

14

2098282

- 1 -

Swashplate Apparatus with Slipper Cavitation Erosion Control and Impact Reduction.

This invention relates to a cavitation erosion control and impact reduction in a piston type hydraulic apparatus.

10

In hydraulic piston type units, pistons are caused to slide within bores of a rotating cylinder block and act against a swashplate. In so doing, mechanical energy is transformed into fluid power or conversely fluid power
15 can be converted into mechanical energy by reversing the operation. Simply stated, a hydraulic piston type unit of the type described, may be operated as a pump or as a motor. To accomplish this, it is necessary to transfer fluid pressure from one level to another. Where the
20 hydraulic unit is operated as a pump, fluid pressure is raised from a low level to some higher level, whereas, when the hydraulic unit is operated as a motor, fluid

pressure is received at a high level and discharged at a lower level. In both of these types of energy transfer situations, it is necessary that a pressure level change or transition take place approximately each 180° of rotation or twice each revolution. It is at these pressure level changes or transitions that slipper-swashplate interface problems occur. A typical problem is that of impact loading of the slipper on the face of the swashplate evidenced by scuffing of the swashplate by the slipper. Another problem is that of erosion typical of that associated with cavitation. The invention to be described hereinafter provides a simple and efficient remedy for these problems.

Historically the problem of cavitation erosion control has been treated in a number of patents to be discussed hereinafter which show swashplates, hydraulic pumps and motors. A number of these patents recognize the cavitation erosion problem that exists between the main ports of a valve plate and ports in the face of a rotary mounted cylinder block positioned in sliding engagement with the valve plate provided with the main ports. The main ports of the valve plate are generally of a kidney shape and experience either high or low pressure. Movement of the cylinder block containing pistons, alternately exposes the ports in the cylinder block to either high or low pressure.

U.S. patent to Slimm, No. 3,369,458, which is directed to a hydraulic apparatus recognizes that there is a sudden pressure change problem between ports 29, Fig. 1 of a rotary cylinder block 25 and fixed high and low pressure ports 33, 34 in a valve plate. An erosion problem that arises because of the sudden pressure changes is relieved by providing an auxiliary port 54, (Fig. 4) in the fixed valve plate 24. The auxiliary port

54 communicates with restricted flow passages 50 and 55 through a check ball valve 58 (Fig. 2 and Fig. 4) in a bridge 52 between the high and low pressure ports. The Slimm hydraulic apparatus has a slipper 41 but makes no provision for slipper-swashplate erosion control.

U.S. patent to Moon et al No. 3,585,901, which is directed to a hydraulic pump, provides for noise reduction at a valve plate 52 and cylinder block 14 port plate 51 interface (Fig. 1). The presence of noise is frequently associated with erosion and cavitation wear problems. Moon et al accomplishes noise reduction by the provision of "fishtails" 76, 86 adjacent the leading edge of high and low pressure ports in the valve plate. The fishtails provide orifices that control the rate of bulk modulus flow. This results in a reduction of wave fronts and a decrease in noise and concomitant wear. Moon et al includes a slipper 34 that has a passage through the slipper 34, not referenced, to provide lubrication to the slipper 34 and swashplate bearing surface interface 32. Moon does not recognize the problem of erosion at the slipper-swashplate interface and entertains no remedy.

U.S. Schauer patent No. 4,096,786, directed to a rotary fluid energy translating device, is in the same class of devices as the patents to Slimm and Moon et al in that noise level reduction is a primary feature of the invention and contemplates the inclusion of structure to reduce the noise level of the device during operation by pressure control within the device during transition between high and low pressure ports of the device and, particularly, by means of employing trapped volumes of fluid to obtain intermediate pressure levels during the transition and by varying the trapped volumes for a controlled rate of pressure change dependent upon the volume of fluid in the device subject to pressure

17
4
transitions. The Schauer patent neither recognizes the
slipper erosion problem nor provides any means that would
inherently treat the problem.

5 U.S. patent to Sperry No. 1,714,145, directed to a
crankless engine, teaches the use of radial grooves 20 in
a slipper ring 15 to provide a lubricant flow path to
reduce friction between a slipper ring 15 and swashplate
11 (Fig. 2). Sperry does not provide a lubrication path
through the pistons 46 as will be described hereinafter
10 with respect to the subject invention.

15 U.S. patent to Alexander No. 3,996,806, involves a
hydrostatic transmission with oscillating output which
shows in Fig. 1, a rocker arm 30, that carries a
plurality of pistons 40. Each piston is provided with a
slipper shoe 54 riding on the surface of a cam plate 14.
The cam plate is provided with a plurality of passages 56
that communicate with a balance pad 32 on one side of the
cam plate 14 as well as the slipper shoe side. The ball
44 and spring 46 act as a check valve and are involved in
20 the pumping of lubricant to balance pad 32. The pressure
on either side of the cam plate 14, i.e. at the slipper
interface with cam plate and balance pad with the back of
the cam plate, "equalize the load on the front and back
of the cam plate" (column 2 lines 3 to 5). The Alexander
25 patent does not feature venting of a slipper to reduce
cavitation and erosion wear as taught in the
specification that follows.

The present invention provides a piston type rotary hydraulic apparatus that includes a rotary cylinder block mounting at least one piston for reciprocal movement therein, port plate means cooperating with the rotary
5 cylinder block to port fluid at first and second fluid pressures to and from the cylinder block on rotation of the cylinder block relative to the port plate, the or each piston having a slipper coupled thereto at one end thereof for sliding engagement with a swashplate and an
10 internal passage extending from one end to the other end thereof to allow fluid from the port plate means to communicate in use through an opening in the slipper to the interface between the slipper and the swashplate, wherein the swashplate includes at least one vent passage
15 having one end thereof opening at the slipper-swashplate interface and the other end opening to an environment in which the ambient pressure is less than the first and second fluid pressures thereby to allow energy dissipation and provide reduced cavitation erosion and
20 load impact effects in use at the slipper-swashplate interface.

The swashplate has a surface upon which the slipper interfaces and the slipper is mounted for movement along
25 the swashplate surface. The first and second fluid pressures are ported in use alternately to and through openings in the slipper to the interface between the slipper and the swashplate.

30 The swashplate advantageously has a pair of vent passages of different sizes. Each of the vent passages has one end thereof opening at the slipper-swashplate interface and the other end thereof opening to an environment in which the ambient pressure is lower than either the first
35 or second fluid pressures thereby to

allow energy dissipation and provide reduced cavitation erosion and load impact effects at the slipper-swashplate interface.

5 In the preferred embodiment of the larger of the vent passages is associated with the lower of the first and second fluid pressures and the swashplate is characterized by the presence of high and low pressure interface regions as a consequence of the alternate delivery of the fluid at the first
10 and second pressures.

The vent passage openings are advantageously located at or near the entrance end of each of the interface regions with the vent passage opening associated with the high pressure interface
15 region advantageously closer to the entrance end of the interface region than the vent passage opening associated with the low pressure interface region.

Brief Description of the Drawings

Figure 1 is a partial cross-section of a hydraulic apparatus that embodies the invention;

5

Figure 2 is a view of a valve member of the hydraulic apparatus of Figure 1 taken along the line 2-2 in Figure 1;

10 Figure 3 is a longitudinal cross section of a piston and slipper assembly employed in the hydraulic apparatus of Figure 1;

Figure 4 is a view of the swashplate used in the
15 invention of the hydraulic apparatus of Figure 1 taken along the line 4-4 in Figure 1 shown with the slippers removed;

Figure 4A is a cross-sectional view taken along the line
20 4A-4A of Figure 4; and

Figure 5 is a view of a prior art swashplate that evidences impact. _____

21
8.
loading wear as well as cavitation erosion scuffing.

Best Mode for Carrying out the Invention

Reference is now made to Figure 1 that illustrates a hydraulic drive 10 particularly suitable for use in a constant speed drive for aircraft, such as that disclosed in the copending Cordner application Serial No. 932,808, filed August 11, 1978, and assigned to the same assignee as the present invention.

The hydraulic drive 10 consists generally of a variable displacement hydraulic unit 11 and a fixed displacement hydraulic unit 12 shown here in dotted outline. Either of the hydraulic units 11 and 12 may be operated as a pump or a motor depending upon control conditions with the associated constant speed drive. Gears 13 and 14 operate either as input or output gears depending upon displacement of hydraulic unit 11 and the torque transfer in a mechanical differential (not shown) conventionally provided in constant speed drives.

Gears 13 and 14 are integral parts to shafts 22 and 23. Shaft 22 is supported on bearings 16 and 18. Shaft 23 is supported by bearings 17 and 19 in the manner shown via a spline connection to a tubular shaft (unreferenced) interposed between the right hand end of shaft 23 and bearing 19. The bearings 18 and 19 are roller bearings seated within a common port plate or valve member 24, and the bearings 16 to 19 support the hydraulic units 11 and 12 within the housing 21. As noted above, gears 13 and 14 and the drive shafts 22 and 23 deliver torque to and from the respective hydraulic units 11 and 12. The valve member 24 has generally arcuate or kidney shaped inlet and discharge passages or ports 25 and 26 as shown in Figure 2. The

section illustrated in Figure 1 shows only arcuate passage 26, which passage 26 is connected via a conduit 27 to what has been designated as a low pressure fluid source 28. The valve member 24 with its arcuate ports 25, 26, allows for the delivering of fluid in a closed circuit fashion between the hydraulic units 11 and 12.

Hydraulic unit 11 includes a rotary cylinder block 31 with a plurality of axially disposed cylinder bores 32 therein formed in annular array around the axis 33 of shafts 22, 23. Axially disposed cylinders 32 communicate with the ports 25, 26 in valve member 24 through passage 34 at the forward end of the cylinder bores. Formed at the other end of the cylinder block 31 is a central axial annular projection 36 extending rearwardly therefrom and a splined bore 37 therein interengaging splines 38 on drive shaft 22, so that the cylinder block 31 rotates with drive shaft 22 and torque may be transmitted therebetween.

Pistons 39, 41 are reciprocally mounted within each of the cylinder bores 32, 35. The piston 39 has a spherically projecting end 43 and the piston 41 has a spherically projecting end 42. Projecting end 42 carries a slipper 44, and projecting end 43 carries a slipper 46. Each of the slippers 44, 46 has a spherical socket 47 such as shown in detail in the longitudinal section of Figure 3, in respect of piston 41. The spherical socket 47 in cooperation with the spherical end 42 allows for pivotal movement therebetween. Each of the slippers 44, 46 have bearing surfaces 45, 48. These slipper bearing surfaces 45, 48 slidably engage a swashplate or cam surface 61 of a swashplate or cam member 60.

The swashplate or cam 60 which produces reciprocating motion of the pistons 39, 41 is pivotally

mounted by trunnions (not shown).

Reference is now made to Figure 3 wherein the piston 41 is shown in greater detail. The piston 41 is seen to consist generally of an integral elongated body member 50 surrounded by a cylindrical cover member 51. The integral body member 50 is generally cylindrical and has a flat radial surface 53 at one end thereof which constitutes a major portion of the working face of the piston 41. As noted earlier, in the other end of the integral body member 50 the spherical projection end 42 is formed. Much of the force of the fluid in the cylinder bores 32, 35 is transferred through the integral body member 50 to the swashplate or cam member 60 as shown in Figure 1.

A fluid passage 54 is centrally disposed in the generally cylindrical body 50 and opens at one end to the radial surface 53 and at the other end to the spherical surface of the projection end 42 as can best be seen in Figure 3.

The piston 41 and slipper 44 assembly of Figure 3 illustrates at the right hand end thereof the presence of fluid under pressure, P_1 or P_2 as evidenced by the arrows directed to the radial surface 53. At the left hand end of the piston 41 and slipper 44 assembly, there is illustrated fluid under pressure P_1' or P_2' as evidenced by the arrows directed to the slipper bearing surface 45. Pressure P_1' and P_2' at the slipper 44 end are slightly less than P_1 and P_2 due to the pressure drop through the internal passage 54 and orifice as shown. As the cylinder block 31 of Figure 1 rotates about its axis, the pressure in the axially disposed cylinder bores 32 and 35 will change from P_1 to P_2 and then back to P_1 during each revolution of

the cylinder block. This pressure change, as the piston porting moves across the surface areas 70, 71 of the swashplate surface 61, can best be appreciated by a review of the illustration of Figure 4.

5 Referring back to Figure 1, and keeping in mind
Figure 4, it can be seen that as the cylinder block 31
rotates with respect to swashplate 60, fluid enters the
cylinders associated with the pistons moving down the
swashplate surface 61 from one of the ports in the valve
10 member 24, and fluid is expelled from the cylinders
associated with the ports moving up the swashplate
surface 61 to the other port in the valve member 24. The
fluid entering or leaving the cylinders may be either
high or low pressure fluid. A coil compression spring 63
15 is provided for resiliently biasing the cylinder block 31
into engagement with the valve member 24 to maintain an
effective sliding seal therebetween. Spring 63 surrounds
the drive shaft 22 and is received within a central
recess 64 in the cylinder block 31. One end of the
20 spring 63 engages a spring seat washer 65 which in turn
is restrained against axial movement by a shoulder
defined by the inner ends of splines 38 on the drive
shaft 22. In this manner the spring 63 reacts against
the drive shaft 22 and through bearing 16 to the drive
25 housing. The other end of spring 63 engages an annular
spring seat 66, axially fixed with respect to the
cylinder block 31 by a suitable snap ring 67 in a groove
not referenced in central recess 64. In this manner, the
spring 63 resiliently urges the cylinder block 31 into
30 engagement with the valve member 24.

In Figure 4 the view of swashplate or cam 60 reveals the swashplate surface 61 on which there is shown in dotted outline arcuate kidney shaped interface regions 72, 73 defining discrete and different portions that

correspond with high or low pressure provided by kidney shaped arcuate high pressure port 25 and kidney shaped arcuate low pressure port 26 as shown in Figure 2.

The outline 74 of a slipper is also shown in dotted outline moving from a low pressure (LP) P_1 interface region 73 into the surface space 70 adjacent high pressure (HP) P_2 interface region 72.

The pressure change as noted earlier as a slipper moves from one region 73 to another region 72 takes place rather abruptly, i.e. in microseconds, producing erosion and/or impact loading. In accordance with the invention, locating energy dissipating orifices or openings 76, 77 in the swashplate face where the pressure transitions occur, prevents the detrimental effects of both erosion and impact loads. The location and size of the orifices 76, 77 is as shown in Figure 4 and these are for a unit which performs either as a pump or a motor. It should be understood that in the practice of the invention, the vent opening or orifice 77 associated with the lower of the pressure sources, P_1' is preferably larger than the orifice 76 associated with the high pressure source P_2' . It is also important in the practice of the invention that in order to obtain optimum results, the vent passage or orifice 76 associated with the high pressure P_2' interface region 72 be always closer to the entrance end of the high pressure interface region than the vent passage opening or orifice 77 associated with the low pressure P_1' interface region 73.

In Figure 4A the section shown illustrates how the orifice 76, or vent opening as it may be termed, connects with a passageway 78 which passageway opens at 79 to an ambient pressure P_3 which is lower than either P_1 , P_2 or P_1' , P_2' . The ambient pressure P_3 is the

internal pressure of the enclosure in which the hydraulic unit is mounted.

5 The use of each of the vents or orifices 76, 77
differs in achieving resolution of the problem. In
operation, when the cylinder block of Figure 1 is
rotating in a clockwise direction as is indicated by
10 slipper dotted outline 74 in Figure 4, the pistons 39, 41
in the cylinder block will, in succession, move from
communicating with the low pressure ($LP-P_1$) porting
kidney 26 in the valve member 24 to having access with
the high pressure ($HP-P_2$) porting kidney 25. When
communication is made with the $HP-P_2$ porting kidney 25,
the piston and cylinder bore are sealed from the $LP-P_1$,
15 porting kidney 26. This produces a sharp rise in
pressure at the flat radial surface 53 of the piston 41,
as well as in the communicating passage 54 in the center
of the piston 41 and at the slipper face 45, and an impact
load results at the slipper 44 and swashplate surface
61. An additional effect to be considered is the
20 collapsing or implosion of minute voids in the fluid
which exist due to entrained gases. This implosion
produces erosion of the surfaces containing the volume of
fluid held between the slipper surface 45 and swashplate
surface 61. The effect of impact and erosion can best be
25 seen by the wear or scuff mark 79 in the prior art
swashplate of Figure 5. The high pressure vent or
orifice 76 and passageway 78 allows this volume of fluid
to communicate with a volume of fluid at the lower
pressure, P_3 , as shown in Figure 4A. This venting
30 dissipates a sufficient amount of energy to prevent any
of the deleterious erosion wear and dampen the impact
effect.

The location of the low pressure vent or orifice 77
is in the proximity of 180° of arc from high pressure

vent 76. A discussion of the size of each orifice has been set forth hereinbefore. As the slipper moves from the high pressure interface region 72 and across the surface area 71 and enters the low pressure interface region 73, another pressure transition takes place. The pistons 39, 41 in the cylinder block 31 will, in succession, move from communicating with the high pressure kidney shaped port 25 in the valve member 24 to making communication with the low pressure kidney shaped port 26. When communication is made with the low pressure kidney shaped port, the piston and bore are sealed from the high pressure kidney shaped port 25, and a sharp drop in pressure occurs at the flat radial surface 53 of the piston 41 in the communicating passage 54 in the center of the piston 41, and at the slipper face 45. Impact loading and cavitation follow this pressure transition in the form of dynamic instabilities.

At this point, the sequence of events differ from that which occurs with orifice or vent 76. Normally, impact loading and cavitation erosion do not occur when transitioning to a lower pressure. The problem develops because the piston 41 slipper 44 assembly and the fluid act as a spring mass system. When the end pressure is quickly changed, as it occurs here, the result is likened to releasing a preloaded spring mass system; the inertia causes the spring to go beyond its free state dimension. If the spring mass system is in compression prior to release, inertia will cause it to extend upon release past the free state length, momentarily, into a state of tension. One or more oscillations may occur before the system comes to rest. In a hydraulic environment, this over extension results in a momentary low pressure or possibly a partial vacuum lower than the P_1 pressure. Bubble growth and subsequent cavitation bubble collapse

are inherent in this mechanism. When the fluid pressure under the slipper bearing surface or face returns to P_1' , it does so very quickly producing cavitation erosion.

5 Figure 5 illustrates the erosion and impact loading wear that appears as a consequence of this movement. The series of scuff or wear marks 80, 81, 82 indicate that the system oscillates several times before a state of rest occurs. Each oscillation produces an impacting of
10 the slipper on the swashplate face or surface 61.

 The installation of the vent or orifice 77 eliminates the formation of an extremely low pressure area preventing cavitation erosion and also provides a dampening effect thereby preventing the aforementioned
15 oscillations and attendant adverse wear problems.

CLAIMS:

1. A piston type rotary hydraulic apparatus that includes a rotary cylinder block mounting at least one piston for reciprocal movement therein, port plate means cooperating with the rotary cylinder block to port fluid at first and second fluid pressures to and from the cylinder block on rotation of the cylinder block relative to the port plate, the or each piston having a slipper coupled thereto at one end thereof for sliding engagement with a swashplate and an internal passage extending from one end to the other end thereof to allow fluid from the port plate means to communicate in use through an opening in the slipper to the interface between the slipper and the swashplate, wherein the swashplate includes at least one vent passage having one end thereof opening at the slipper-swashplate interface and the other end opening to an environment in which the ambient pressure is less than the first and second fluid pressures thereby to allow energy dissipation and provide reduced cavitation erosion and load impact effects in use at the slipper-swashplate interface.
2. An apparatus according to claim 1, wherein the swashplate has two vent passages.
3. An apparatus according to claim 2, wherein the vent passages are of mutually different sizes.
4. An apparatus according to claim 3, wherein the two vent passages are each in axial alignment with a respective port of the port plate, the larger sized vent passage being aligned with the port plate port that is at the lower of the first and second fluid pressures.
5. An apparatus according to claim 4 wherein each port



20

- 17 -

in the port plate is arcuate and has an entrance end for initially porting fluid at the respective first or second hydraulic pressure to and from the cylinder block on rotation of the cylinder block in the intended direction of rotation in use, and each vent passage is aligned near the entrance end of its associated pressure plate port.

5 6. An apparatus according to claim 5, wherein the vent passage associated with the port plate port at the higher fluid pressure in use is aligned closer to the entrance
10 end of its port plate port than is the vent passage associated with the port plate port at the lower fluid pressure.

7. A piston type rotary pump or motor substantially as described herein with reference to the drawings.
