April 5, 1938. H. H. STINNES ET AL 2,112,934

SWASH PLATE DRIVE SYSTEM AND THE LIKE

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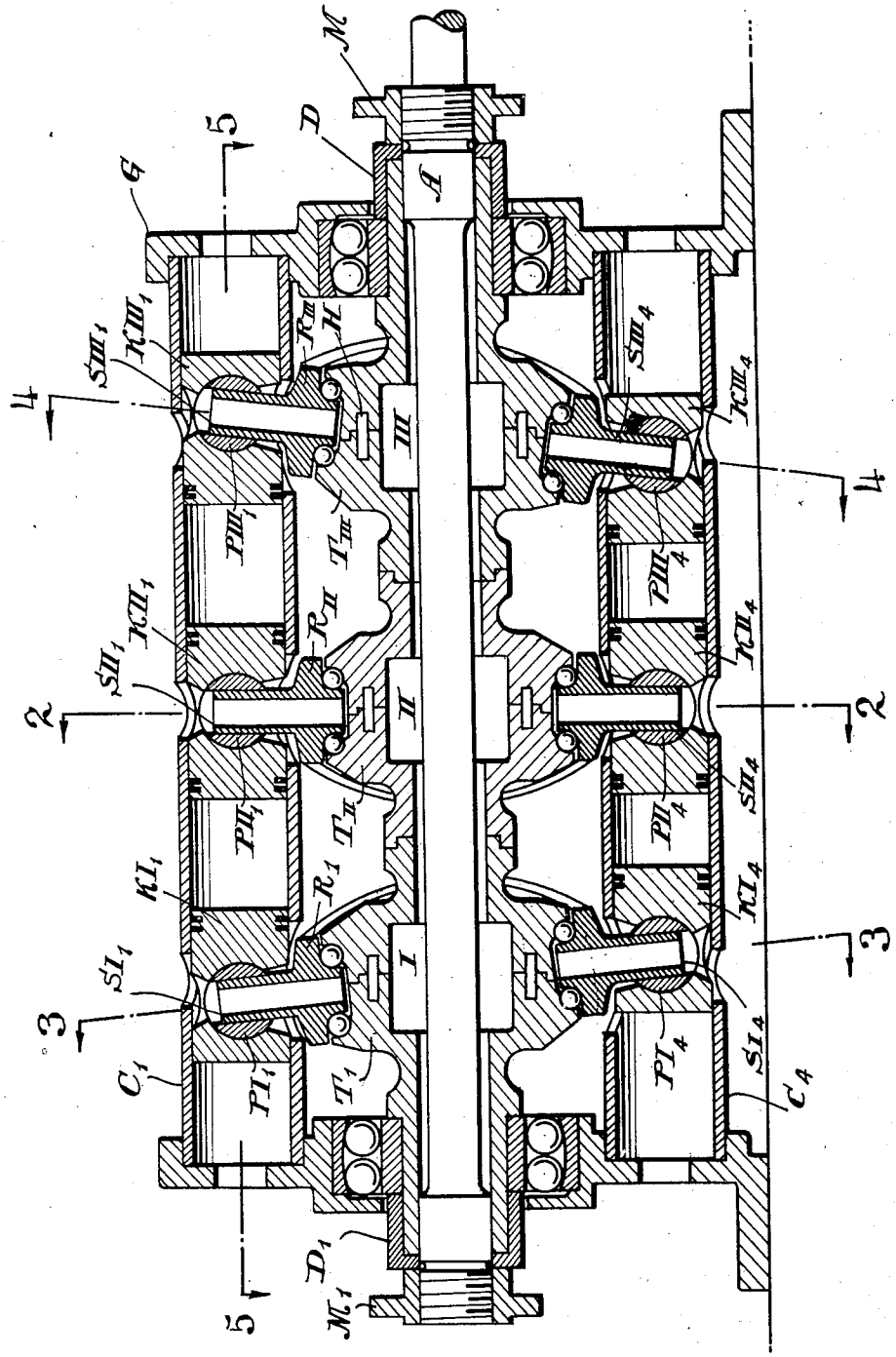



Fig. 1.

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SWASH PLATE DRIVE SYSTEM AND THE LIKE

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Fig. 2.

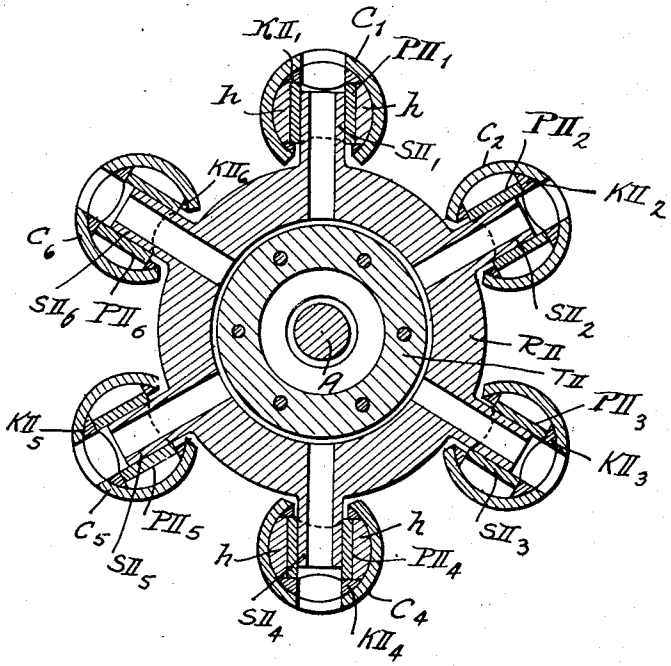
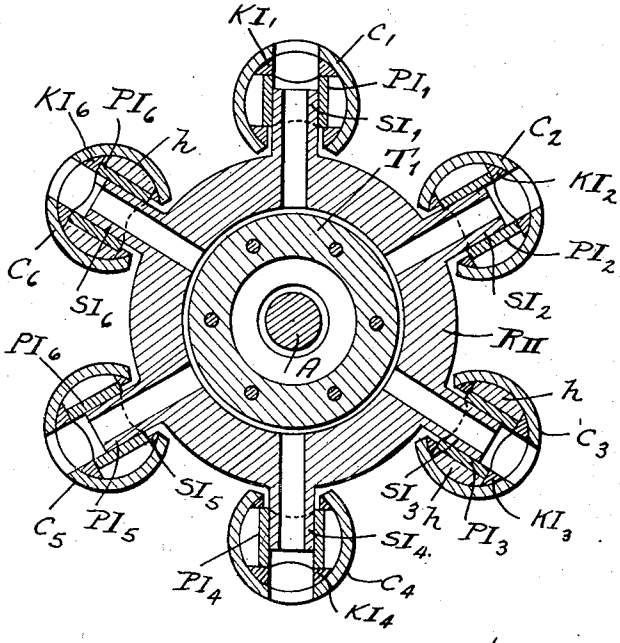



Fig. 3.




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SWASH PLATE DRIVE SYSTEM AND THE LIKE

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Fig. 4.

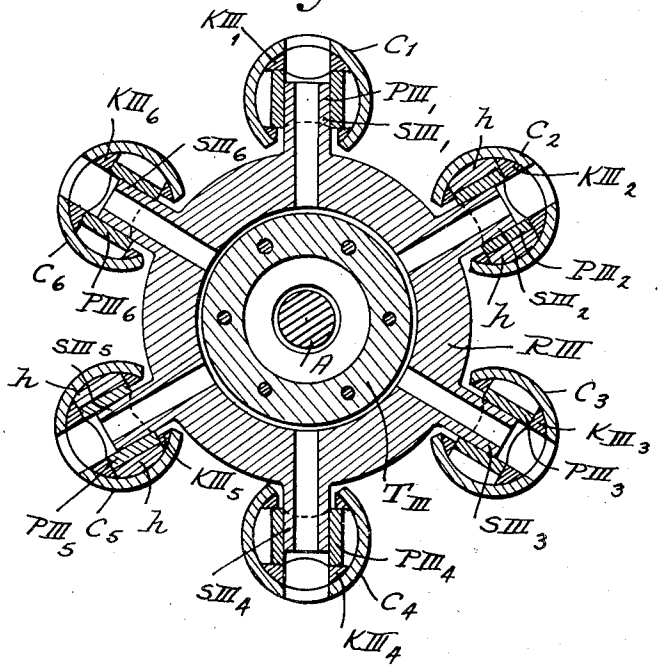
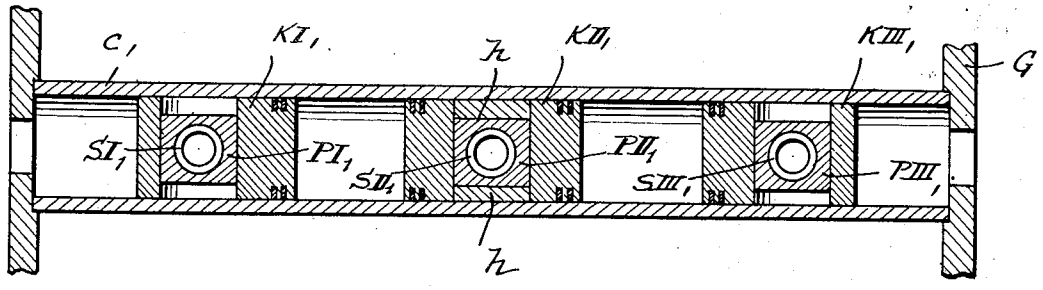



Fig. 5.




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SWASH PLATE DRIVE SYSTEM AND THE LIKE

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Fig. 6. Fig. 7.

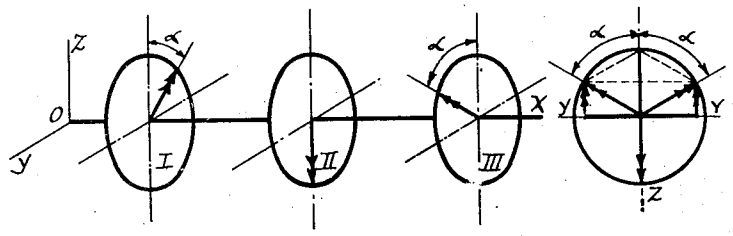



Fig. 8.

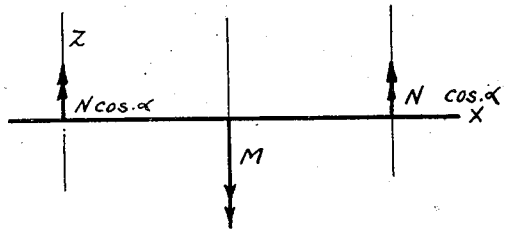



Fig. 9.

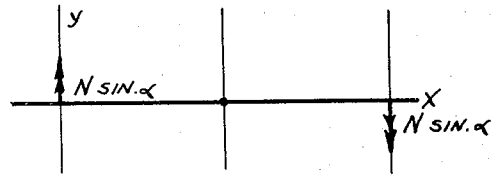



Fig. 10.

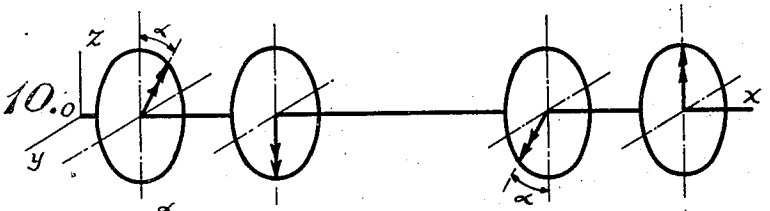



Fig. 11.

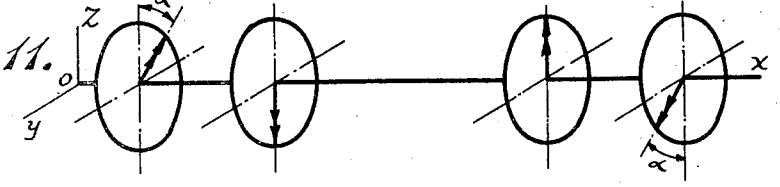



Fig. 12.

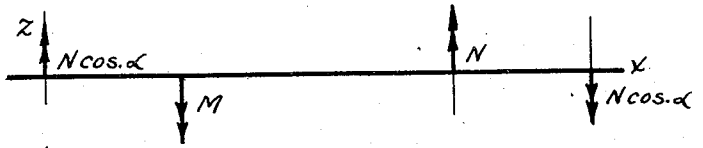
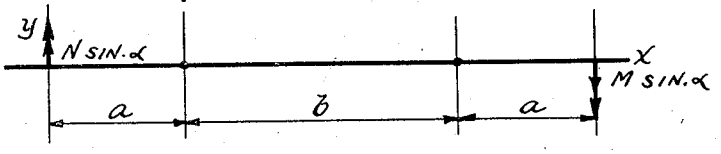



Fig. 13.




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Patented Apr. 5, 1938 2,112,934

# UNITED STATES PATENT OFFICE

2,112,934

## SWASH PLATE DRIVE SYSTEM AND THE LIKE

Hanns Heinz Stinnes and Nikolaus Lebedenko, Berlin, Germany

Application February 23, 1937, Serial No. 127,016
In Germany May 11, 1932

3 Claims. (Cl. 74—60)

This invention relates to balanced swash plate drives, spherical crank gear systems, so-called drunken or staggering gear units or sets, and the like.

The present application is a continuation in part of our copending U. S. patent application filed May 5th, 1933, Serial No. 669,506.

Swash plate drives comprise usually a rotatable shaft and one or more plates or discs which are mounted upon said shaft and are inclined relatively thereto, said plates being rotatable along with the shaft. The outer circumference of each plate is usually provided with a groove within which a ring is situated. This ring does not rotate along with the shaft and the plate but is shifted by the rotation of the latter and carries out a three-dimensional oscillatory-rolling or wobbling motion which may be represented theoretically by lemniscate curves.

However, there are two diametrically opposed points upon the ring which do not participate in this wobbling motion but merely describe arcs. One of these two points may be situated anywhere upon the circumference of the ring. From this point on, the sidewise movement of other points upon the ring circumference is increased until a point is reached which forms an angle of 90° with the first-mentioned point and which has the greatest sidewise movement. Then the extent of the sidewise movement diminishes gradually until it becomes zero at a point which is diametrically opposite the first-mentioned point. Consequently, the extent of the accelerations of those points or mass units of the ring, which are moved sidewise, depends upon their distances from the two points moving along linear arcs.

This movement of the ring may be easily transformed into a straight reciprocatory motion, for instance, by providing several studs upon the ring which reciprocate pistons in directions parallel to the longitudinal axis of the shaft, said pistons moving within cylinders arranged circumferentially around the plate. Studs which are situated at the two above-mentioned points will reciprocate along arcuate linear curves, while other studs will describe lemniscate curves.

The purpose of the swash plate drives is to transform the rotary motion of a plate into an oscillatory-rolling or wobbling motion of a ring and, finally, to transform this last-mentioned motion into the reciprocatory straight-line movements of the pistons. Obviously, this operation may be reversed and the devices may be used for transforming the reciprocatory movement of the pistons into the rotary movement of the shaft.

Spherical crank gear systems differ from swash plate drives in that the former comprise a disc which is vertically mounted upon a crank inclined relatively to the axis of rotation of the crank shaft. Otherwise, the construction and the operation of these types of devices are rather similar, and the expression "swash plate drives" as used in the following description and claims, is intended to cover all types of such devices.

The feature common to all these devices is that they comprise a wobbling element having points upon its circumference which carry out reciprocatory movements in the direction parallel to the direction of the axis of rotation of the elements actuating said wobbling element.

It is frequently advisable to provide several swash plates upon a single shaft, each of the plates having its separate ring and a separate drive for the pistons. Sometimes, the plates are so mounted upon the shaft that the angle of inclination of each plate relatively to its shaft and to the adjacent plates may be changed at will.

Drives of the described type may be conveniently employed for a variety of purposes, for example, for driving a series of pistons which have different relative positions at each moment of their operation, said pistons being used as pumps or compressors for providing an uninterrupted flow of gas or liquid.

It was found that one of the important drawbacks of constructions of this type is the difficulty of properly balancing the rotating and reciprocating masses. This difficulty does not arise when the device consists merely of rotating inclined plates which are not connected to any reciprocating masses. But when the construction comprises unbalanced or incorrectly balanced reciprocating masses, forces developed within the various elements of the drives in the course of their operation, particularly in the oscillating rings carrying out a three-dimensional movement, may easily cause considerable damage or complete breakage of the construction. Obviously, the important problem facing the constructor is that of dynamic balancing, which would eliminate excessive dynamic strains.

Of course, the problem of balancing the described swash plate drives does not exist whenever all the plates extend parallel to each other. However, such construction has little practical value, since it cannot be used for providing a phase difference in the movements of the various pistons operated by the swash plates.

Furthermore, the problem of balancing systems

of swash plate drives does not arise whenever there is an even number of discs and whenever the phase difference between the motions of two discs constituting a pair is equal to 180°, since in such cases the balancing problem is substantially the same as that of other rotary bodies. Each pair of such discs is balanced by itself, so that the constructor or the operator need not use any special means to balance it.

However, very often it is necessary to provide motions of pistons and the like, the phase difference of which is other than 180°. Constructors have attempted to accomplish this result through the use of at least three of the wobbling elements of the described devices by suggesting that the corresponding number of discs of a balanced swash plate drive system be shifted relatively to each other to a predetermined extent. It was found, however, that the system is then immediately thrown out of balance. Attempts to construct balanced systems for that special purpose were also unsuccessful, so that in prior art, no mechanical means were known which would restore or provide this equilibrium with the result that it was considered impossible to use the described drive systems for the purpose of transmitting substantial power, to use them on a large scale, to drive them at high speeds or to construct devices of fairly large dimensions.

An object of the present invention is to balance all movable masses of swash plate drive systems or the like, having at least three wobbling elements driven by a common shaft, the reciprocating parts of said systems having a phase difference which is other than 180°.

The present invention is based upon the discovery that in order to balance such system the same kinematic law must be followed as far as the movements of the inclined swash plates and the movements of the pistons and other masses driven by the wobbling motion of the rings are concerned.

In applying this principle to practice it is necessary to provide a construction wherein the angles formed by planes which contain the axis of the shaft and the longitudinal axis of the pistons and by vertical planes containing the axis of the shaft are equal to the relative angles of inclination of the swash plates, i. e. to the desired phase differences.

If this requirement is followed, the bending moments caused by the movements of the rotating plates, the wobbling rings and the reciprocating masses will change synchronously and following the same dynamic law depending upon the positions of the shaft and the speed of rotation thereof.

When, for example, there are two swash plate drives, the swash plates of which have the required relative angle of inclination, these two swash plate drives may be balanced by the addition of one or more swash plate drives arranged in the described manner relatively to the first two.

Another prerequisite for the dynamic balancing is the proper selection of the moments of inertia of the swash plates and all the oscillating masses of the system depending upon the angle of the phase difference.

Since the changes in the bending moments of the individual swash plate drives follow the same dynamic law, it is sufficient to determine the equilibrium of the system for any one instant.

In other words, in order to provide a complete dynamic balance for the described system, it is necessary that the system be balanced in two directions, namely, in the direction of the driving shaft and in the direction transverse to the shaft.

The system is balanced in the direction of the shaft by the proper selection of the weight of the rings, studs and pistons of the individual drives. We have discovered that in order to attain this balancing the weight of these parts should be made dependent from, or be made an angular function of, the angle formed by the inclined swash plates.

Let it be assumed that the desired angular phase difference is equal to $\alpha°$. Then the relative angle of inclination of two swash plates will be also $\alpha°$. In order to balance such system the weight of the wobbling rings and the masses reciprocated thereby should be selected depending upon this angle $\alpha°$ and should be determined by the formulae mass times sine $\alpha$ or mass divided by cosine $\alpha$. In the case of three swash plate drives, the question which of these two formulae is to be used, depends upon whether the weight of the two outer drives is determined depending upon the middle drive, or whether the weight of the middle drive is determined depending upon the weights of the two outer drives.

The system is balanced in the direction transverse to the shaft by arranging the relative positions of the studs reciprocating along arcs so that these studs are shifted relatively to each other depending upon the angle formed by the inclined swash plates.

In case of three adjustable drives, if the desired angular phase difference is $\alpha°$, and one of the drives which had originally a phase difference of 180° with respect to another drive, is to be shifted relatively to that second drive to the extent of $\alpha°$, then one of the outer drives should be advanced to the extent of $\alpha°$ relatively to the inner drive and the other outer drive should be set back relatively to the middle drive to the extent of $\alpha°$. As already mentioned, this advancing and retarding of the drives takes place by shifting the relative positions of the studs which connect the wobbling rings with the pistons.

It should be noted that the accelerations of these studs which are moved along lemniscate curves also depend upon said angle $\alpha°$, since the phase advancement of one drive relatively to another is equal to that same angle.

Therefore, theoretically speaking, in order to balance the system, those points of the ring of an outer drive which move along arcuate linear curves should be set back relatively to the similar points of the ring of the inner drive to the same extent to which the swash plate of said outer drive was advanced relatively to the swash plate of the inner drive, said extent being measured by the angle $\alpha°$. A reverse procedure takes place as far as the second outer drive is concerned.

The system is completely balanced when it is balanced in both directions in the described manner.

The invention will appear more clearly from the following detailed description when taken in connection with the accompanying drawings showing, by way of example, preferred embodiments of the inventive idea.

In the drawings:

Figure 1 is a vertical longitudinal section through a swash plate drive system constructed in accordance with the principles of the present

invention and having three swash plate drives, the phase difference of which is other than 180°.

Figures 2, 3, and 4 are cross sections along the lines 2—2, 3—3, and 4—4 of Figure 1, respectively.

Figure 5 is a horizontal section along the line 5—5 of Figure 1.

Figure 6 is a diagram showing vectors which represent bending moments caused by the movements of the masses of the individual swash plate drives;

Figure 7 shows projections of the vectors shown in Figure 6 upon the plane ZOY.

Figure 8 shows projections of the vectors shown in Figure 6 upon the plane ZOX.

Figure 9 shows projections of the vectors shown in Figure 6 upon the plane YOX.

Figures 10 and 11 are diagrams illustrating balanced systems each of which comprises four swash plate drives.

Figure 12 illustrates projections of the vectors shown in Figure 11 upon the plane ZOX.

Figure 13 shows projections of the vectors shown in Figure 11 upon the plane YOX.

The swash plate drive system illustrated in Figures 1 to 5 of the drawings comprises a main shaft A, operating the three swash plate drives indicated by the numerals I, II and III. The system is supported by the casing G which encloses it on two sides. The shaft A comprises two threaded portions which are situated on opposite sides of the casing G and which carry the two nuts M and $M_1$. Three swash plates $T_I$, $T_{II}$ and $T_{III}$ which are inclined relatively to the longitudinal axis of the shaft A to the extent of an angle $\alpha°$ and which have cylindrical end portions, are mounted upon this shaft. The inner ends of the two outer swash plates $T_I$ and $T_{III}$ engage firmly the two ends of the inner swash plate $T_{II}$. The outer ends of the two outer swash plates $T_I$ and $T_{III}$ engage sleeves or pressure pieces D and $D_1$ which are in contact with the nuts M and $M_1$. Due to this arrangement, the entire system is held together by the nuts M and $M_1$ which press the swash plates $T_I$, $T_{II}$ and $T_{III}$ one against the other; the swash plates $T_I$, $T_{II}$ and $T_{III}$, the sleeves D and $D_1$ and the nuts M and $M_1$ rotate along with the shaft A.

As shown more clearly in Figures 2 to 4, the swash plates may be shifted relatively to the shaft A when the device is not in operation and may be arranged at different angles relatively to each other.

A number of cylinders are arranged circumferentially around the shaft A. In the example illustrated in the drawings there are six cylinders $C_1$ to $C_6$, the longitudinal axis of each of these cylinders forming an angle of 60° with the longitudinal axis of an adjacent cylinder. Each of the six cylinders contains three pistons and each of these three pistons is operated by a different swash plate drive. The six pistons driven by the swash plate drive I are indicated by the symbols $KI_1$ to $KI_6$ in the drawings, while the pistons driven by the swash plate drive II are indicated by the symbols $KII_1$ to $KII_6$ and the pistons driven by the swash plate drive III are indicated by the symbols $KIII_1$ to $KIII_6$.

The three wobbling rings of the system are indicated by the symbols $R_I$, $R_{II}$ and $R_{III}$. Each ring is carried by a separate swash plate and is mounted upon bearings situated within grooves formed in the swash plate.

As shown more clearly in Figures 2, 3, and 4, each ring comprises six studs which are surrounded by swivel blocks movable along with the studs and situated within the pistons. The studs of the drive I are indicated by symbols $SI_1$ to $SI_6$, the studs of the drive II are indicated by symbols $SII_1$ to $SII_6$ and the studs of the drive III are indicated by symbols $SIII_1$ to $SIII_6$. The swivel blocks of the three drives are indicated by symbols $PI_1$ to $PI_6$, $PII_1$ to $PII_6$ and $PIII_1$ to $PIII_6$. The studs project through openings which are formed in the cylinders. The swivel blocks fit into openings provided in the pistons. In general, the openings of the cylinders and pistons should be sufficiently wide to permit the studs and the swivel blocks not only to reciprocate the pistons along straight lines but also to carry out a sidewise movement, whereby each point of a stud will follow the path of a lemniscate curve.

As has been mentioned already, there are two diametrically opposite points upon the circumference of each wobbling ring which carry out movements along linear arcs and have no sidewise movement. For practical purposes it may be assumed that there are two diametrically opposed studs upon each ring, which will have no sidewise movement. As shown in Figures 2, 3, and 4, inserts or pieces *h* are situated within two of the six pistons of each drive, in order to direct studs and swivel blocks reciprocating these pistons along arcuate curves.

Consequently, four of the six swivel blocks and four of the six studs of each drive will carry out a three-dimensional movement along a spherical lemniscate curve, the ordinate of which is constituted by the longitudinal axis of the shaft A, while the other two swivel blocks and the other two studs will describe linear paths.

In order that the described system be in equilibrium, it is necessary that it be balanced dynamically both in the direction of the shaft A and in the direction transverse to that shaft.

The dynamic balance in the direction transverse to the shaft A is provided by the relative positions of those swivel blocks and guides which are guided along linear paths through the insertion of the pieces *h* (Figures 2, 3, and 4). It is apparent from these figures that these studs and swivel blocks are radially shifted in relation to each other to the extent of an angle $\alpha°$ which is equal to the angular phase difference of the drives. In general, the relative positions of the linearly guided studs and the swivel blocks are determined by this angle and by the direction of rotation of the shaft A.

As shown in Figure 2 the studs $SII_1$ and $SII_4$ and the swivel blocks $PII_1$ and $PII_4$ of the drive II are guided along linear paths. As shown in Figure 3, the studs $SI_3$ and $SI_6$ and the swivel blocks $PI_3$ and $PI_6$ of the drive I are guided along linear paths. As shown in Figure 4, the studs $SIII_2$ and $SIII_5$ and the swivel blocks $PIII_2$ and $PIII_5$ of the drive III are guided along linear paths.

In the described construction, the swash plate drive I is set back relatively to the swash plate drive II to the extent of $\alpha°$ in the direction opposite to the direction of rotation, while the swash plate drive III is advanced relatively to the swash plate drive II to the extent of $\alpha°$. Therefore, there is a phase difference of $2\alpha°$ between the swash plate drive I and the swash plate drive III. The swash plate drive II has a phase difference of $\alpha°$ relatively to the swash plate drives I and III, namely, the swash plate drive II is advanced to the extent of $\alpha°$ relatively to the swash plate

drive I, and the swash plate drive III is also advanced relatively to the swash plate drive II to the extent of $\alpha°$.

If it is desired to change the described positions of the swash plates, the relative positions of studs and guides moving along linear paths should also be changed, in order to restore the balance.

The balancing of the system in the direction of the shaft A is carried out by balancing the bending moments to which the system is subjected, and which are indicated symbolically by vectors in Figures 6 to 9 of the drawings. In Figure 6 each vector represents a bending moment to which a swash plate drive is subjected; the relative positions of these vectors in space with reference to the coordinate axes XO, YO and ZO are also indicated in Figure 6. Figures 7, 8, and 9 show the projections of these vectors upon the planes ZOY, ZOX, and XOY, respectively. Each of the vectors is indicated by the letter N. As shown in Figure 6, the phase difference of the three vectors is measured by the same angle $\alpha°$ which in the example illustrated, is equal to 60°. The axis XO passes through the axis of rotation of the shaft A and of the swash plates $T_I$, $T_{II}$ and $T_{III}$ (Figure 1).

It is obvious from an examination of Figures 7, 8, and 9 that the vector components or projections are balanced in each of the three planes, since in each plane vectors having one direction are balanced by vectors having a different direction. Consequently, the entire system, indicated symbolically in Figure 6 is also balanced.

It is apparent from the above description that as soon as the required phase difference $\alpha°$ is determined, a constructor can design a completely balanced system by arranging those elements of the drives which are guided along linear paths, in the manner illustrated in Figures 2, 3, and 4 and by determining the weight of the rotating and reciprocating masses of the system by means of a simple calculation; the formulae for this calculation can be easily determined on the basis of the described vector diagrams.

Figures 10 and 11 are vector diagrams illustrating two swash plate drive systems each of which comprises four swash plate drives. Figures 12 and 13 show the components of the vectors illustrated in Figure 11, in the planes ZOX and YOX, respectively. Vectors shown in Figure 10 may be easily analyzed in the same manner. It is apparent from an examination of these vectors that both systems are completely balanced.

What is claimed is:

1. A swash plate drive system and the like, comprising at least three swash plate drives and a common shaft for said drives, each of said swash plate drives comprising a swash plate which is inclined relatively to said shaft and which is rotatable along with said shaft, a separate ring rotatably mounted upon each swash plate, means reciprocating along straight lines, means connecting said ring with the first-mentioned means, the rings of said drives carrying out an oscillatory-rolling lemniscate-like motion when the swash plates carrying said rings are rotated, the second-mentioned means transforming said motion of the rings into a reciprocatory motion of the first-mentioned means, and means connected with at least some of said swash plates and said shaft for adjusting the relative positions of said swash plates, whereby said swash plates may be offset at a desired angle relatively to each other, each of said rings having a diameter, the points of which reciprocate along arcs in the course of the lemniscate-like motion of said rings, the diameters of said rings being offset relatively to each other to the extent of an angle equal to the relative angle of inclination of the corresponding swash plates.

2. A swash plate drive system comprising at least three swash plates which have a relative angular phase difference, a common shaft, said swash plates being firmly connected with said shaft, a separate ring rotatably mounted upon each of said swash plates, whereby said rings do not participate in the rotation of said swash plates, but carry out lemniscate-like movements, each of said rings having a diameter, the points of which carry out a linear movement while the ring as a whole carries out a lemniscate-like movement, a plurality of separate studs firmly connected with each ring and movable along therewith, a plurality of reciprocating means, a plurality of connecting means connecting said pins with the first-mentioned means to drive the first-mentioned means, and guiding means contacting some of the second-mentioned means of each ring for guiding two of the studs of each ring along arcuate paths while the remaining studs of each ring carry out lemniscate-like movements along with said ring, said system being characterized in that the weight of the rings is a function of the angular phase difference of the swash plates to balance the masses of the system in the direction of the shaft, said system being further characterized in that the last-mentioned means of one swash plate are set off relatively to the last-mentioned means of another swash plate to the extent of the angular phase difference of these swash plates, and that said diameters of the rings are set off relatively to each other to the extent of the angular phase difference of the swash plates carrying these rings, whereby the system is balanced in a direction transverse to the shaft.

3. A swash plate drive system and the like, comprising at least three swash plate drives, a common shaft for driving said swash plate drives, each of said swash plate drives comprising a separate swash plate which is rotatable along with said shaft and which is offset relatively to another swash plate, a separate ring carried by each swash plate, a plurality of separate studs firmly connected with each ring, a separate swivel block connected with each stud, reciprocating means connected with said swivel blocks; and means for guiding some of the swivel blocks of each swash plate drive along linear curves, said rings carrying out a lemniscate-like movement when said swash plates are rotated, said system being characterized in that the weight of said rings, said studs, said swivel blocks and the first-mentioned means is a function of the angular phase difference of the swash plates, and that the amount of said weight is such that the masses of the rings, studs, swivel blocks and the first-mentioned means are balanced in the direction of the longitudinal axis of said shaft; said system being further characterized in that the second-mentioned means of each drive are offset relatively to each other to the extent of the same angle to the extent of which the corresponding swivel plates are offset relatively to each, whereby the masses of the rings, studs, swivel blocks and the first-mentioned means are balanced in the direction transverse to the longitudinal axis of said shaft.

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