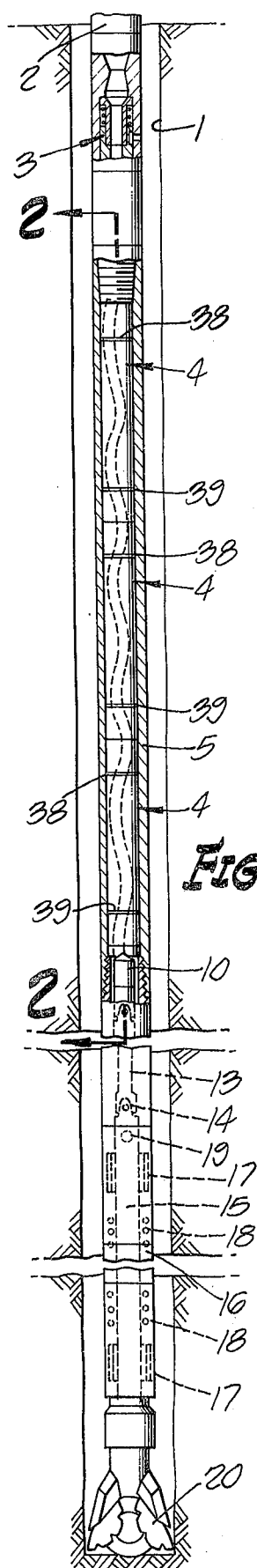


FIG. 1.

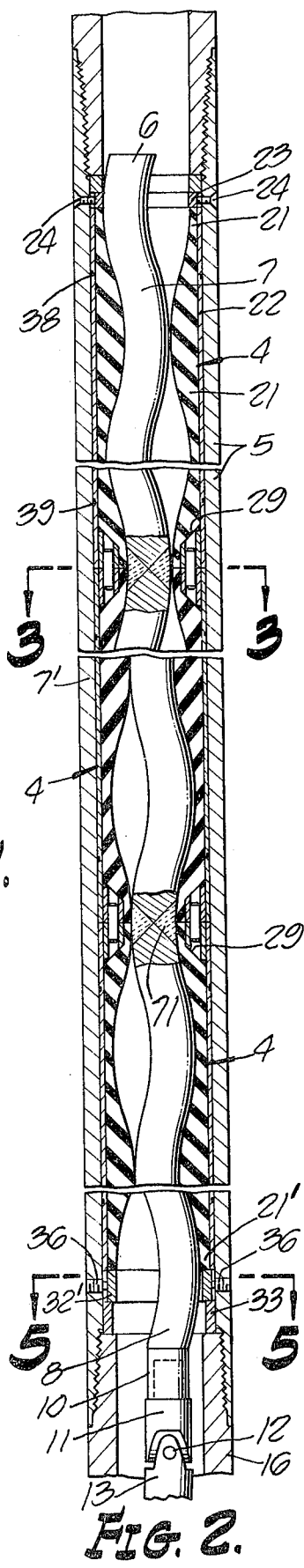


FIG. 2.

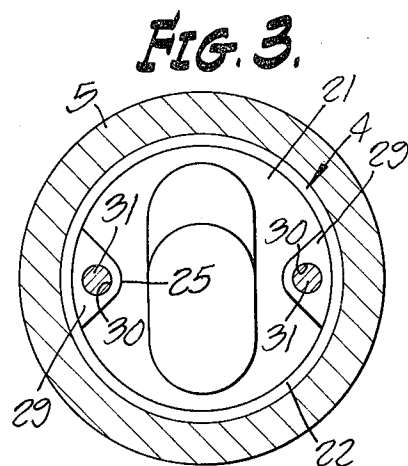


FIG. 3.

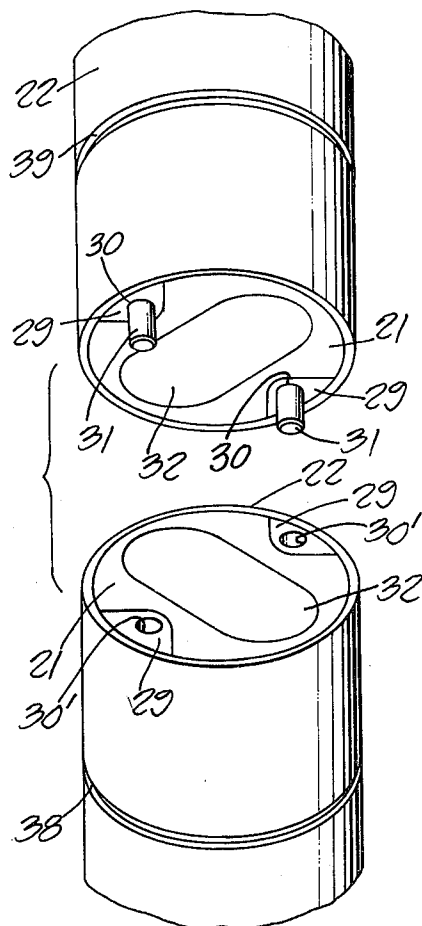


FIG. 4.

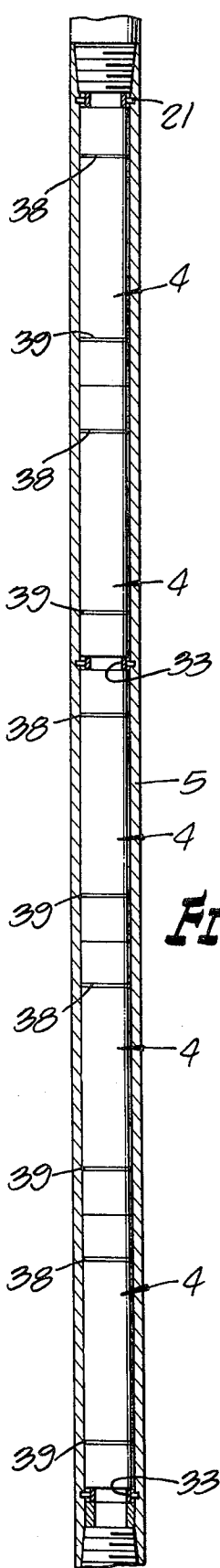


FIG. 7.

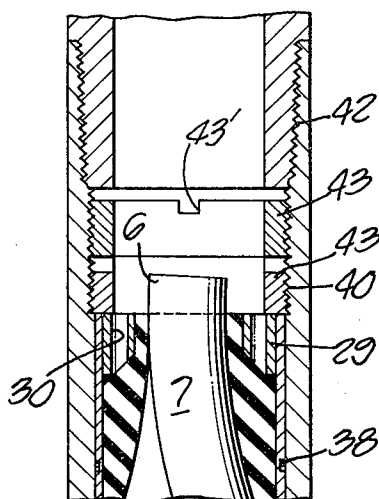


FIG. 6.

FIG. 8.

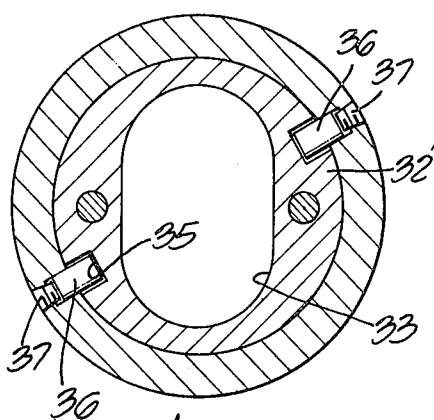
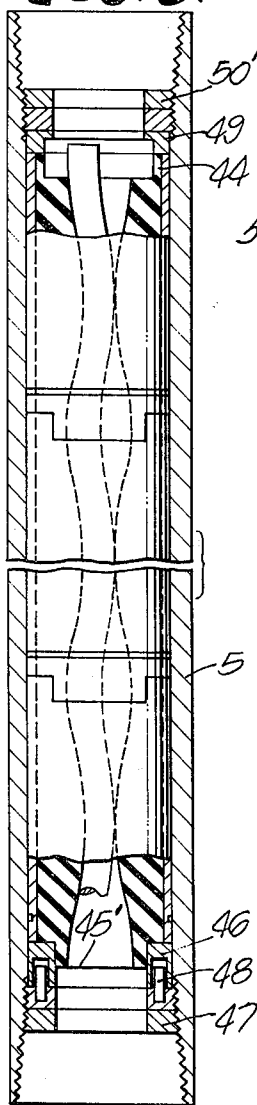


FIG. 5.

FIG. 10.

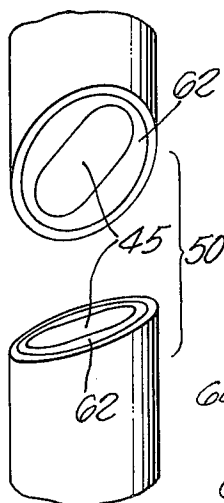
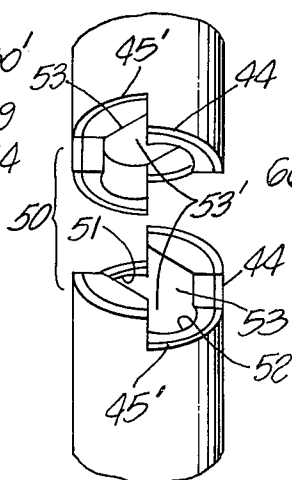
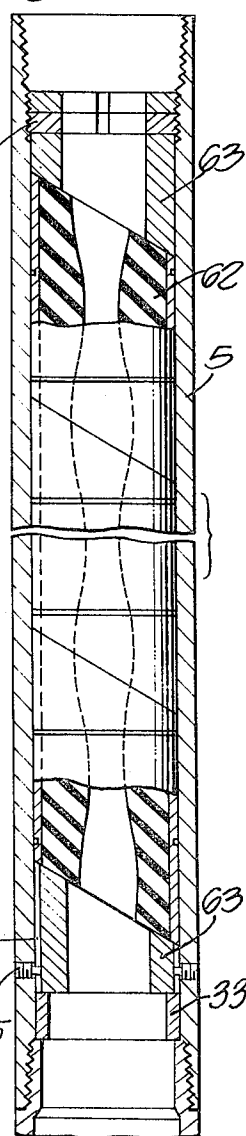


FIG. 11.

FIG. 9.



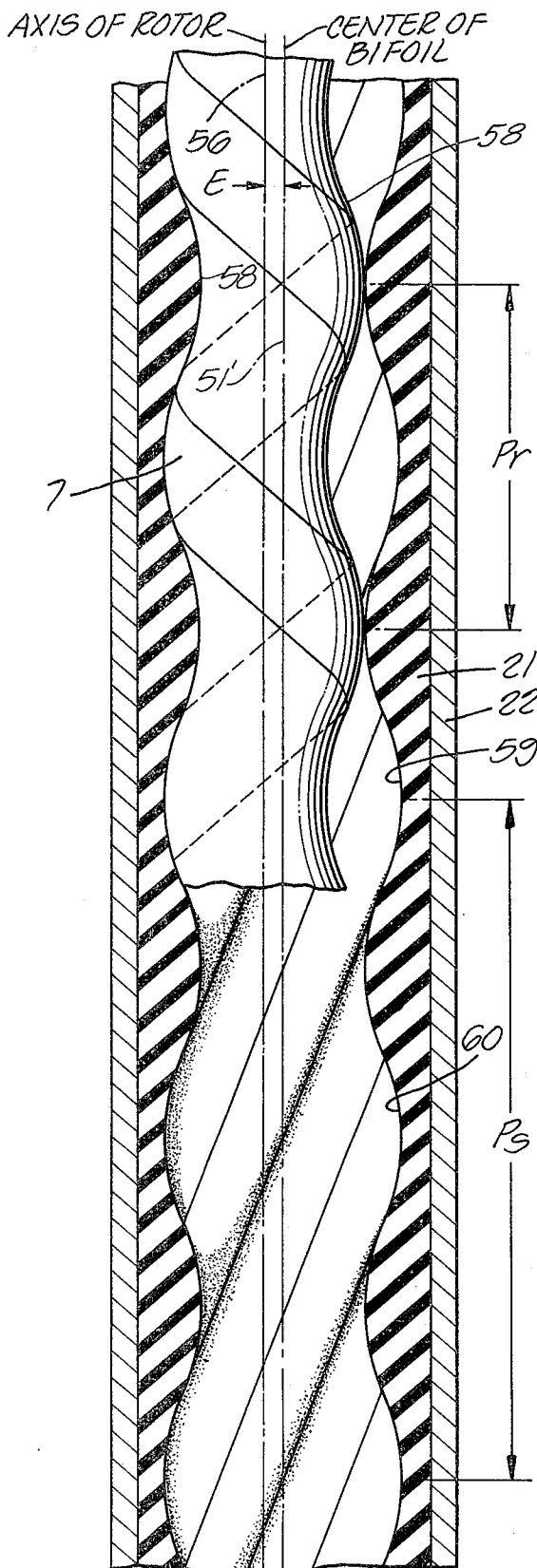


FIG. 12.

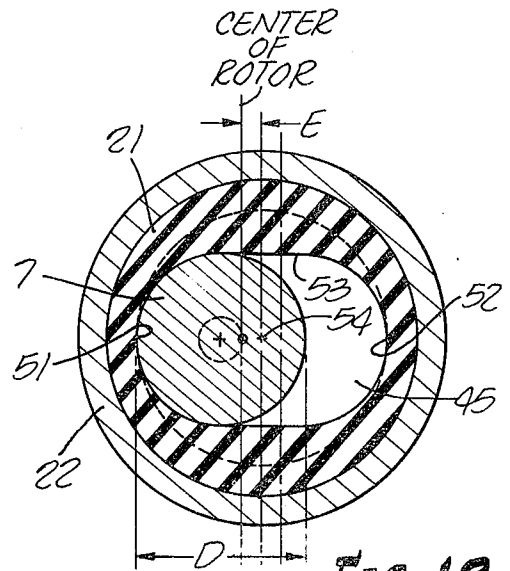


FIG. 13.

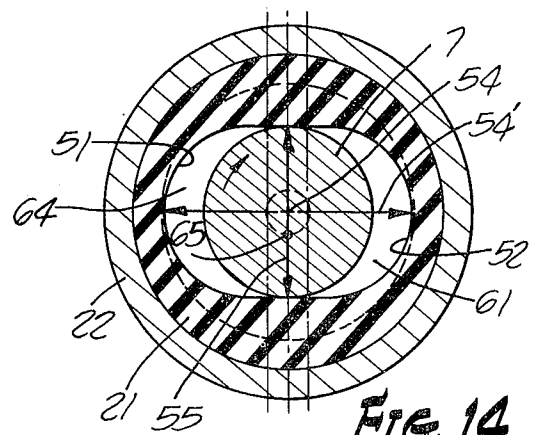


FIG. 14.

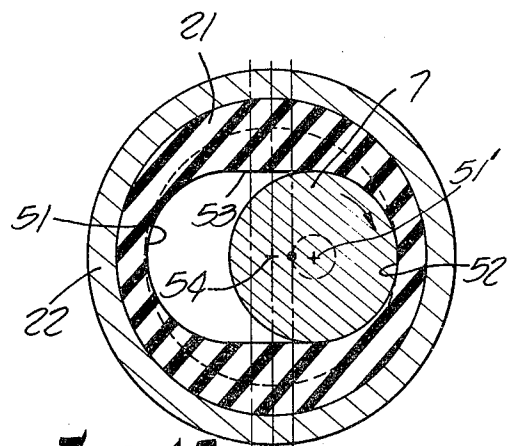


FIG. 15.

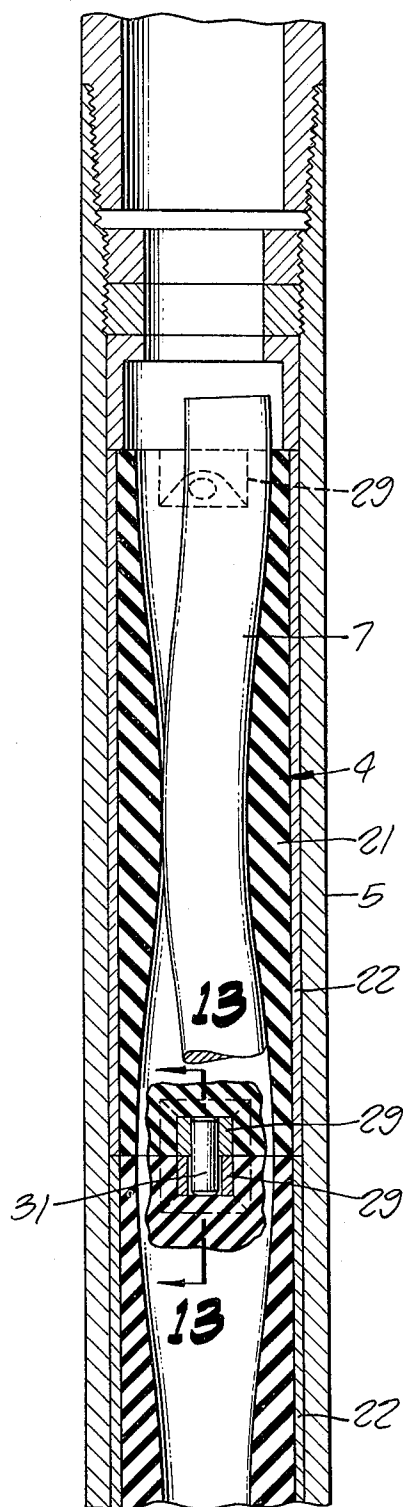


FIG. 16.

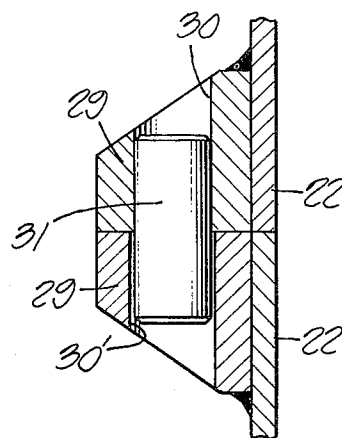


FIG. 17.

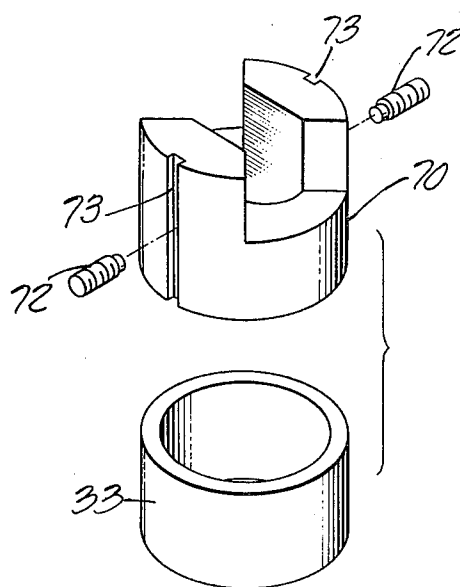


FIG. 18.

SEGMENTED STATOR FOR PROGRESSIVE CAVITY TRANSDUCER

This invention relates to progressive cavity transducers composed of a helicoidal rotor and a complementary helicoidal stator. When the rotor is rotated by an external force, the transducer acts as a pump, moving fluid from an inlet to an outlet connection to the stator. When the fluid is forced to flow between the stator and the rotor from the inlet to the outlet, the transducer acts as a motor delivering rotary power at the end of the rotor adjacent the discharge end of the fluid from the stator.

In a well-known form of such transducer, both when acting as pump and when acting as motors, the stator is formed of an elastomer hereinafter referred to as a rubber, bonded to a steel housing.

When the transducer acts as a pump, rotation is imparted to a shaft to rotate the rotor; and fluid introduced at one end of the stator is pumped through the stator to an outlet connector to the stator. When fluid is forced into the stator between the rotor and the stator, it rotates the rotor, and the shaft connected thereto is then a power takeoff point. Since the rotor of the transducer rotates in an eccentric manner, moving from side to side inside the stator, it is necessary to convert this motion into a true rotation about a fixed axis so that power may suitably be imparted or taken from the motor. This is accomplished by connecting the end of the rotor to a connecting rod by means of a universal joint and connecting rod to a shaft by means of a second universal joint to permit the shaft to rotate about a true axis. Such motors have been for many years used in bore-hole drilling (see the Clark U.S. Pat. No. 3,112,801, patented Dec. 3, 1963) and have been widely distributed by Smith International, Inc. under their registered trademark Dyna-Drill. Such motors are described in the article by H. M. Rollins "Bit Guiding Tools Provide Better Control of Directional Drills," *World Oil Journal* 1966, pages 124-135; the Garrison Pat. Nos. 3,456,746 and 3,489,231.

The use of such motors in bore-hole drilling, especially in drilling for oil and gas but also mining operations, have been a standard procedure in the art. Such motors are employed to rotate drills for boring in the earth. The motors may be used for an oil-field operation, such as tube cleaning, milling operations, and other conventional oil-field operations where it is desired to rotate a rod at the end of which a tool is to be rotated. Such motors are referred to as in-hole drills when designed to be run at the end of a pipe and adjacent to the drill bit. In the usual case, the rotor of the motor and the drill bit rotate with respect to a stator which, in turn is connected to the conventional drill string composed, in the case of the drilling of well bores, of a "kelly," drill pipe, and drill collar as required. The string extends to the surface with the kelly mounted in the rotary table. Where the in-hole motor is used in drilling, the liquid is the usual drilling fluid, i.e., mud or gas. It serves its usual function in the drilling operation, returning to the surface carrying the cuttings resulting from the drilling operation. For this purpose, it is necessary to provide the necessary fluid volumetric velocities (gallons per minute, G.P.M.) at the bit nozzles; and the necessary pressures at the nozzle so that cuttings may be moved through the annulus

between the drill string and the bore hole wall and thus to the surface.

In motors used in connection with the earth-drilling operations, the pressure drop across the stator may be of the order of several hundred pounds with the drilling mud flow through the stator, from 300 to about 600 G.P.M., the total pressure at the outlet of the stator depending upon the depth, nature of the mud, size of the tool, design of the nozzles of the bit. The bit manufacturer usually supplies a recommended nozzle pressure drop to give the required lifting effect. It has been observed in transducers and particularly in motors which deliver a substantial torque effort at the drive shaft that the rubber of the stator frequently fails near the fluid outlet point of the stator, and this usually occurs in the lower third of the stators.

This effect appears to be related to the working of the rubber by the eccentric motion of the rotor and the magnitude of the pressure drop across the rotor. The resultant hysteresis in the rubber deleteriously affects the properties of the rubber.

An additional problem with rubber stators is in the influence of the geothermal effect. The temperature in the bore hole may range up to several hundred degrees F. above ground temperature, depending on the depth. This adds to the heat developed by the working of the rubber, due particularly to the low heat conductivity of the rubber, which is thus not readily carried away by the circulating mud.

Despite the cooling effect of the fluid, this temperature taken together with the working of the rubber which develops a hysteresis in the rubber, operates to impair the physical properties of the rubber. The result is a reduction in the life of the stator, and it is frequently necessary to replace stators with undue frequency which may be more frequent than any other effect requiring the withdrawal of the motor from operation and thus adding to the cost of operations.

The result is a loss of portions of the rubber which break away from the body of the rubber called "chunking" usually at its lower third or it may strip away from the encasing housing due to bond failure, or both may occur.

When this occurs, the motor must be disassembled and a new stator installed. This stator must, of course, have the necessary pitch to compliment the rotor and give the required pressure drop.

The torque developed is the greater the greater the effective pressure drop across the stator. For any given through-put, i.e., G.P.M., the pressure drop will be the greater the greater the length of the stator, the less the leakage factor and the greater the diameter of the rotor which requires a greater diameter stator, all other design parameters being the same.

However, there is a practical limit on how large a stator can be fabricated due to difficulties in molding the stator and bonding the stator rubber to the housing.

Molding of the rubber to produce a successful bond to the housing and the necessary helical configuration at its surface becomes more difficult as the diameter of the stator and its length increase.

However, for many uses, it is desirable to develop a greater torque than is now practically available.

Where the motor is used as a down-hole motor in earth boring, as stated above, the requirements of the system include a sufficient flow, i.e., gallons/minute (G.P.M.) of mud or other fluid flow in order to estab-

lish the necessary velocity through the bit orifices and thus the desirable fluid velocity in the annulus to raise the detritus. This requires a sufficient pressure at the output of the stator so as to provide the necessary pressure and volumetric flow of the fluid at the bit nozzles.

Since for any fluid rate, gallons per minute, in any particular stator-rotor combination, the revolutions per minute (r.p.m.) is fixed, being directly proportional thereto, the torque is proportional to the pressure drop across the stator. These considerations influence the minimum pressure drop which can be tolerated and obtain the necessary fluid velocities and pressures at the bit nozzles.

In order to increase the torque, the product of the eccentricity (E) and the rotor diameter (D) and the stator pitch (Ps) and the effective pressure drop (Δp) across the stator must be increased, since the torque is directly proportional to this product. In the case of oil-well or other bore-hole drilling, the size of the bore hole fixes the size of the diameter of the housing of the motor; and this, in turn, fixes the diameter of the rotor (D) and the eccentricity (E) which is practically available. The increase in the pressure drop (Δp) may be obtained by increasing the flow resistance through the stator by increasing the length of the stator. While this will result in an increase in the torque, it may be impractical because of molding problems. If the torque is increased by making the product ($E \times D \times Ps$) greater, the r.p.m. is decreased, at a constant G.P.M.

This dichotomy has introduced a practical limitation in the power available from motors of this character when used as bore-hole in-hole motors. This limitation taken with the reduction in stator life resulting from use of excessive pressure drop has been one of the limitations in this technology.

STATEMENT OF THE INVENTION

My invention also solves the problem by making the torque (T) and horsepower (HP) in the above transducers independent of the stator pitch length, rotor diameter, eccentricity and pressure drop across the transducer. It also to a large measure solves the problem of the deterioration of the rubber resulting in chunking and stripping and thus increases the life of the stator element. I may, contrary to the present designs of transducers, increase or decrease the torque by independent changes in the design parameters, that is, the diameter of the rotor element (D), the pitch length of the stator elements (Ps) the eccentricity (E), and the effective pressure drop across the stator (Δp) of the combinations. I, therefore, do not need to increase the rotor diameter, the stator pitch length or the eccentricity or the pressure drop across any stator to obtain the increased torque; and thus, I do not have to increase the diameter or the length of the stator elements. I may so vary the torque, increasing or decreasing the torque developed at any stator-rotor element independently of the r.p.m. at any G.P.M. I am thus able to independently produce the desired torque at any desired r.p.m.

An additional and critical problem in the prior art transducer is the deterioration of the rubber resulting in the chunking of the rubber and the stripping away of the rubber from the housing, previously referred to. This, as I have found, is associated with excessive pressure drops across the stator. It is believed that this deterioration is a result of the working of the rubber which in addition to the loading of the rubber by the eccentric

motion of the rotor described above results in the generation of heat and a deterioration of the rubber. An additional force which aids in the deterioration of the rubber adjacent the end of the stator, is the oscillatory forces imposed by the mass of the universal joints connecting the rotor to the drive shaft through the connecting rod.

By reducing the pressure drop across the unitary stator-rotor combination of the prior art, while maintaining the same terminal pressure, that is, in a transducer used as an in-hole motor, when the pressure at the bit nozzles is maintained at the required value, an increase in the life of the stator results.

However, to accomplish this reduction in pressure drop in the prior art rotor-stator combinations, without changing the other parameters of the system, the torque which is developed is reduced. I may reduce the G.P.M. throughput and thus reduce the pressure drop, but this may be impractical because of other requirements for such throughput as described above. Furthermore, the reduction in the throughput, keeping the other design parameters constant, reduces the r.p.m.; and, therefore, the horsepower is reduced.

I accomplish the increase by using multiple stators connected in series. I connect the stators of the units in series so as to establish a flow path from the input to the initial stator through the succeeding stators to the output from the last stator of the series. The rotor of the first stator unit is connected to the rotor of the succeeding units in series so that the rotors rotate together.

The rotor in each stator is rigidly connected to the rotor in all the other succeeding stators and is at its terminal end as it exits the last of the stators, connected by universal joint and connecting rod to the shaft.

The diameter of the rotor (D), pitch length of the stator (Ps) of the stator-rotor combination may be different but the eccentricity of the stator-rotor elements should be substantially the same.

The above relationship between torque and pressure drop assumes that there is no by-pass of the fluid between the rotor and stator, that is, that all of the fluid passes through the progressing cavities. Any by-pass thus reduces the effective pressure drop (Δp). The hydraulic efficiency depends on the percentage of the G.P.M. which is fed to the stators which passes through the cavities. The effective pressure drop (Δp) is equal to the measured pressure drop across the stator (ΔP) at the developed torque, multiplied by the efficiency, i.e., the leakage factor (K).

Preferably, however, it is desirable that the product of the parameters $D \times E \times Ps$ be all substantially the same. The torque developed at each rotor element is directly proportional to the above product multiplied by the effective pressure drop (Δp) across the rotor-stator element.

This consequence arises from the fact that the r.p.m. is inversely proportional to the product at a fixed gallons per minute. If the r.p.m. is less than is required for the greater value of the product, the excess is forced to be bypassed.

There are further practical difficulties arising from such interdependence if there is a difference in the above product ($D \times E \times Ps$) of the stator-rotor elements. If the product ($D \times E \times Ps$) be greater than in adjacent stator-rotor element, while the gallons per minute passing through the stators be the same, some of the fluid will bypass the progressing cavities and be

forced through the stator between the stator and rotor while the remainder is passing through the progressing cavities at a reduced rate proportional to the lower value of the product ($D \times E \times P_s$). This excessive leakage reduces the efficiency of the rotor, i.e., the value of K and reduces the available torque for the total G.P.M.

In order to minimize the leakage at each stator-rotor element, I, therefore, design the rotor-stator elements of the transducer so that the eccentricities of each stator-rotor element of the transducer be substantially the same, and the product ($D \times E \times P_s$) of the rotor, diameter, eccentricity and stator pitch length for each stator rotor be substantially the same in each of the elements.

The stator pitch length need not be the same in all of the stators if the diameter of the rotor and the stator pitch are properly adjusted. The contribution of the torque output from each rotor-stator combination need not be the same although the r.p.m. is the same. The required torque is obtained by using the necessary number of elementary units.

In order to assemble the stators, it is desirable for convenience that the outer diameter of the housing be the same and that they are oriented with respect to each other so that they are circumferentially coincident. This may require an angular adjustment of the stator with respect to its axis so that the projection of its housing be coincident with an upper and a lower housing.

Since, for practical reasons as described above, it is desirable to have all of the rotor-stator units interchangeable, the pressure drop across each unit will be substantially the same; since the fluid flow is the same in each unit, the torque contribution developed at each rotor-stator assembly will be the same and no undue twist will be developed at the rotor between stators.

The rotor need not be of the same diameter or pitch in each of these units, but the eccentricity must be substantially alike in all of the units, provided, however, that the product of the eccentricity (E) and rotor diameter (D) and stator pitch (P_s) be substantially the same in each rotor-stator unit. Since the rotor pitch (P_r) is one-half of the stator pitch, where the stator pitch is different in any adjacent stator, the pitch of the rotor must bear the above relationship to the stator.

If the rotors be different diameters or stators of different pitch (P_s), provided the eccentricity be substantially the same and, therefore, rotor elements be different designs in the various units, the rotor would need to be made of joined elements or a unitary rotor machined into an intricate shape. Furthermore, the stator opening through which the rotor must be moved longitudinally will be smaller for the rotor section of smaller diameters; and interference may be encountered when such longitudinal displacement in assembly and use is necessary.

For this reason, I desire that in my preferred embodiment that the rotor diameter be the same for all portions of the rotor in the stators and that the intermediate portions be not of greater effective diameters. Since it is desirable to avoid leakage, and since the rotors are necessarily all at the same r.p.m. being rigidly connected, it is desirable that the stator pitch and, therefore, the rotor pitch in the stators be all substantially the same. The eccentricity is the same for each rotor-stator combination.

This also makes the stators interchangeable, which is desirable. If the rotor is made of uniform diameter and pitch, a single integral rotor may be used and is preferred.

The angular orientation of the stators is preferably adjusted in the manner described for the previously described form employing separate rotor elements. However, in this case, the central axis of the stators should preferably also be substantially in line.

The torque developed by the assembly of the rotor-stator combinations is directly proportional to the design product ($D \times E \times P_s$) multiplied by the pressure drop from the inlet to the initial stator through the outlet of the terminal stator and is thus the sum of the pressure drop (Δp) across each of the stators, ignoring intermediate pressure drops between stators.

One of the practical advantages of the transducers of my invention is that any desired torque may be developed by adding rotor-stator stages. Each stage being of modest length, they may be readily molded by presently available molding techniques; as has been conventional in this art. While theoretically one unitary long stator may function to give the desired pressure drop and torque in the place of the multiple stators, there is a practical impossibility since there is a practical limit to the length of stators of practical eccentricity and pitch which modern rubber technology may produce.

By breaking the stator in small sections, the problem of molding rubber stators that will resist destruction is made easier than in the case of a long stator. Not only will the life of the stator be improved, the difficulty of molding the stator is minimized and the replacement of stators facilitated.

Should, however, failure occur in any stator employing my invention, it is merely necessary to strip the damaged stator from the rotor and replace it.

Since the total torque at subsequent rotors progressively increases, it may be desirable to make the rotors in the subsequent stators stronger to transmit the increased torque. This may be accomplished by increasing the diameter of the rotor. Since it will be desirable to maintain the same eccentricity, the stator pitch length will need to be reduced to compensate for the increased rotor diameter. While the r.p.m. of the rotors are thus substantially equalized, the stators will not be interchangeable. However, since the tandem relationship is maintained, the ability to disassemble and replace stators is retained.

This invention will be described further in connection with the drawings of which:

FIG. 1 shows in schematic form the transducer of my invention employed as a down-hole motor;

FIG. 2 is a section in line 2—2 of FIG. 1;

FIG. 3 is a section on line 3—3 of FIG. 2;

FIG. 4 is a perspective view of details of the ends of adjacent elements;

FIG. 5 is a section on line 5—5 of FIG. 2;

FIG. 6 is a vertical section of a detail of a modification of a detail shown in FIG. 2;

FIG. 7 is a vertical section with parts in elevation of a modified form of my invention;

FIG. 8 is a vertical section of a modified form of stator interlock;

FIG. 9 is a vertical section through another modified form of my invention;

FIG. 10 is a perspective view of the ends of abutting stators shown in FIG. 8;

FIG. 11 is a perspective view of ends of adjacent stators shown in FIG. 9;

FIGS. 12 through 15 show progressive positions of the rotor during one revolution of the rotor and further illustrate the design parameters.

FIGS. 16 through 18 show modified details of the assemblies.

FIG. 1 shows schematically the arrangement of the segmented stator elements employed at the end of a drill string 2 in a bore hole shown at 1. The motor assembly is connected to the drill string through the bypass valve 3. As shown in the schematic FIG. 1, the motor is composed of a plurality of stator-rotor assemblies forming elements of the motor. The stators 4, FIGS. 1 and 2, may be used in any desired number arranged serially as is illustrated by the broken lines on FIG. 2.

These stators and the containing tubular housing 5 are of conventional design as is described in the previously mentioned references and as will be described more fully below. Each of the stators contains a rotor element shown on FIGS. 1 and 2. The rotor 7 may be unitary or assembled from sections by welding at 71. It is free and not connected to any members at its upper end 6. The lower end 8 of the rotor 7 terminates in the cylindrical end 10 to which is connected the connector 11 which carries the universal joint 12. The universal joint may be as shown in the above Garrison patent or in the Neilson et al. U.S. Pat. No. 3,260,069 or 3,260,318. The connecting rod 13 is connected to the universal joint 12 and to the hollow drive shaft by universal joint 14.

The hollow drive shaft is positioned within the housing 16 by means of upper and lower radial bearings 17, such as shown in the above Garrison patent. Thrust bearings 18 whose function is as is conventional for this type of drill, as shown in the above Garrison or Neilson patents or such as is described in my copending applications, Ser. No. 354,954 and Ser. No. 385,836 which are herewith incorporated by this reference.

Drilling mud as is usually employed in this type of drilling operation is introduced through the drill string 2 and through the by-pass valve 3; and it passes into the upper stator around the rotor 7, discharges from the lowermost stator to pass through housing 16 around the connecting rod 13 and enters the ports 19 in the tubular drive shaft 15. Part may be by-passed around the shaft 15 and through grooves in the upper radial bearing 17 and around the thrust bearings 18 and the grooves of the lower radial bearing 17 and discharge from the end of the housing 16. The portion passing through the ports 19 passes through the hollow drive shaft 15 to be discharged through the nozzles of the rotary bit 20 and then to be passed upwardly in the bore hole 1 in the annulus between the bore hole and the housings 5, and by the drill string 2 eventually to reach the top as is conventional in this type of drilling operation.

Each of the stator elements 4 is composed of an internally grooved elastomer, for example, rubber stator 21 bonded to a tubular sheath 22.

The terminal end of the uppermost stator elements 4 is positioned and secured by means of rings 23 held in position by a plurality of set screws 24 passing through housing 5 and entering notches, provided in the ring

23. The terminal ends of the lowermost stators are made to abut the ring 32 to be described below.

It is a property of the bifoil (see FIGS. 8-12) that unless the major and minor axes of the bifoils of the adjoining stators are in substantial parallelism, i.e., with the helical grooves in phase, the circular external periphery 50 of abutting stators will not be concentric.

In order to provide concentricity, with an adjacent stator, the subsequent stator as it is pushed over the rotor or into tubular housing 5 is adjusted angularly until the circumferences of the adjacent stators are co-incident, and the major and minor axes of the bifoils are in substantial parallelism.

Both ends of stators 4 (see FIGS. 2, 3-5, 16 and 17) are provided with two indexing lugs 29 which are welded to the inside of tubular sheath 22, and flush with the end of said sheath. These lugs are identical except for bores 30 and 30'. The two indexing lugs 29 at the lower end of each stator 4 carry bores 30 receiving pins 31 which are press fitted into bores 30.

The two indexing lugs 29 at the upper ends of each stator 4 carry bores 30' receiving pins 31 in a slidable manner. Bores 30 and 30' are symmetrical and diametrically opposed and concentric with stators 4 and sheath 22, and are abutting each other, as shown in FIG. 4.

Since the bores 30 and 30', and the indexing lugs 29 are symmetrically arranged about the abutting ends of stators 4, the angular orientation of the stators is automatically obtained so that the bifoil openings 32 of the stators (FIG. 2) are oriented with their minor and major axes coinciding with each other in the adjacent stator ends, thus forming a continuous spiraled cavity throughout the stator assembly (FIG. 2).

The lowermost end of the lowermost stator 4 is retained by the retainer 32' which is longitudinally grooved and retained by pins 36 which as does also the ring 23 has an interior opening in the form of a bifoil of the same shape but greater than the bifoil cross-section 32 of the stator 4, with its minor and major axes contiguous to those of the bifoil cross-sections of the stators 4. They may be, however, and preferably are designed to have a cylindrical interior cross-section of diameter not less than the major axis of the stator bifoil.

The stators are clamped between the rings 33 (see FIG. 2) and 23 and held against the pin ends of the housings 3 and 16.

The lower ring 32' (see FIGS. 2 and 5) is held by pins 36 in notch 35, which extends the vertical length of the ring 32'. The pins 36 are introduced into the receiving bores in the housing before assembly and are held in place by pipe plugs 37 which are also seals off housing 5 thus preventing mud flow from inside the assembly into the annulus between bore hole 1 and housing 5.

The stator sheaths 22 are slidably fitted into the housing 5 and are sealed against the housing 4 by O rings fitting into a pair of O ring grooves 38 and 39.

FIG. 6 illustrates an alternative method of locking the stators in position. FIG. 6 shows an alternative fitting at the upper end of the uppermost stator which may and preferably is used also at the lowermost end of the lowermost stator. These ends are provided with rings 29 (see FIGS. 2 and 3) carrying bores 30 (see FIG. 6). To secure the ends of the uppermost and lowermost stator in position, the housing 4 at the upper and lower ends has pipe threads 40 in addition to the API tool joint threads 42 where oil field operations are in view.

The lock nuts 43 provided with notches 43' to receive a suitable wrench are screwed into position both at the top end of the uppermost stator and the lower end of the lowermost stator. In such case, all the stators are interchangeable.

Where a large number of stators is to be employed (illustrated schematically in FIG. 7), it may be desirable to employ end and also intermediate retaining rings, such as 33.

FIG. 8 illustrates an alternative means for locking and indexing adjacent stators. As shown in FIGS. 8 and 9, the stators are each of one pitch length. At each end, the stator is notched at 45' to form dovetails. At one end, the notch is at the arcs 51 and 52 (see FIGS. 8, 10, and 13 through 15); and the opposite end of the stator is notched at 45' at the tangent 53 of the bifoil. The extending sides of the male end 44 of the stator are positioned in the notches 45' of an abutting stator to complete the stator assemblies with the major and minor axes of the bifoils at abutting ends of the two stators in congruent positions.

The interlock forms both a locking and an indexing means. Due to the dovetail interlock, angular displacement, i.e., rotation of one of the stators with respect of the other stator is prevented.

In order to hold the stators in the housing, the assembled stators are locked in position by a locking member at the end of the assembly. The ring 46 dovetails with the notched end 45' of the lowermost stator. The ring 46 is locked by the internal nut 47 which is screwed into housing 5 and held by means of pins 48 carried in bores in the ring 46. The ring 46 is held by ring lock nut 47. The end 44 of the uppermost stator is held by means of the dovetail ring 49 which dovetails with the notched end 45'. The ring 49 is held by ring lock nuts 50'.

The major and minor diameters of the bifoil opening in the rings 46, 47, 49 and 50' should be coincident with the diameters of the bifoils of the adjacent stators or have openings whose minor diameter is at least equal to the major diameter of the adjacent stator bifoil and preferably have a diameter at least equal to and preferably somewhat larger than the major diameter of the stator bifoil in order to avoid rubbing of the rotor against the rings.

While for illustrative purposes the drawings show each stator as of one pitch length, the stators may be of any fraction or multiple of a pitch length; but the notches, in order to provide for congruence of the bifoils, should be notched to provide such congruent orientation of the bifoils at their abutting ends.

FIGS. 9 and 11 show an alternate means for orienting the adjacent stators and locking them into position into housing 5. Each stator segment has terminal ends which are inclined at an acute angle to the vertical axis 54 (FIGS. 13 through 15) of the bifoil of the stator. As in the case of the form of FIG. 9, the length of the stator elements 62 is related to the internal stator pitch of each section so that when they are assembled in registry and abutting relationship the minor and major axes 54' and 55 (FIGS. 13 through 15) of the abutting stators, as set forth hereafter, are congruent and in line. The result will be a continuous groove with recurrent pitch lengths as if it were one continuous stator. The stators are mounted in the housing 5 by end fittings 63 having terminal ends which are parallel to the terminal ends of the stators against which they are placed in the

housing 5. The fitting 63 carry grooves 64 in which pins 65 are positioned. The fittings are held in position by lock nuts 66 which carry complimentary notches into which an assembly wrench may be positioned.

FIG. 16 shows a modification of the end clamp employed in the assembly of FIG. 2, in which the end fitting such as 49 (FIG. 8) is employed.

FIG. 18 shows an end fitting 70 which may be used in place of 48 of FIG. 8. It is held against rotation by screws 72 which enter longitudinal grooves 73. The stators are thus locked to the housing so as to prevent rotation of the stators.

FIGS. 12-15 illustrate the critical dimensions of the stator-rotor assembly. It will be observed that the pitch length of the stator (P_s) is twice the pitch length of the rotor (P_r). Further, it will be observed that the cross-section of the stator is a bifoil consisting of two semicircles 51 and 52 connected by tangents 53. The vertical axis of the bifoil is at 54. The major horizontal axis is at 54', and the minor axis perpendicular thereto is at 55. The radius of the semicircle is equal to the radius of the rotor which has a circular cross-section of diameter D .

The vertical axis of the rotor is at 56. The rotor is symmetrical about this axis. The center 51' of each cross-section is on a helix parallel to the helical external surface 58. On rotation of 90° of the rotor clockwise as viewed at FIG. 13, the rotor translates to position shown in FIG. 14; at 180° rotates to position shown in FIG. 15.

The stator is formed of a spiraled bifoil cavity 59 and 60 which houses and conforms to the rotor.

By moving the rotor in rotation and translation, the cavity at 61 is sealed from all other cavities. As the rotor rotates and translates from the position in FIG. 13 to the position in FIG. 14, the cavity at 61 is connected with the cavity at 64 by the spiraled bifoil in the stator. A further 90° rotation cuts off the cavity 61 and 64 from other cavities, closing cavity 61.

In translating and rotating, the rotor executes an eccentric motion such that a point 65 moves in a circular path of radius E , i.e., the eccentricity of the rotor motion.

The stator is composed of an interior interconnecting spiraled bifoil cavity 59 and 60, having a pitch (P_s) twice that of the pitch of the rotor (P_r).

It will be observed that the total flow G.P.M. through each of the stators is the same.

The parameters E , D , P_s are related so that r.p.m. = $\text{G.P.M.} \times 231 / (E \times D \times P_s) 4$

with E , D , and P_s in inches.

Furthermore, the torque T is:

$$T = 0.636 \times E \times D \times P_s \times K \Delta P$$

$$K \Delta P = \Delta p$$

T is in inch-pounds and ΔP and Δp are in pounds per square inch. The r.p.m. of the rotors in each assembly is of course the same since the rotors are rigidly connected. Since some machining tolerances are necessary and since molding techniques are not so advanced as to equal machining precision to produce identity in E and P_s in adjacent stators, the exact equality of the products $E \times D \times P_s$ may not be obtainable. However, following good practice in these arts, a substantial equality may be obtained.

If there be excessive differences in the product ($E \times P \times P_s$) so that the product ($E \times D \times P_s$)¹ of a motor

be less than in an adjacent motor while the r.p.m. is the same, then the following relation will appear.

$$\text{r.p.m.} < \text{G.P.M.}/4(E \times D \times P_s)^1$$

The result is that a portion of the G.P.M. bypasses as leakage so that the effective (G.P.M.)¹ which causes rotation is again established for the equality with the enforced r.p.m.

$$\text{r.p.m.} = (\text{G.P.M.})^1/4(E \times D \times P_s)^1$$

The leakage plus the (G.P.M.)¹ being the total throughput.

But to the degree that (G.P.M.)¹ is not equal to (G.P.M.) the effective pressure drop Δp across the rotor is reduced, reducing the torque.

The ratio (G.P.M.)¹/G.P.M. = K the efficiency factor.

It will be observed, also, that should the wear occur usually on the lower rotor-stator assembly, the lower unit may be disconnected by unscrewing the bit, unscrewing the housing 16. The stators may be stripped over the rotor and replaced by a new stator which is pushed over the rotor. The units are reassembled.

The total torque and horsepower are produced at the bit 20 via the shaft 15. With the design parameter $E \times D \times P_s$ substantially the same for each rotor-stator assembly, the total torque is proportional to the total pressure drop between the entry to the upper stator 4 and the discharge from the last stator 4. This is substantially equal to the sum of the pressure drops at each stator.

The segmental rotor formed in sections and assembled as in FIG. 2 is satisfactory. Instead one continuous rotor may be fabricated, but this adds to manufacturing difficulties in producing a long rotor. The assembled rotor is used as a guide and the housings and connectors pushed over the rotor and assembled as shown.

While in this specification I have referred to the bifoil as my preferred embodiment, the bifoil may be replaced by any of the forms shown in the Moineau U.S. Pat. No. 1,892,217 of Dec. 27, 1932.

I claim:

1. A progressing cavity fluid transducer assembly comprising a plurality of separate stator elements, said assembly having a vertical axis, an internal helical groove in the internal surface of said stator elements, said separate stator element having co-operating surfaces formed with at least one projection and recess with respect to a plane perpendicular to the said vertical axis to register said separate stator elements and means to connect the output end of one of said stator elements with the input end of a succeeding stator element in series into a continuous fluid passageway, a helical rotor element extending through said series of stator elements, a fluid flow connection to the first of said stator elements in said series, a fluid flow connection to the last of said stator elements in said series, the pitch of said stator groove (P_s) being twice the pitch of the rotor (P_r), and in which each of said rotor elements adapted to move in a rotary and eccentric motion in the stator elements.

2. In the transducer of claim 1, the cross-section of each stator being a bifoil and the major axis of the bifoils at the terminal ends of adjacent stator elements being substantially parallel and means to hold the said stators in said series.

3. The transducer of claim 1 in which the cross-section of each stator element has a bifoil opening and said projections and recesses comprise a dove-tail ring

and notch in the co-operating surfaces, said dove-tail ring and notch being oriented with respect of the major axes of the bifoils in the co-operating surfaces of the adjacent stator elements to position the major axes of the bifoil openings in the co-operating surfaces substantially parallel.

4. The transducer of claim 1 in which the cross-section of each stator element has a bifoil opening and the terminal ends of adjacent stators are on a plane at an acute angle to the vertical axis of said assembly, a portion of said terminal ends projecting above said perpendicular plane and a portion of said terminal ends projecting below the said perpendicular plane to register said separate stator elements with the major axes of the bifoils in the co-operating surfaces substantially parallel.

5. In the transducer of claim 1, in which the helical rotors have a circular cross-section and in which in each of the stator-rotor elements the product of the diameter (D) of the cross-section of the rotor, the eccentricity (E) of rotor motion in the stator-rotor combinations, and the pitch of the stator grooves (P_s), to wit, ($D \times E \times P_s$) being substantially the same in each of the stator-rotor elements.

6. In the transducer of claim 5, the cross-section of each stator being a bifoil and the major axis of the bifoils at the terminal ends of adjacent stator elements being substantially parallel and means to hold the said stators in said series.

7. In the transducer of claim 5 in which the pitch (P_s) and the diameter (D) and the eccentricity (E) in each of the stator elements in said series are all substantially equal.

8. In the transducer of claim 5 in which the eccentricity of the rotor motion (E) in each stator element is substantially the same.

9. In the transducer of claim 8, the cross-section of each stator being a bifoil and the major axis of the bifoils at adjacent ends of said stator elements being substantially parallel and means to hold the said stators in said series.

10. In the transducer of claim 5 in which the pitch (P_s) of the stator grooves in each of the stator elements in said series are all substantially equal.

11. In the transducer of claim 10, the cross-section of each stator being a bifoil and the major axis of the bifoils at adjacent ends of said stator elements

12. In the transducer of claim 5 in which the diameter of the rotors (D) in each of the stator elements are all substantially equal.

13. In the transducer of claim 12, the cross-section of each stator element being a bifoil and the major axis of the bifoils at adjacent ends of said stator elements being substantially parallel and means to hold the said stators in said series.

14. The transducer of claim 1 in which the cross-section of each stator element has a bifoil opening and said projections and recesses including pins mounted in the surface of one of said stator elements and bores in the co-operating surface of the adjacent stator element, said pins and bores being oriented with respect of the major axis of the bifoils in the co-operating surfaces of adjacent stator elements to position the major axes of the bifoil openings in the co-operating surfaces substantially parallel.

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15. In the transducer of claim 14 in which the eccentricity of the rotor motion (E) in each stator element is substantially the same.

16. In the transducer of claim 14 in which the pitch (Ps) of the stator grooves in each of the stator elements in said series are all substantially equal.

17. In the transducer of claim 14, in which the helical rotors have a circular cross-section and in which in each of the stator-rotor elements the product of the diameter (D) of the cross-section of the rotor, the eccentricity (E) of rotor motion in the stator-rotor combinations, and the pitch of the stator grooves (Ps), to wit, $(D \times E \times Ps)$ being substantially the same in each of the stator-rotor elements.

18. In the transducer of claim 17 in which the diameter of the rotors (D) in each of the stator elements are all substantially equal.

19. In the transducer of claim 17 in which the diameter (D) and the eccentricity (E) and the pitch (Ps) are all substantially equal.

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20. In the transducer of claim 14, in which the helical rotors have a circular cross-section and in which in each of the stator-rotor elements the diameter (D) of the cross-section of the rotor, the eccentricity (E) of rotor motion in the stator-rotor combination, and the pitch of the stator grooves (Ps) are substantially the same in each stator-rotor element.

21. In the transducer of claim 20, in which the helical rotors have a circular cross-section and in which in each of the stator-rotor elements the product of the diameter (D) of the cross-section of the rotor, the eccentricity (E) of rotor motion in the stator-rotor combinations, and the pitch of the stators grooves (Ps) are substantially the same in each rotor-stator element.

22. The transducer of claim 20 in which the cross-section of each stator element has a bifoil opening and said projections and recesses comprise a dove-tail ring and notch in the co-operating surfaces substantially parallel.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,912,426 Dated Oct. 14, 1975

Inventor(s) JOHN E. TSCHIRKY

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

1. Col. 1, line 15: Change "pump" to - pumps - .
2. Col. 8, line 21: Change "ends" to - end - .
3. Col. 10, line 1: Change "fitting" to - fittings - .
4. Col. 10, line 56: Change " Δ P and Δ P " to
- Δ P and Δ p - .
5. Col. 12, line 49: After "elements" add:
being substantially parallel and means
to hold the said stators in said series.

Signed and Sealed this

third Day of February 1976

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks

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