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KINEMATICS OF RELATIVE DISPLACEMENTS OF CONTACT SURFACES OF THE PORT PLATE UNIT OF AN AXIAL PISTON HYDRAULIC MACHINE

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Abstract

Modern precision hydraulic drives are widely spread in mechatronics, robotics and heavy machinery. High energy consumption allows to minimize the whole drive mass-dimensional characteristics. However, such benefits require hydraulic machines to have high efficiency.

This work presents the research of kinematics of the port plate unit, as friction forces and leakages in the cylinder block – port plate interface are significant for the axial piston swash plate hydraulic machine efficiency. The dependences obtained allow computing the hydrodynamics of this unit and also to conduct further research in order to improve the whole hydraulic drive performance.

Keywords: Kinematics; Hydraulic machines; Axial piston machine; Machinery; Hydraulic drive.

1. The port plate unit influence on the axial piston machine performance

Friction forces and volume losses in the units of hydraulic machines of a high-precision hydraulic drive have a significant impact on the characteristics of the entire system, in particular on the dead zone and, consequently, its control range [1].

One of the critical components of axial piston hydraulic machines is the port plate [2], [3], [4], [5]. Figure 1 shows a cylinder block unit (right) and the port plate unit (left).

Under nominal operating conditions, the port plate is pressed against the end surface of the cylinder block. However, when straining the hydraulic machine and at high dynamic loads, the gap between the mating elements can open and the surface of the port plate can make a complex spatial movement relative to the end surface of the cylinder block.

The opening of the joint leads to an increase in volume losses, and the local contact of the conjugate surfaces leads to an increase in friction forces.

To study the hydromechanical processes in the port plate interface, it is necessary to conduct a kinematic analysis of the relative motion of the conjugate surfaces [6].

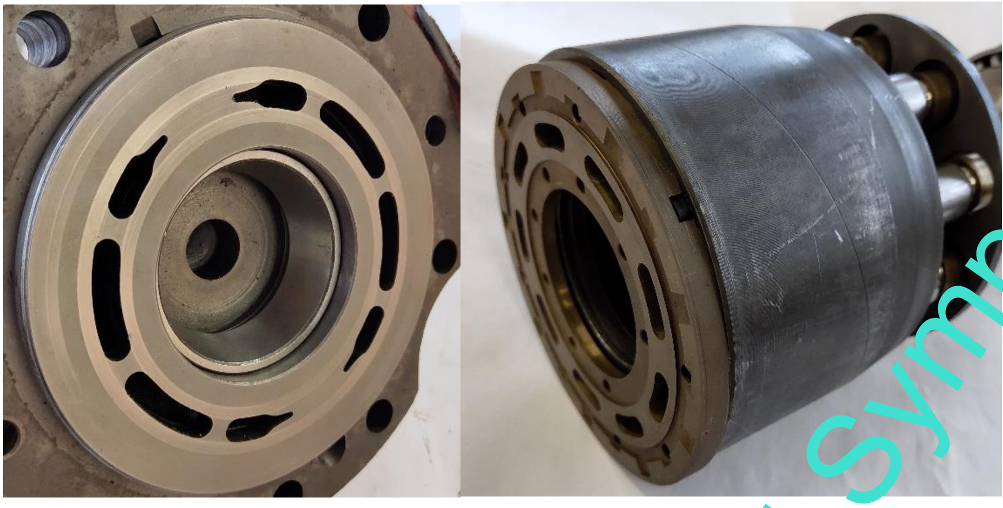

Fig. 1. Port plate unit of an axial piston hydraulic machine

2. Kinematic analysis of the port plate unit

Let's use the principle of inversion of motion of conjugate elements. We will consider the cylinder block fixed in space, then the distribution disk can generally perform spherical motion relative to its support surface. Its centre is located in the centre of the spline joint of the block with the shaft of the hydraulic machine. There is also a reciprocating motion within the end gap between the support surfaces of the cylinder block and the port plate.

Figure 2 shows an arbitrary position of the port plate relative to the support surface of the cylinder block.

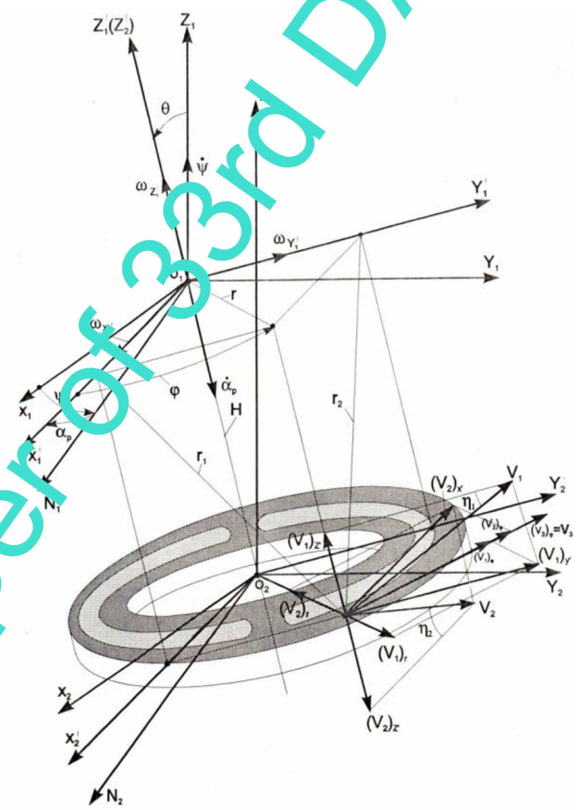

Figure 2. Scheme of the velocities of a point on the port plate surface

$0_1X_1Y_1Z_1$ is a coordinate system rigidly connected to the cylinder block with the origin in the centre of its spline joint with the shaft of the hydraulic machine.

$0_2X_2Y_2Z_2$ is a coordinate system parallel to the coordinate system $0_1X_1Y_1Z_1$ with the origin in the centre of the plane of the port plate facing the cylinder block.

$0'_2X'_2Y'_2Z'_2$ is a coordinate system rigidly connected to the port plate and the origin coinciding with the origin of the $0_2X_2Y_2Z_2$ coordinate system.

$0'_1X'_1Y'_1Z'_1$ is a coordinate system parallel to the coordinate system $0'_2X'_2Y'_2Z'_2$ with the origin coinciding with the origin of the coordinate system $0_1X_1Y_1Z_1$.

θ- NUTATION ANGLE -the angle between the axis of the block and the port plate.

Ψ - PRECESSION ANGLE - the angle between the axis perpendicular to the plane of the port plate skew (node line N) and the X1 axis.

α_P - ROTATION ANGLE - the angle that characterizes the position of the port plate when it rotates relative to its own axis.

Figure 2 shows three components V_1 V_2 V_3 of the total velocity of an arbitrarily selected point A on the surface of the port plate with its spherical motion relative to the origin 0_1.

The projections of the components V_1 V_2 V_3 on the directions of the cylindrical coordinates r, z and ϕ can be written as follows

$$\begin{cases} (V_1)_r = V_1 cos\mu_1 sin\varphi \\ (V_2)_r = -V_2 cos\mu_2 cos\varphi \\ (V_3)_r = 0 \\ (V_1)_\varphi = V_1 cos\mu_1 cos\varphi \\ (V_2)_\varphi = V_2 cos\mu_2 sin\varphi \\ (V_3)_\varphi = V_3 \\ (V_1)_z = V_1 sin\mu_1 \\ (V_2)_z = -V_2 sin\mu_2 \\ (V_3)_z = 0 \\ \mu_1 = arctg(\frac{r}{H} sin\varphi) \\ \mu_2 = arctg(\frac{r}{H} cos\varphi) \end{cases} \quad (1)$$

H is the distance from the center of the spline connection of the cylinder block and the shaft of the hydraulic machine to the support surface of the port plate.

Grouping the velocity projections by the corresponding coordinates:

$$\begin{cases} (\boldsymbol{V_s})_{\boldsymbol{r}} = (-\dot{\psi} \cdot sin\theta \cdot sin\alpha_P + \dot{\theta} cos\alpha_P)\sqrt{H^2 + r^2 sin^2\varphi} \cdot cos\left(arctg\left(\frac{r}{H} sin\varphi\right)\right) \cdot sin\varphi - \\ (-\dot{\psi} \cdot sin\theta \cdot cos\alpha_P + \dot{\theta} sin\alpha_P)\sqrt{H^2 + r^2 cos^2\varphi} \cdot cos\left(arctg\left(\frac{r}{H} cos\varphi\right)\right) \cdot cos\varphi \\ (\boldsymbol{V_s})_{\boldsymbol{\varphi}} = (-\dot{\psi} \cdot sin\theta \cdot sin\alpha_P + \dot{\theta} cos\alpha_P)\sqrt{H^2 + r^2 sin^2\varphi} \cdot cos\left(arctg\left(\frac{r}{H} sin\varphi\right)\right) \cdot cos\varphi + \\ (-\dot{\psi} \cdot sin\theta \cdot cos\alpha_P + \dot{\theta} sin\alpha_P)\sqrt{H^2 + r^2 cos^2\varphi} \cdot cos\left(arctg\left(\frac{r}{H} cos\varphi\right)\right) \cdot sin\varphi + (\dot{\alpha_P} + \dot{\psi} cos\theta) r \\ (\boldsymbol{V_s})_{\boldsymbol{z}} = (-\dot{\psi} \cdot sin\theta \cdot sin\alpha_P + \dot{\theta} cos\alpha_P)\sqrt{H^2 + r^2 sin^2\varphi} \cdot sin\left(arctg\left(\frac{r}{H} sin\varphi\right)\right) \cdot cos\alpha_P - (V_2)_\varphi = V_2 cos\mu_2 sin\varphi \\ (-\dot{\psi} \cdot sin\theta \cdot cos\alpha_P - \dot{\theta} sin\alpha_P)\sqrt{H^2 + r^2 cos^2\varphi} \cdot sin\left(arctg\left(\frac{r}{H} cos\varphi\right)\right) \cdot sin\alpha_P \end{cases} \quad (2)$$

The expressions obtained can be significantly simplified if we take into account that the angle of the tilt of the port plate is very small, that is, if we take $sin\theta = 0$, $cos\theta = 1$:

$$\begin{cases} (V_s)_r = \dot{\theta} H sin(\varphi - \alpha_P) \\ (V_s)_\varphi = \dot{\theta} H cos(\varphi - \alpha_P) - \dot{\alpha_P} r + \dot{\psi} r \\ (V_s)_z = \dot{\theta} r (cos^2\alpha_P sin\varphi - sin^2\alpha_P cos\varphi) \end{cases} \quad (3)$$

3. Conclusions and further work

The obtained dependences describing the mutual motion of the conjugate surfaces of the port plate and the cylinder block can serve as a basis for the subsequent mathematical description of hydrodynamic processes in the port plate unit of an axial piston hydraulic machine and determination of its energy characteristics under various operating conditions.

Following steps should consider hydrodynamic processes, overall dynamics of the cylinder block and complete hydromechanical efficiency of the axial piston swash plate machine.

4. References

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