FIG. 6.

Torque

angle of tilt (θ)

dθ

FIG. 7.

FIG. 8.
This invention relates to swash plate type hydraulic machines, whether pumps or motors.

In some types of swash plate machines, each piston bears on the swash plate through a slipper articulated to the piston or piston rod, and in all settings of the swash plate about its pivotal axis, other than the neutral or no stroke setting, the plane of the swash plate is inclined to the axis of the cylinder block. Consequently, the locus of the point at which the combined piston thrusts are deemed to act on the surface of the swash plate is not coincident with the pivotal axis and a mean resultant torque is applied to the swash plate which tends to restore it to the neutral or no stroke position. This imposes an increasing force on the swash plate as the latter is moved from the no stroke position.

The swash plate of a pump or motor is a relatively large and heavy body, and its pivotal axis is normally designed to lie in or near, and parallel to, the working surface on which the slippers bear. The centre of gravity of the swash plate is remote from the plane of this surface and hence torsional vibrations acting on the swash plate tend to displace the centre of gravity in directions normal to the axis of the pump shaft, so that heavy vibrations are set up in the trunnions. These vibrations impose relatively heavy fatigue loading on the trunnions which in turn transmit the vibrations to the frame or bed of the machine.

According to the present invention a swash plate machine has the axis of tilt of the swash plate off-set with respect to the point of intersection of the axis of rotation of the cylinder block and the plane of contact of the slippers with the swash plate in the direction for reducing the maximum torque required to tilt the swash plate during operation of the machine.

Preferably the axis of tilt passes through the centre of gravity of the swash plate so that the forces acting on the trunnions are substantially parallel to the axis of rotation of the cylinder block.

The amount of the offset of the axis of tilt may be fixed for a given machine, or provision may be made for adjustment thereof—for example, by mounting the trunnions in the machine frame by means of pairs of coating eccentric bushes, the bushes of each pair being relatively rotatable. If such provision is made the swash plate can be made to tend to assume any desired position between full stroke and no stroke, and the only torque which must be applied from outside to tilt the swash plate will be that necessary to overcome friction, the main torque being derived from the action of the pistons themselves. If no such provision is made for adjustment of the axis of tilt, the whole of the tilting torque will have to be applied externally of the swash plate, e.g. by a pair of rams acting near the periphery of the swash plate or by torque applied to the trunnions.

A practical embodiment of the present invention which is illustrative only thereof, will now be particularly described with reference to the accompanying drawings in which:

FIGURE 1 is a fragmentary axial section through a swash plate machine taken normal to the axis of tilt of the swash plate;

FIGURE 2 is a transverse section on the line II—II of FIGURE 1, some parts being shown in elevation;

FIGURE 3 is a schematic view of a slipper and adjacent parts;

FIGURE 4 is a diagram of forces acting on the parts shown in FIGURE 3 under one set of conditions;

FIGURE 5 is a diagram of forces acting on the parts shown in FIGURE 3 under another set of conditions;

FIGURE 6 is a graph relating tilting torque to the angle of tilt, and

FIGURES 7 and 8 are corresponding diagrams illustrating the effects of inclining the axes of the cylinders with respect to that of the cylinder block.

Referring first to FIGURES 1 and 2 of the drawings, the machine illustrated, which will be assumed to be a pump, consists of a main frame having front and back end plates 1, 2 clamped by four pillars 3 (FIG. 2). Each end plate 1, 2 carries a journal bearing 4, 5 respectively, for a short rigid drive shaft 6. Adjacent the bearing 5 in the back end plate 2, the shaft 6 is formed with a locking taper section 7 on which is locked a cylinder block 8. This block is drawn up on the taper by a backnut 9 on the shaft. The cylinder block 8 contains a number of cylinders 10, and a piston 11 in each cylinder is reciprocated under the control of a normally fixed swash plate 12 carried on trunnions 13 (FIG. 2) springing from side extensions or ears 12' of the swash plate. The common axis O of the trunnions 13 is shown in FIGURE 1 as lying in the plane of the working face of the swash plate.

The working face of the swash plate is recessed at 15a to accommodate an annular bearing pad 15 and an annular slipper plate 16. The latter is free to rotate under the frictional drag of slippers 17 each of which is engaged with a respective piston 11. For clarity of illustration in FIGURE 1, only one cylinder 10, piston 11 and slipper 17 is shown.

The swash plate 12, as already noted, is mounted on trunnions 13 and these are carried in bushes 18, 19 (FIG. 2) mounted in side walls 20, 21 of the pump casing. By counter-rotation of the bushes of each pair, the common axis O of the trunnions 13 can be offset with respect to the axis Q of the shaft 6 for the purposes of minimizing some of the effects of the reactions on the swash plate 12 from each piston 11 as it successively pumps during the delivery stroke and idles during the charge or inlet stroke, as will be described below. The bushes 18, 19 are locked in position by means of cap screws 22.

Referring now to FIGURE 3 of the drawings, where the trunion axis O is shown intersecting the axis Q of the shaft 6, and considering the forces acting between the swash plate 12 and a slipper 17, the swash plate acts on the slipper to apply a driving force to the slipper in a direction F normal to the face of the swash plate. If the face of the swash plate is at an angle other than 90° to the axis Q of the cylinder block, the direction F of the force will be inclined to the axis Q and will have
the same inclination to the axis $P$ of the piston 11, if $P$ and $Q$ are parallel. In other words, a point $f$ on the swash plate 12 at which the driving force $F$ acts is not coincident with a point $p$ on the swash plate through which the axis $P$ of the piston passes. If the swash plate 12 is at right angles to the axis $Q$ of the cylinder block, the point $f$ coincided with $p$ will be coincided at a point $m$ on the swash plate lying on a circle whose centre is on the swash plate pivot axis $O$ and whose diameter is equal to the pitch circle of the cylinders 10, or in other words, for a given value of $P$ the moment about $O$ will change as the angle of tilt changes.

The slippers 17 act in a manner analogous to connecting rods and cause the swash plate 12 to assume the no stroke position if the swash plate is pivoted at $O$ as shown in FIGURE 3. If, however, the swash plate is pivoted about an axis $O_3$ lying in a plane containing all the pivot centres $O$ of the slippers 17 and intersecting the cylinder block axis $Q$, the swash plate will tend to remain at any angle to which it happens to be tilted. It is not easy in practice to achieve this, owing partly to the increase in height of the ears 12 which is then necessary in order to accommodate the trunnion anchorages, and partly to the resultant lateral displacement of the main body of the swash plate 12. Both these factors lead to an increase in the clearance space necessary within the pump casing.

Where these requirements cannot be satisfied, therefore, a compromise may be adopted whereby the swash plate pivots about a point displaced so that the swash plate 12 tends to assume a mean angle of tilt within the normal working range. This reduces the torque required to bring the swash plate to any one desired working position.

FIGURE 4 shows diagrammatically the forces and moments acting on the swash plate 12, pivoted on a trunnion axis at $O$, due to two diametrically opposite pistons 11, which are, for convenience, shown at the top and bottom dead centre positions, although the conditions postulated may occur over a range of angles of rotation of the cylinder block.

The points $f$ and $f'$ at which the driving forces act on the slippers 17 will move in the same direction along a line (or parallel lines) on the face of the swash plate 12 as the latter is tilted. Thus a point $r$ on the swash plate midway between the points $f$ and $f'$ at which the resultant of the reaction forces of the slippers acts will vary as the swash plate is tilted. The torque on the swash plate due to the resultant reaction $R$ at the point $r$ will tend to bring the swash plate to the no stroke position at right angles to the axis of the shaft 6, i.e., so that the vectors $f$ and $p$ (or $f'$ and $p'$) will be coincident, and the point $r$ will lie on the pivot axis $O$. In other words the sum of the moments taken about $O$ for all the pistons will only be zero when the swash plate 12 is in the no stroke position.

In order to tilt the swash plate from the no stroke position, a considerable torque must be applied, the torque increasing as the angle of tilt $\theta$ of the swash plate is increased. By offsetting the pivot axis of the swash plate in the plane of its working face to a position $O_4$ about which the sum of the moments of the forces acting on the swash plate is zero when the swash plate is in a predetermined intermediate position between the no stroke and full stroke positions, the torque required to tilt the swash plate in the intermediate position to full stroke or no stroke can be reduced to a minimum. Preferably, the point $O_4$ is chosen so that the swash plate will tend to assume the position at which it is expected that it will most frequently operate. In this way the amount of energy required to control the angle of tilt $\theta$ of the swash plate 12 during normal operation can be reduced.

FIGURE 5 is a graph of mean torque required to hold the swash plate 12 at an angle $\theta$, plotted against $\theta$. Curve A is for a swash plate pivoting on an axis intersecting the axis $Q$ of the cylinder block. Curve B is for a swash plate pivoted on an axis at a perpendicular distance $Z$ from the cylinder block axis, the intercept $d_0$ being proportional to $Z$, and $\varphi$ is proportional to the displacement, measured along the cylinder block axis $Q$ (FIGS. 2-5), of the axis of tilt of the swash plate from the position $O$, in FIGURE 3. The curves A and B can be assumed to be straight lines if $\theta$ is small. The instantaneous reaction torque varies (due to the different number of cylinders discharging at any instant), the extent of the variation being shown by the dotted lines $a$, $a'$ and $b$, $b'$.

It can be seen from FIGURE 6 that if the pivot axis of the swash plate is adjustable, the torque required to hold the swash plate at any given inclination can be made zero, or alternatively the instantaneous torque can be made wholly positive or negative.

The number of cylinders 10 (FIG. 1) which, at any one instant, are discharging (or charging) varies as the cylinder block 8 rotates and the instantaneous value of the reaction force $R$ (FIG. 4) varies. Thus, referring to FIGURE 5 and assuming, for purposes of analysis, that the pivot axis is at $O'$, a varying torque is applied to the swash plate 12 tending to pivot the plate about the axis $O'$ and hence to displace the centre of gravity $G$ of the swash plate 12 in a direction normal to the axes $Q$ and $O'$ of the shaft 6 and trunnions 13, respectively. A varying force, acting in a direction normal to the shaft 6, is therefore set up in the swash plate 12, and this varying force sets up vibrations in the machine in a direction normal to the shaft.

However, if the trunnion axis is made to pass through the centre of gravity $G$ of the swash plate 12, the swash plate 12, cylinder block B, and trunnions 13 are subjected only to forces acting parallel to the shaft 6. That is to say, by balancing the swash plate 12 about the axis of the trunnions 13, vibrations normal to the shaft 6 are theoretically eliminated, whilst vibrations parallel to the shaft are not increased. In order to achieve these conditions in practice, the centre of gravity $G$ of the swash plate 12 is preferably brought to the desired position—for example, on the axis $O$, in FIGURE 4—by making the ears 12' (FIG. 1) which carry the trunnions 13 act as balance weights.

In the case of a swash plate pump in which the cylinder axes 10 are not parallel to the shaft 6, there will still be vibrations normal to the shaft even if the swash plate 12 is balanced about its axis of tilt $O$. Nevertheless, the effect of balancing the swash plate will be to reduce vibrations in a direction normal to the shaft and so reduce the total vibration in the machine.

The inclination of the axes of the pistons has the further advantage that, when the trunnion axis does not lie in the plane containing the centres $S$ of the slipper pivots, as shown at $O_1$ in FIGURE 3, the reaction torque tending to displace the swash plate is reduced. This can best be seen from a comparison of FIGURES 7 and 8.

In FIGURE 7, the angle $\phi$ between the cylinder axes $P$, $P'$ and the shaft axis $O$ is zero. When the angle of tilt $\theta$ of the swash plate is zero, the mean points of contact of two diametrically opposite slipers with the working surface of the swash plate 12 are at $K$, and $K_1$, respectively. When the swash plate is tilted by $\theta$, the mean points of contact move to $K_2$ and $K_2$, respectively, where the distance $OK_2$ is significantly less than the distance $OK_2^2$.

In FIGURE 8, however, where the cylinder axes $P$, $P'$ are inclined at $\phi$ to the shaft axis $O$, the initial mean points of slipper contact are $K$, $K_1$ move to $K_2$, and $K_2$, respectively, as $\theta$ increases from zero. It will now be noted, however, that the distance $OK_2$ is not substantially different from the distance $OK_2^2$. Hence, for a given value of $\phi$, it will normally be possible to select a corresponding value of $\phi$ for which the reaction torque will be zero.

From the foregoing it will be noted that, in a swash
plate machine according to the present invention, the axis of tilt \( \Omega \) of the swash plate 12 is offset with respect to the point of intersection of the axis of the shaft 6 and the working surface of the swash plate in a direction, and through a distance, such that the reaction torque about the axis of tilt is zero or a minimum.

We claim:

A swash plate machine comprising a casing; a shaft mounted in bearings in said casing; a cylinder block secured on said shaft and having a plurality of cylinders disposed equiangularly around the axis of said shaft on a common pitch circle; a swash plate embracing said shaft; a piston working in each cylinder; and a slipper pivotally connected to each piston and slidably engaged with the working surface of the swash plate; coaxial trunnions projecting laterally from the swash plate; a first eccentric bearing bush surrounding each trunnion; a second eccentric bearing bush snugly embracing the first eccentric bush and rotatably received in the casing; and means for locking the eccentric bushes in a desired angular position relative to each other whereby the common axis of the trunnions can be so located as to reduce to zero the reaction torque in the swash plate about the trunnion axis in any selected position of adjustment of the swash plate.

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