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RESEARCH INTO THE INFLUENCE OF MECHANICAL LOSSES IN THE PLUNGER PAIR ON THE PERFORMANCE OF THE HYDRAULIC DRIVE

Viunyk O., Eng.
Komar A.S., Eng.
Dyachenko I., student
Dmytro Motornyi Tavrija State Agrotechnological University, Zaporizhzhia, Ukraine

Problem Statement. The work is part of a series of articles devoted to increasing the durability of plunger pairs of axial piston pumps. The structural parameters that affect the mechanical losses of an axial piston hydraulic pump include the wear of parts in the following combinations: "annular heel support - cradle support" (for a hydraulic pump) and "plunger block sleeve". Let us consider the working hypothesis that the wear of the annular support causes mechanical losses that affect the performance of the hydraulic drive. Let us conduct a preliminary analysis of the technical condition of the annular heel support in operating conditions at a qualitative level, and also consider the operating conditions of the plunger pair [1 – 3].

Primary Research Materials. As a result of an organoleptic examination of the piston heel of an axial piston hydraulic pump, which was repaired, clear scratches were found, caused by hydroabrasive wear of the ring support and, as a result of this wear, traces of crushing of the ring support as a result of a malfunction of the hydrostatic bearing. This state of affairs is due to the fact that during the operation of the plunger pair, its parts perceive significant loads from the action of the main forces, which are schematically presented in Fig. 1 [4].

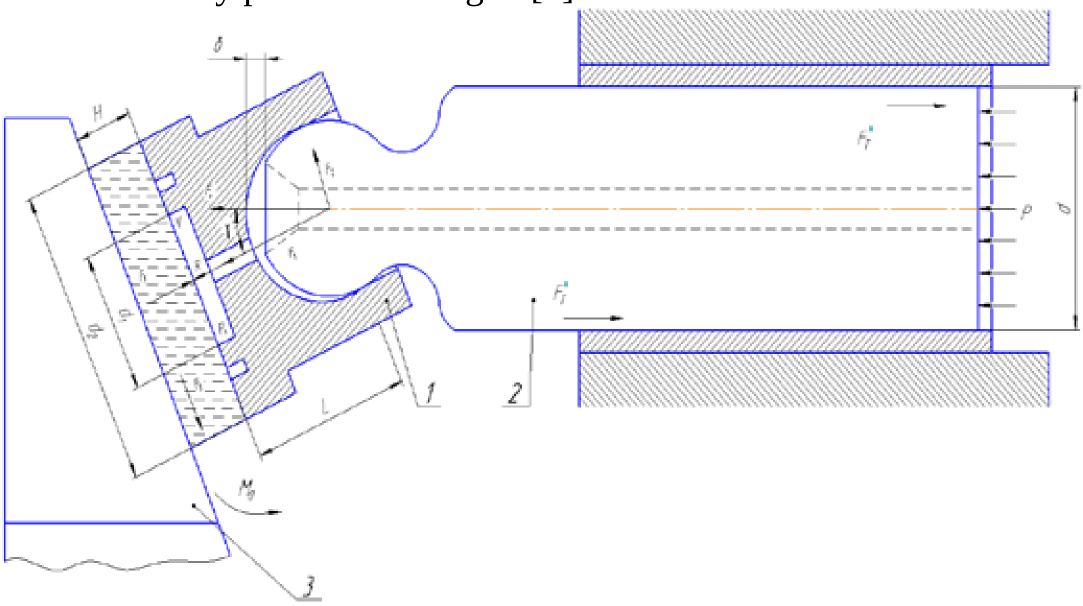

Fig. 1. Scheme of operation of a hydrostatic balanced support:1 – plunger heel; 2 – plunger; 3 – inclined washer, 4 – sleeve.

Let us consider the forces acting on the plunger, heel and sleeve of the block in accordance with (Fig. 1): $F_{жс}$ – the force is caused by the action of the working fluid on the end of the plunger (decomposed on its spherical support into a force that presses the plunger heel against the inclined washer F_1 and tangential force F_2, which determines the torque of the block; F_p – the force that pushes the plunger heel away from the swash plate (or hydraulic pump cradle) and provides hydrostatic support for the plunger heel on the inclined surface of the swash plate.; F_T – friction force in the coupling "ring support of the heel - support of the cradle" (for a hydraulic pump); F_T' – friction force friction force in the coupling "block sleeve - plunger"; $F_и, F_ц$ – inertial and centrifugal forces acting on the plunger, heel, separator; F_C – force of the springs on the separator to fix the plunger heel.

The effect of inertial $F_и$ and centrifugal forces $F_ц$ on the plunger is not significant and is approximately 2% of the acting force [5, 6]. In addition, the forces $F_и$ i $F_ц$ mutually compensated with force F_C, which is created by the separator springs. It is obvious that the mechanical losses will depend on the friction forces F_T i F_T' in the conjunction "ring support of the heel - cradle support", as well as "block sleeve - plunger".

At the nominal technical condition of the heel, a liquid lubrication regime takes place between the friction pairs, which ensures the absence of direct contact of metal surfaces. In this case, the friction force does not depend on the state of the friction surfaces, but is determined only by the internal properties of the lubricant [6]:

$$F_T = - t \times s \frac{W}{H}, \qquad (1)$$

where t – dynamic viscosity of a liquid; s – area of friction surfaces; W – speed of movement of friction pairs; H – working fluid layer thickness.

However, during operation of the hydraulic drive, abrasive particles of various sizes get into the parts operating in the “heel ring support - inclined washer” and “heel ring support - cradle support” couplings, which are pressed into the softer surface of the brass or bronze heel, forming hydroabrasive channels of various depths and profiles.

The presence of these channels leads to a redistribution of the working fluid flow in the hydrostatic bearing, violates its axial rigidity and creates prerequisites for the occurrence of non-parallelism between the heel ring support and the cradle or inclined washer support [7 - 9].

The non-parallelism of the surfaces of the parts in the “heel ring support - cradle support” coupling during operation leads to the occurrence of boundary lubrication conditions, when some areas of the working surfaces of the mating parts have metal contact. Under boundary lubrication conditions, the friction force can be considered as the force of dry friction at the peaks of irregularities and liquid friction in the cavities formed by the profile of the end surface of the annular support. [6]:

$$F_T = f\cdot\left(P\cdot S_T + \tau\,\frac{\omega}{H}\cdot S_M\right), \qquad (2)$$

where f – friction coefficient for boundary conditions; S_T – area where solid bodies come into contact; H – thickness of the lubricant layer in the channels that are formed as a result of wear; S_M – area where the lubricant layers shift.

Further wear of the annular support of the plunger heel ends with a transition from boundary friction conditions to an increase in the dry contact areas between the surfaces of the thorn.:

$$F_T = \varphi\cdot F_1, \qquad (3)$$

where φ – dry friction coefficient; F_1 – the force that presses the plunger heel against the friction surface.

A change in the operating conditions of the parts in the connection leads to an increase in the friction force and is manifested by a violation of the thermal regime of their operation.

An increase in the temperature regime of the parts in the connections "annular heel support - cradle support" for an axial-piston hydraulic pump, and "annular heel support - inclined washer" for a hydraulic pump, ultimately leads to complete crushing of the annular heel support with subsequent rolling of its output channel, which ensures the supply of working fluid to the heel and the operation of the hydrostatic bearing as a whole (Fig. 3, 4).

Fig. 3. Common type of plunger heel wear

Fig. 4. Complete wear of the heel ring support with rolling of the hydrostatic bearing hole

The operation of the connection parts under such conditions is accompanied by a sharp increase in the overturning moment. M_{Π}, which is defined by the expression:

$$M_{\Pi} = F_{T} \cdot l , \qquad (4)$$

where M_{Π} – moment of force directed to tip the plunger; l – height of the center of the spherical support of the plunger.

The increase in the overturning moment is the main reason that leads to the destruction of the plunger heel bearing (Fig. 5). The heel breaking out of the plunger bearing leads to a sudden emergency failure, because the direct contact of the spherical surface of the plunger with the inclined washer leads to the seizure of metals, which causes the jamming of the pumping unit of the axial-piston hydraulic machine.

Fig. 5. Heel separation from the plunger bore

Thus, the considered relationship between the wear of the heel ring support and the operability of the hydraulic drive shows that it leads to disruption of the hydrostatic bearing in the connection, which causes an increase in friction forces, a change in the temperature regime, which during operation leads to mechanical losses in the units, significant structural changes and geometry of the heel ring support and ends with an emergency failure as a result of the plunger jamming in the block sleeve. To confirm this working hypothesis, there is a need to conduct experimental studies that allow determining the relationship between the technical condition of the heel ring support and the temperature regime of the connection.

At the same time, the conducted studies have shown that one of the measures that will allow avoiding an emergency failure caused by wear of the heel ring support and jamming of the plunger in the sleeve is to reduce the friction forces in the contact of the plunger with the sleeve at the moment of its skew, and the duration of this contact. This can be done by structural changes to the block sleeve, which will reduce the action of forces in the contact zone of the plunger with the sleeve during its skew due to damping of vibration loads and absorption of shocks by using elastic-damping elements in the sleeve design.

The conducted studies show that the presence of tangential forces that arise when the heel slides along the support during the rotation of the block causes the plunger to "skew" in the sleeve, which leads to characteristic wear of parts and causes an increase in mechanical and volumetric losses, and in the future can lead to jamming of the plunger in the sleeve and, as a rule, an emergency failure.

To prevent this failure, it is recommended to make a constructive change to the block sleeve, which will reduce the action of forces in the area of contact of the plunger with the sleeve during its skewing due to damping of vibration loads and absorption of shock loads.

The proposed design of the sleeve is shown in Fig. 6.

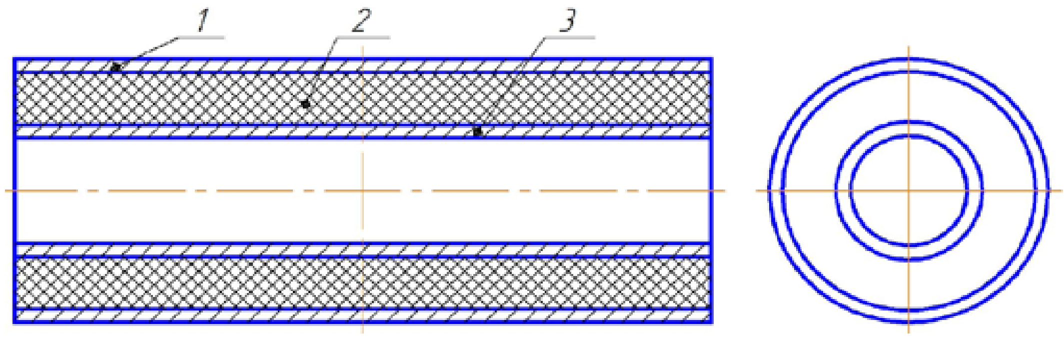

Fig. 6. Block sleeve design: 1 – outer sleeve; 2 – elastic-damping element; 3 – inner sleeve

The sleeve consists of an outer 1 and an inner 3 sleeves, which are interconnected by an elastic-damping element 2.

The proposed design of the sleeve works as follows. When the plunger is skewed, friction forces arise at the points of contact between it and the sleeve, which increase due to an increase in the overturning moment, which is caused by tangential forces that arise when the heel slides along the support during rotation of the block. The increase in friction forces between the plunger and the sleeve leads to an increase in the pulsation of the working fluid and, as a result, vibration loads. To dampen the latter, an elastic-damping element 2 is placed between the inner 3 and outer 1 sleeves, which deforms and absorbs wave energy.

In addition, damping reduces the duration of contact between the sleeve and the plunger when they are in the zone of maximum tangential forces, which significantly improves the operating conditions of the mating parts, increases the reliability of the units, and prevents a decrease in the number of emergency failures.

Conclusions. Analytical studies of the influence of wear of the annular support of the plunger heel on the performance of the hydraulic drive, due to the growth of mechanical losses, allow us to draw the following conclusions:

1. Analysis of the forces acting on the heel and plunger, as well as the technical condition of the annular support of the plunger heel, showed that

the growth of its wear violates the axial rigidity of the hydrostatic bearing and is accompanied by non-parallelism between the friction surfaces, which leads to a change in the operating conditions of the connection, the transition from liquid friction through the limit to dry and ends with an emergency failure due to the heel digging out from the plunger jamming.

2. Reducing the number of emergency failures caused by jamming of the plunger in the block sleeve is possible due to structural changes to the block sleeve, which will reduce the action of forces in the contact zone of the plunger with the sleeve during its skewing due to damping of vibration loads and absorption of shock loads.

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