Nov. 29, 1966 Z. A. LOMNICKI 3,287,993

HYDRAULIC PISTON PUMPS AND MOTORS

Filed Jan. 4, 1965 4 Sheets-Sheet 1

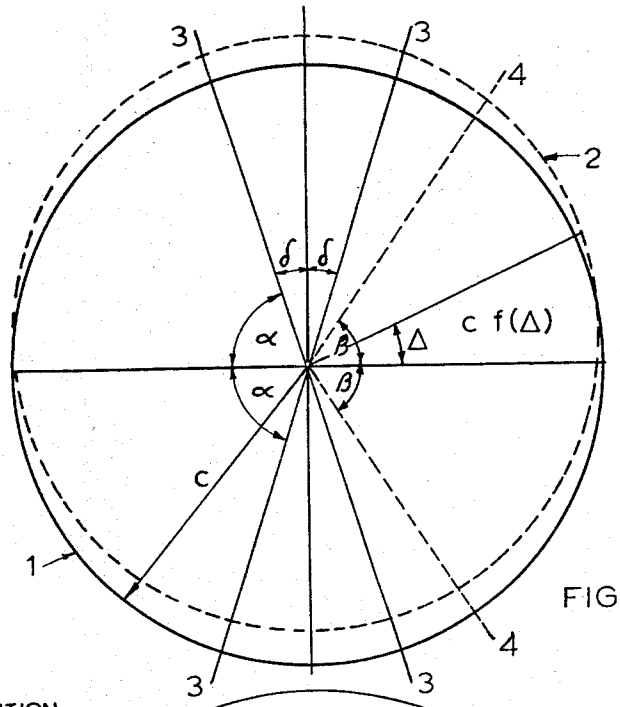


FIG. 1.

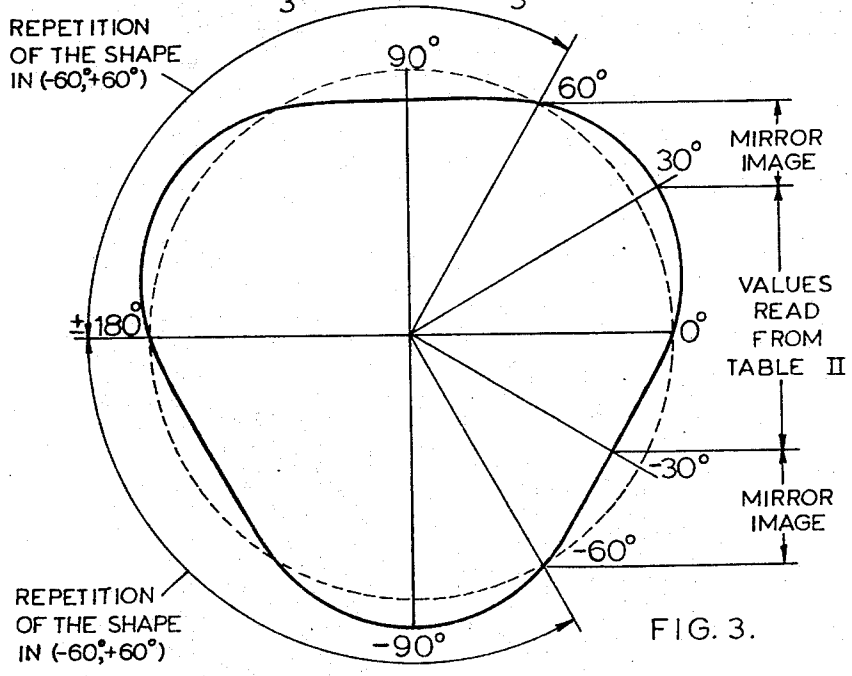


FIG. 3.

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HYDRAULIC PISTON PUMPS AND MOTORS

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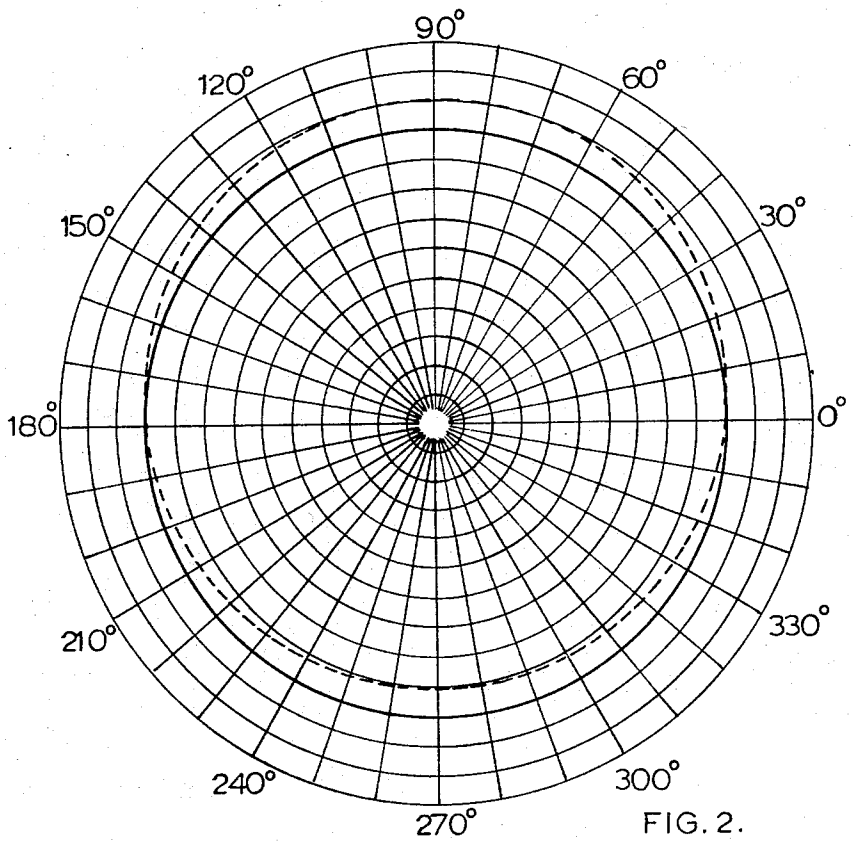
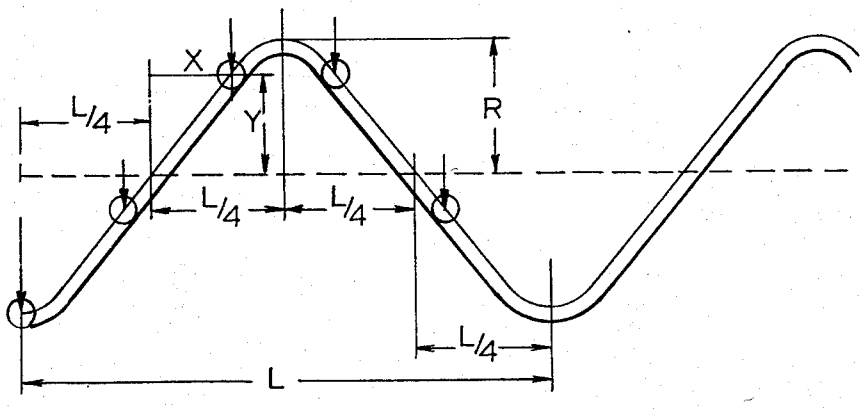


FIG. 2.



$X = \frac{L\Delta}{360°}$ $Y = Rf(\Delta)$ FIG. 4.

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HYDRAULIC PISTON PUMPS AND MOTORS

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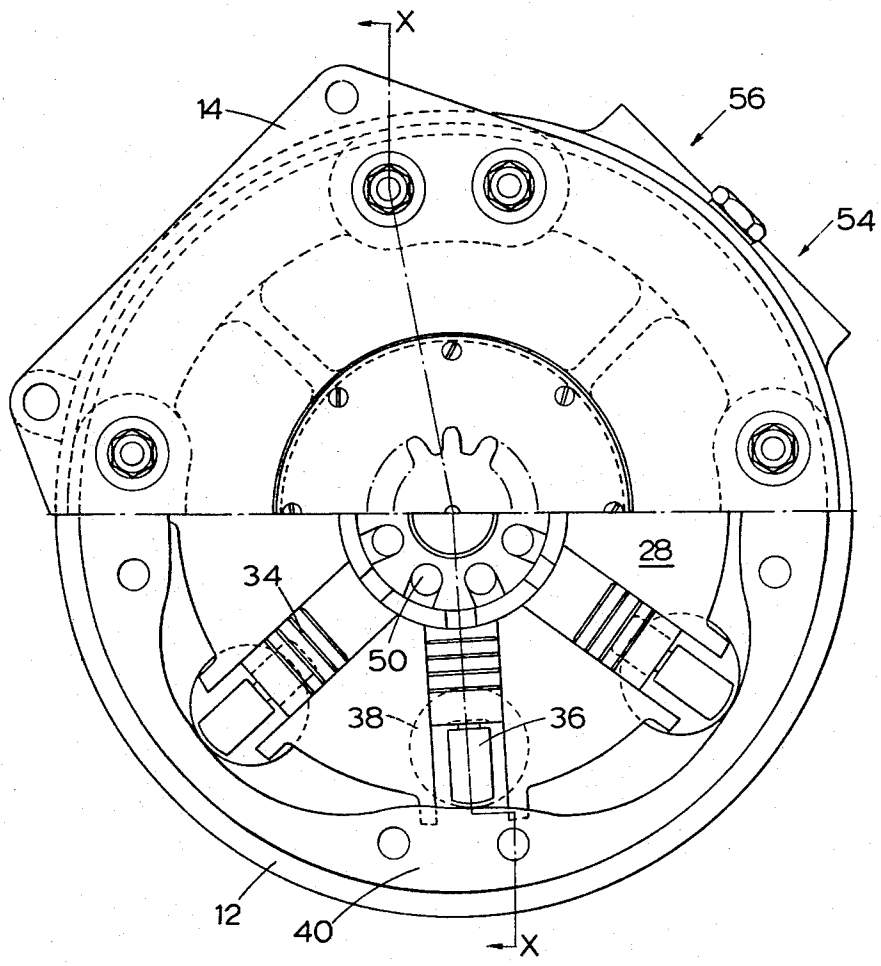


FIG. 5.

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HYDRAULIC PISTON PUMPS AND MOTORS

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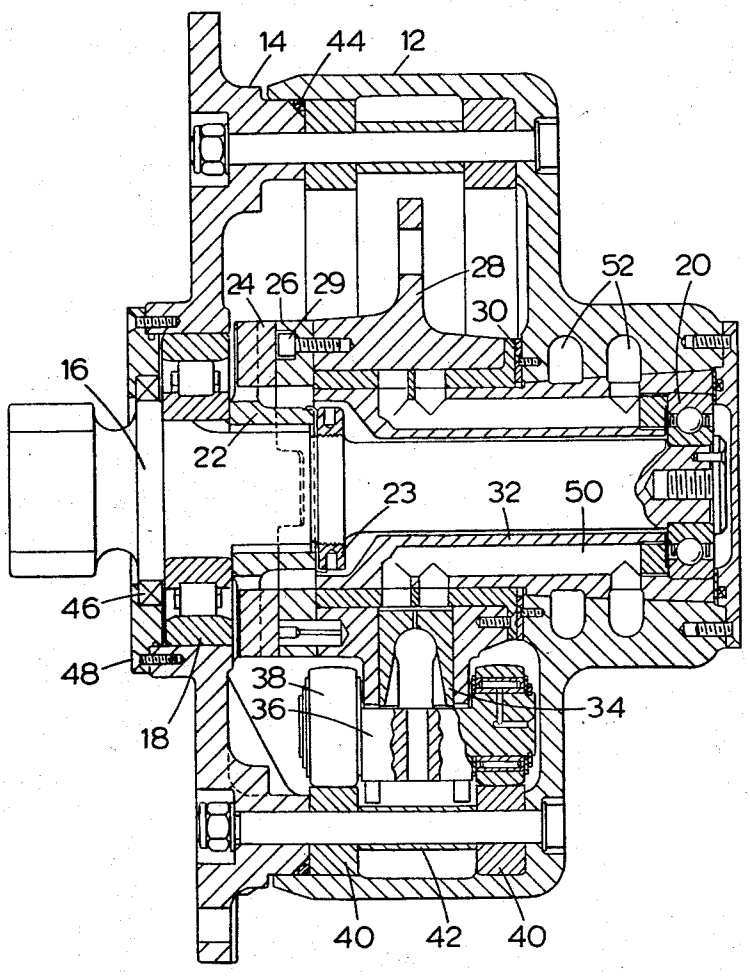


FIG. 6.

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United States Patent Office

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HYDRAULIC PISTON PUMPS AND MOTORS

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Filed Jan. 4, 1965, Ser. No. 423,017
Claims priority, application Great Britain, Jan. 10, 1964, 1,256/64
8 Claims. (Cl. 74—567)

The present invention relates to track members for hydraulic piston pumps and motors.

In the specification of our co-pending United States patent application Serial No. 252,128, filed January 17, 1963, hereinafter referred to as the parent specification, there is described and claimed a track ring for a hydraulic pump or motor of the radial piston type having five or more pistons, in which ring part of the section of the running surface thereof is the locus of the end of a radial line rotating about the centre of the basic circle as defined therein, the length of the line being $C+f(\Delta)$, where C is the radius of the basic circle and Δ is the angle between the radial line and the bisector of the angle subtended by an arbitrarily chosen working sector as defined therein and in which $f(\Delta)$ is defined by the following conditions:

$$f(\Delta)=-R \text{ for} -\frac{\pi}{2}\leq\Delta\leq-\alpha$$

$$f(\Delta)=R\left[\frac{\Delta}{\alpha}+\frac{1}{\pi}\cdot\sin\frac{(\pi.\Delta)}{\alpha}\right] \text{for} -\alpha\leq\Delta\leq\alpha$$

$$f(\Delta)=R \text{ for } \alpha\leq\Delta\leq\frac{\pi}{2}$$

in which conditions R is the lift of the pistons, 2α is the angle subtended at the centre of the basic circle by the limits of the working sector, and α is defined by $\alpha=(n-1).\pi/2n$ if n is odd, and by $\alpha=(n-2).\pi/2n$ if n is even, where n is the number of pistons, the remainder of the section of the running surface being a mirror image of the above function.

There is also defined and claimed a similar arrangement but having S working strokes per revolution, wherein $f(\Delta)$ is compressed S times so as to assume its complete cycle of values S times per revolution.

The parent specification is applicable only to hydraulic pumps or motors of the radial piston type having five or more pistons.

We have now succeeded in making the invention applicable to three or more pistons and also to hydraulic pumps or motors of the axial piston type and of the linear movement type.

Pumps and motors of these types are known in which the rate of movement and volume rate of flow are not strictly proportional, resulting in an irregular pump delivery or uneven motor torque or force, as the case may be, even when the pump is driven at a constant rate or the motor is supplied with the liquid at constant pressure.

The present invention provides cams or track members by means of which the volume rate of flow is uniformly proportional to the rate of movement.

According to one aspect of the present invention there is provided a track ring for hydraulic pumps or motors of the radial piston type having three or more pistons, in which part of the transverse axial section of the running surface of the track ring is the locus of the end

of a radial line rotating about the centre of the basic circle as defined below, the length of the line being $C+(\Delta)$ where C is the radius of the basic circle and Δ is the angle between the radial line and the bisector of the angle subtended by an arbitrarily chosen working sector as defined below, and in which $f(\Delta)$ is defined by the following conditions:

$$f(\Delta)=-R \text{ for} -\frac{\pi}{2}\leq\Delta\leq-\alpha$$

$$f(\Delta)=\frac{-R}{\alpha+\beta}\left[-\Delta+\beta-\frac{\alpha-\beta}{\pi}\sin\left(\frac{\Delta+\beta}{\alpha-\beta}\cdot\pi\right)\right] \text{for} -\alpha\leq\Delta\leq-\beta$$

$$f(\Delta)=\frac{2R\Delta}{\alpha+\beta} \text{for} -\beta\leq\Delta\leq\beta$$

$$f(\Delta)=\frac{R}{\alpha+\beta}\left[+\Delta+\beta+\frac{\alpha-\beta}{\pi}\sin\left(\frac{\Delta-\beta}{\alpha-\beta}\cdot\pi\right)\right] \text{for } \beta\leq\Delta\leq\alpha$$

$$f(\Delta)=R \text{ for } \alpha\leq\Delta\leq\frac{\pi}{2}$$

in which condition R is the lift of the piston between $-R$ and $+R$, 2α is the angle subtended by the working sector extending from $-\alpha$ to $+\alpha$, and 2β is the angle subtended by that part of the working sector over which the distance $C+f(\Delta)$ of the track ring from the centre of the basic circle is proportional to the angle, i.e. over which the track ring forms a part of a simple spiral, and in which the various sets of values α and β to be applied are specified in Cases II, III and IV of Table A below, Case I having been covered in the parent specification, Table A being taken to extend also to such pumps and motors as are specified by provisos (a) and (b) below, the remainder of each cycle of the said section being a mirror image of the above function.

In one embodiment of the present invention there is provided a cam or track member in the form of a rack for relative linear movement for linear hydraulic motor or pump arrangements where the specific track shape, including Case I of Table A, calculated in accordance with the formulae for $f(\Delta)$ above can equally well be treated as the track shape of the said rack by treating the polar co-ordinates r, Δ (where $r=C+f(\Delta)$), as Cartesian co-ordinates, y, x, respectively. Other terms take the appropriate and obvious definitions, remembering that angles α, β become abscissae.

In another embodiment of the present invention there is provided a cam or track member for hydraulic pumps or motors of the axial piston type having three or more pistons, in which the specific track shape, including case I of Table A, calculated by using the Cartesian co-ordinates as indicated above, can equally well be treated as the track shape of a cylindrical cam or track member by relating the Cartesian co-ordinates to cylindrical co-ordinates, r, θ, z, wherein $y=C+f(\Delta)$ becomes z, and x becomes the circumferential distance ($r\theta$) from an arbitrary initial radial line, such that the new independent co-ordinates θ takes the values of the old independent co-ordinate Δ and r is constant.

The invention will first be described as it relates to the radial piston type of pump or motor.

The cross-section of the running surface of the track ring of the present invention differs from a true circle, hereinafter called the "basic circle" by amounts which are functions of the angle "Δ" defined between a radial

line rotating about the centre of the basic circle and the bisector of an arbitrarily chosen working sector as defined below.

The "dwell sectors" are those sectors of the basic circle between the limits of which $d/d\Delta\ (C+f(\Delta))=0$, and the "working sectors" are the sectors lying outside the dwell sectors. The spirality sector is that part of the working sector between the limits $-\beta$ and $+\beta$ of which $d/d\Delta\ (C+f(\Delta))$ is a constant $r2R/(\alpha+\beta)$.

The formulae for $f(\Delta)$ hold true for $-\pi/2\leqslant\Delta\leqslant\pi/2$, i.e. over one semi-circle; and for the interval $\pi/2$ to $3\pi/2$, i.e. for the remaining semi-circle, $f(\Delta)$ is defined as $f(\pi-\Delta)$, thus becoming a mirror image of the function in the first semi-circle.

Table A gives the four possible cases with respect to dwell and spirality sectors, and indicates the (alternative) conditions imposed on the number of pistons n, and gives the values of the remaining angles where appropriate, corresponding to each case, for a pump or motor having one stroke per revolution. Thus the various possible sets of values of the angles α, β and Δ, according to the number of pistons, are set out in Table A, where $\delta=\pi/2-\alpha$ is the angle corresponding to a half of the dwell sector.

Cases II and III produce a constant torque but have no dwell periods during which the rate of piston movements would be zero. Solutions given in Case IV allow arbitrary values of dwell region to be introduced provided that they are small and considerably below the limits given in the last column of the table; these dwell regions may be necessary in some circumstances to improve the design of the pump or the motor.

The formula above refers to pumps or motors with one stroke per revolution and n pistons. Pumps and motors with more than one, say S strokes per revolution and n pistons have also the required property provided that

(a) The number of pistons n divided by the highest common factor d of n and S i.e. the "reduced" number of pistons $n_1=n/d$ satisfies one set of the conditions set out in Table A, and

(b) For the track ring corresponding to n_1 pistons, $f(\Delta)$ is contracted into S working sectors, each S times smaller than the working sector in the case of one stroke per revolution. In other words, a new track ring is defined in this case by the formula for the radial length $C+g(\Delta)$ where $g(\Delta)=f(S\Delta)$ and $f(\Delta)$ is assumed to have a period of 2π. When Δ ranges from 0 to 2π, Δ/S ranges from 0 to $2\pi/S$ and, for S strokes per revolution, the same movements of the pistons relatively to the basic circle are repeated S times per revolution.

TABLE A

Case	Description	Conditions imposed on number of pistons n	Value of the remaining angles
I	Positive dwell $\delta>0$ No spirality sector $\beta=0$	n even ≥ 6 n odd ≥ 5	$\alpha=(n-2)\pi/2n\quad \delta=\pi/n$ $\delta=(n-1)\pi/2n\quad \delta=\pi/2n$
II	No dwell $\delta=0$, $\alpha=\pi/2$ No spirality sector $\beta=0$	n even ≥ 4	
III	No dwell $\delta=0$, $\alpha=\pi/2$ Positive spirality sector $\beta>0$	$n=6$ n even ≥ 8 n odd ≥ 3 { $n+1$ divisible by 4, $n+3$ divisible by 4,	$\beta=\pi/6$ $\beta=\pi/n$ or $2\pi/n$ $\beta=\pi/2n$ $\beta=3\pi/2n$
IV	Small dwell $\delta>0$, $\alpha=\pi/2-\delta$ Positive spirality sector $\beta>0$	n even ≥ 6 { n divisible by 4, $n+2$ divisible by 4 n odd ≥ 3 { $n+1$ divisible by 4, $n+3$ divisible by 4	$\beta=2\pi/n+\delta$, $\delta<n-4/4n\cdot\pi$ $\beta=\pi/n+\delta$, $\delta<n-2/4n\cdot\pi$ $\beta=\pi/2n+\delta$, $\delta<n-1/4n\cdot\pi$ $\beta=3\pi/2n+\delta$, $\delta<n-3/4n\cdot\pi$

The track ring of the present invention has a contour such that the sum of the contribution of the pistons to the fluid delivery from the pump or to the motor per angular displacement is constant at each angular position.

A radial piston hydraulic pump with the present track ring will produce a constant rate of fluid flow when driven at a constant rate of rotation. The torque required to drive the pump will also be uniformly proportional to the pressure at which the fluid is delivered.

A radial piston hydraulic motor with the present track ring will produce a constant torque when supplied with fluid at a constant pressure. The volume of flow demanded by the motor will also be uniformly proportional to the rotational speed of the motor and vice versa for a pump.

The track ring design to produce the above features is dependent upon the number of pistons and upon the number of strokes in one revolution of the pump or motor.

The track ring contour is derived as a function of angular position, to be added to or subtracted from the basic circle. It is dependent upon the number of pistons and upon the piston lift.

The radius of the basic circle C, the piston lift R and the rate of rotation, control the pumping rate of the pump or the torque of the motor. If this can be achieved by a piston lift, R, for one stroke per revolution, then a pump or motor with 2, 3, or more strokes per revolution and the same rate of rotation will produce the same pumping rate or torque, provided the piston lift is reduced proportionally, i.e. $R/2$, $R/3$ etc.

The aforesaid designs have the additional property of producing piston accelerations as continuous functions and consequently providing relatively smooth operation. Moreover, pumps and motors having the number of strokes per revolution and the number of pistons satisfying conditions (a (see above) with the value d greater than 1 will be designs in which the resultant forces form a pure couple.

The improved track ring design can further be applied to variable delivery pumps and variable torque motors, again with the advantage of removing irregularities in the pump or motor output. In this case the pistons of the pump or motor co-operate with a three-dimensional track surface comprising a plurality of axially-spaced track rings of the present invention, smoothly merging into each other. With this embodiment the maximum piston lift R is a function of the longitudinal position of the track surface relatively to the plane of the pistons. By relative displacement of the track surface perpendicularly to this plane the pistons move around effectively different track rings so that the pump delivery or motor torque can be varied in any desired manner.

The choice of the number of pistons is determined by the requirement of the pump or motor. The torque of a motor is given by piston area multiplied by the product of n, S and R and thus, for a given output torque, these items may be varied as desired provided that the final product is unaltered.

Of the following two tables, Table B gives the angles β of the spirality and the angles Δ of the dwell sectors corresponding to the number of pistons of a pump or motor having one working stroke per revolution, and Table C gives the radial distances from the centre of the basic circle to the track ring of a pump or motor with $n=3$ pistons,

$R=1$ unit and $C=10$ units. In Table B both β and Δ are given in degrees.

TABLE B

		Number of pistons $n=$						
		3	5	6	7	8	9	10
Casre III $\delta=0$ $\alpha=\pi/2$	Angle β	30	54	30	12⅞	22½ or 45	30	18 or 36.
Case IV $\delta>0$	Angle β Angles δ less than	$30+\delta$ 30	$54+\delta$ 18	$30+\delta$ 30	$12⅞+\delta$ 38⅞	$45+\delta$ 22½	$30+\delta$ 30	$18+\delta$. 36.

TABLE C

Angular position	Position lift	Radial dimension of Cam at (Δ)	Radial dimension of Cam at ($-\Delta$)
Δ in degrees	$f(\Delta)$	$C+f(\Delta)$	$C-f(\Delta)$
0	0.000000	10.0000	10.0000
3	0.050000	10.0500	9.9500
6	0.100000	10.1000	9.9000
9	0.150000	10.1500	9.8500
12	0.200000	10.2000	9.8000
15	0.250000	10.2500	9.7500
18	0.300000	10.3000	9.7000
21	0.350000	10.3500	9.6500
24	0.400000	10.4000	9.6000
27	0.450000	10.4500	9.5500
30	0.500000	10.5000	9.5000
33	0.549897	10.5499	9.4501
36	0.599182	10.5992	9.4008
39	0.647255	10.6473	9.3527
42	0.693549	10.6935	9.3065
45	0.737540	10.7375	9.2625
48	0.778759	10.7788	9.2212
51	0.816808	10.8168	9.1832
54	0.851365	10.8514	9.1486
57	0.882195	10.8822	9.1178
60	0.909155	10.9992	9.0908
63	0.932195	10.9322	0.0678
66	0.951365	10.9514	9.0486
69	0.966808	10.9668	9.0332
72	0.978759	10.9788	9.0212
75	0.987540	10.9875	9.0125
78	0.993549	10.9935	9.0065
81	0.997255	10.9973	9.0027
84	0.999182	10.9992	9.0008
87	0.999897	10.9999	9.0001
90	1.000000	11.0000	9.0000

The nomenclature describing the track ring will now be explained with reference to the drawings in which:

FIG. 1 is a diagram showing the basic circle and a track ring contour based thereon, to indicate the extent of the various sectors;

FIG. 2 is a polar diagram of a track ring having the measurements set out in Table C;

FIG. 3 is a diagram showing the basic circle and a track ring contour based thereon having three strokes per revolution;

FIG. 4 is a diagram, showing a basic straight line and a cam or tracking member contour based thereon, being the shape of a linear moving rack in a linear hydraulic motor or pump arrangement;

FIG. 5 shows a partially cut away end view of a motor having seven pistons, the track ring providing four strokes per revolution and the running surface thereof depicted diagrammatically; and

FIG. 6 shows a section along the line x—x of FIG. 5.

In FIG. 1, the basic circle **1** is shown in full lines and the track ring contour **2** is shown in broken lines. This latter consists of two lobes, one inside and one outside the basic circle. The lines **3** mark the boundaries between the working and dwell sectors. Lines **4** mark the boundaries between the spirality sector ($-\beta$ to $+\beta$) and the remaining part of the working sector, the mirror images of lines **4** in the left hand side of the diagram not being shown in FIG. 1.

As shown, each working sector subtends an angle of 2α at the centre of the basic circle **1**, having a radius C. The distance from the centre of the basic circle to a point on a track ring contour is $C+f(\Delta)$. The angle subtended at the centre of the basic circle by the limits of each dwell sector is 2δ.

FIGURE 2 illustrates the shape of the track ring of which the measurements are set out in Table C. This track ring is for a pump or motor having three pistons, a piston lift of one unit, and a basic circle of radius ten units, the working sector subtending an angle of 180°, from which $2\times30°=60°$ is the spirality sector while $2\times60°=120°$ corresponds to the remaining parts of the working sector. In this example of Case III the dwell sector is non-existent.

FIG. 3 is derived as follows. In the case of motors or pumps with S strokes per revolution the angles given in Table B furnish the necessary data provided that the values in the top row, (i.e. the number of pistons n), are taken as values of $n_1=n/S$, i.e. where n has been divided by S to obtain the values in this top row. Similarly the values given in Table C for $n=3$, $S=1$ define automatically the shape of the track ring for any other admissible number S of strokes per revolution provided that the numbers of the first column (angular position) are divided by S. Thus in the case $n=9$, $S=3$, the highest common factor d is 3, so that $n_1=9/3=3$ and the angular positions should be divided by $S=3$ so that the radial dimensions of the track range from 9.0000 at $-30°$ to 11.0000 at $+30°$. The radial dimensions thus obtained for the sector ($-30°$ to $+30°$) are extended as mirror images to the sectors ($-60°$ to $-30°$) and ($30°$ to $60°$) this shape ($-60°$ to $+60°$) is repeated twice more ($+60°$ to $+180°$), ($-180°$ to $-60°$) and fills the whole circle. This is what is shown in FIG. 3.

Reverting now to one of the other aspects of the invention mentioned originally, i.e. the linear hydraulic motor or pump arrangement, FIG. 4 is derived as described above by means of a change to Cartesian co-ordinates. L is one track cycle and is an arbitrary dimension depending upon the precise values of constant rack force and velocity concerned. R is the lift of a piston. X and Y are the co-ordinates of a point on the track where $X=L\Delta/360°$ and $Y=Rf(\Delta)$. This means that the abscissae measurements are proportional to the original arc length $2\pi C\Delta/360°$ and the ordinate measurements to $C+f(\Delta)$. It follows that the cam shape, repeated on the rack outline the requisite number of times, dependent on the linear travel required, can be applied to a linear hydraulic motor or pump in which the movement of the pistons at right angles to the length of the rack arrangement produces relative lengthwise movement between the rack and the piston-carrying member.

By arranging n pistons in the sector covering one cam cycle a linear hydraulic motor can be constructed which produces a constant longitudinal component of force and a constant rate of rack movement when the pistons are subjected to constant fluid supply pressure, and vice versa for a linear hydraulic pump. An additional advantage is that the output force can readilly be increased by suitably providing extra blocks, of n pistons each, for example, as a linear continuation of the original block on a single cam form rack, or again for example on the opposite side of a double cam form rack.

The features of the radial piston type of pump or motor indicated above apply similarly to the axial piston type except for the change in shape indicated above by the

change of co-ordinate system, and the consequent additional considerations noted below.

The improved track design according to the invention can be applied to any of the stated types of variable delivery pumps or variable torque or force motors, as the case may be. In general terms, to achieve this, the pistons of the pump or motor co-operate with a three-dimensional track surface comprising a plurality of spaced tracks according to the present invention, smoothly merging into each other, being spaced along the direction which is perpendicular both to the reciprocation axis of each piston and to the direction of working movement of each (piston) cylinder relative to the track member. In the case of the radial piston type the spacing is along the axis of rotation, as mentioned above. In the case of the linear movement types the spacing is perpendicular both to the linear movement and to the axis of each piston, i.e., to the x and y directions respectively, mentioned above. In the case of the axial piston types the spacing is radial, but while radial adjustment of the (piston) cylinders is more difficult to achieve technically, there is the advantage of being able to vary the mechanical advantage of the slope on which the piston bears while keeping constant the force, torque and stroke of the piston, an important consideration for frictional losses.

The motor illustrated in FIGS. 5 and 6 has seven pistons each performing four strokes per revoltuion. The motor comprises a casing **12** closed by an end cap **14**, in which is mounted a main shaft **16** rotatable in roller journal **18** and ball journal **20**. The main shaft **16** is connected to the cylinder block **28** by a coupling member **22** secured to the shaft by ring **23**, intermediate coupling member **24** and a coupling member **26** connected to the cylinder block **28** by screws **29**. The cylinder block bears against an end bearing plate **30**, and is rotatable about a distributor **32**, through the centre of which passes the main shaft **16**. Seven pistons **34** are mounted for radial reciprocation in the cylinder block **28** and carry trunnions **36** on which are mounted rollers **38** for bearing on two track rings **40**, which are spaced apart by spacers **42**. An oil seal **44** is provided between end cap **14** and casing **12**. An oil seal **46** is held on shaft **16** by gland **48** mounted on end cap **14**. The distributor **32** contains four flow and and four return passages **50**, interconnected respectively by flow and return passages **52** in the housing, connecting to a flow inlet **54** and return outlet **56**, FIG. 5.

In operation, a hydraulic medium supplied to inlet **54** passes through the flow passages **52** and **50**, and into those of the cylinders connecting with these passages by virtue of the instantaneous position of the cylinder block **28**. The pistons **34** in these cylinders are therefore urged outwardly and, bearing against the track rings **40**, cause the cylinder block **28** to rotate counter-clockwise (FIG. 5) by reaction. Those cylinders connecting with the return passages **50** and **52** wil return the hydraulic medium forced out of them by virtue of reaction between their pistons and the track rings **40**, to the outlet **56**. If the roles of the inlet **54** and outlet **56** are interchanged the cylinder block will rotate the opposite way. Either motion is conveyed to a gear mounted at the end of the main shaft **16**.

The formula given for the running surface of the track member only applies to the profile of the track member in the ideal condition when the outline defined by that profile corresponds to the path which a point on the central longitudinal axis of a piston would take assuming the piston was moved relative to the track member along the path which the track member would constrain the piston to take. In the event, for example, of a roller follower being used as in the embodiment of FIGS. 5 and 6, the above mentioned ideal condition is not obtained. In order for the piston movement to be that required, the profile is shaped so that the formula would apply to the "surface" which would be traced out by the central longitudinal axis of each roller **38** if the roller was moved along the profile, and it is this "surface" which would constitute the "running surface" of the track member. The profile would be produced by using a milling cutter of the same diameter as the roller **38** and constraining the cutter *centre* to move along the "ideal" running surface profie given by the formula.

I claim:

1. In a machine having at least three pistons, the improvement comprising a track member having a cam surface in driving connection with each of said pistons, said cam surface comprising a pair of half peripheral sections, one of said half sections being a mirror image of the other half section, and one half section being shaped such that, assuming a motion of each of said pistons along a path determined by said cam surface, a point passing through the central longitudinal axis of each of said pistons would have an axial displacement $f(\Delta)$ from the medial position of the piston, where Δ is the relative displacement, having one working stroke in the range lying between 0 and 2π, and where $f(\Delta)$ is defined by the following conditions:

$$f(\Delta) = -R \text{ for} -\frac{\pi}{2} \leqq \Delta \leqq -\alpha$$

$$f(\Delta) = \frac{-R}{\alpha+\beta}\left[-\Delta+\beta-\frac{\alpha-\beta}{\pi}\sin\left(\frac{\Delta+\beta}{\alpha=b}\cdot\pi\right)\right] \text{ for} -\alpha \leqq \Delta \leqq -\beta$$

$$f(\Delta) = \frac{2R\Delta}{\alpha+\beta} \text{ for} -\beta \leqq \Delta \leqq \beta$$

$$f(\Delta) = \frac{R}{\alpha+\beta}\left[+\Delta+\beta+\frac{\alpha-\beta}{\pi}\sin\left(\frac{\Delta-\beta}{\alpha-\beta}\cdot\pi\right)\right] \text{ for } \alpha \leqq \Delta \leqq \alpha$$

$$f(\Delta) = R \text{ for } \alpha \leqq \Delta \leqq \frac{\pi}{2}$$

in which conditions 2R is the stroke of the piston, 2α is an arbitrarily chosen working section within the range of Δ and 2β is the range of Δ within the working sector throughout which the displacement $f(\Delta)$ is a linear function of Δ, and in which one of the three separate sets of values α and β to be applied are those hereinbefore specified in Table A as Cases II, III and IV.

2. The improvement of claim **1** wherein there are S working strokes in the range lying between 0 and 2π, the axial displacement of said point of each of said pistons from its medial position being $g(\Delta)$, where $g(\Delta)=f(S\Delta)$ and $f(\Delta)$ is defined by the conditions set out in claim **1**, and the function $g(\Delta)$ and its image being repeated S times in each range of 2π, in which the quotient of dividing the number of pistons n by the highest common factor d of n and S satisfies one set of the conditions set out in Table A.

3. The improvement of claim **1** wherein said track member has a three dimensional cam surface of which the section that contacts the pistons during said relative movement changes in shape in the direction normal to the directions of reciprocation and said relative movement such that the surface is able to be displaced along the normal relatively to the pistons to vary the output of the machine.

4. The improvement of claim **1** further comprising follower means coupled to one end of each of said pistons and cooperating with the cam surface of said track member, and wherein the center of said follower means behaves precisely the same as said point.

5. The improvement of claim **4** wherein said follower means comprises a roller.

6. In a radial piston type machine having at least three pistons, the improvement comprising a track ring having a cam surface in driving connection with each of said pistons, said cam surface comprising one circumferential section and thereby complementary to one stroke of each of said pistons per revolution of said pistons and track ring relative to each other, one half of said section being a mirror image of the other half, and one of said section

halves being shaped such that, assuming a motion of each of said pistons around the center of said track ring along a path determined by said cam surface thereof, a point on the central longitudinal axis of each of said pistons would trace out an arcuate pattern, being the locus of the end of a radial line rotating about the center of the basic circle as defined below, the length of the line being $C+f(\Delta)$ where C is the radius of the basic circle and Δ is the angle between the radial line and the bisector of the angle subtended by an arbitrarily chosen working section as defined below, and in which $f(\Delta)$ is defined by the following conditions:

$$f(\Delta)=-R \text{ for} -\frac{\pi}{2}\leqq\Delta\leqq-\alpha$$

$$f(\Delta)=\frac{-R}{\alpha+\beta}\left[-\Delta+\beta-\frac{\alpha-\beta}{\pi}\sin\left(\frac{\Delta+\beta}{\alpha-\beta}\cdot\pi\right)\right] \text{ for} -\alpha\leqq\Delta\leqq-\beta$$

$$f(\Delta)=\frac{2R\Delta}{\alpha+\beta} \text{ for} -\beta\leqq\Delta\leqq\beta$$

$$f(\Delta)=\frac{R}{\alpha+\beta}\left[+\Delta+\beta+\frac{\alpha-\beta}{\pi}\sin\left(\frac{\Delta-\beta}{\alpha-\beta}\cdot\pi\right)\right] \text{ for } \beta\leqq\Delta\leqq\alpha$$

$$f(\Delta)=R \text{ for } \alpha\leqq\Delta\leqq\frac{\pi}{2}$$

in which condition R is the lift of the piston between $-R$ and $+R$ 2α is the angle subtended by the working sector extending from $-\alpha$ to $+\alpha$, and 2β is the angle subtended by that part of the working sector over which the distance $C+f(\Delta)$ of the track ring from the center of the basic circle is proportional to the angle, i.e. over which the track ring forms a part of a simple spiral, in which the various sets of values α and β to be applied are specified in Cases II, III and IV of Table A.

7. The improvement of claim **5** wherein there are S working strokes in the range lying between 0 and 2π, the length of said radial line being $C+g(\Delta)$ where $g(\Delta)=f(S\Delta)$ and $f(\Delta)$ is defined by the conditions set out in claim **5**, and the function $g(\Delta)$ and its image being repeated S times in each range of 2π, in which the quotient of dividing the number of pistons n by the highest common factor d of n and S satisfied one set of the conditions set out in Table A.

8. The improvement of claim **6**, further comprising roller follower means coupled to one end of each of said pistons and cooperating with the cam surface of said track member, and wherein the center of said roller follower means behaves precisely the same as said point on the central longitudinal axis of each of said pistons.

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