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ANALYSIS OF LOADING AXIAL BEARING OF SLEWING PLATFORM DRIVE MECHANISMS IN HYDRAULIC EXCAVATORS

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Abstract

The paper presents a procedure of a mathematical model and a developed program for determining the load spectrum of the axial bearing of the reverse platform of hydraulic excavators using a computer. The mathematical model includes the general configuration of the kinematic chain of hydraulic excavators with executive tools in the form of a depth bucket. Equivalent loads are defined on the basis of which the size of the axial bearing of the excavator is selected. At the end of the paper, as an example, the load spectra of the axial bearing of a slewing platform are given, as well as the determination of the size of hydraulic excavators, equipped with a crawler support-movement mechanisms and a support-movement mechanisms on wheels.

***Key words**: hydraulic excavator, axial bearing, support-movement mechanisms*

1 INTRODUCTION

Spatial manipulation of the excavator is enabled by a kinematic pair (Fig. 1): support-movement member L_1 - slewing platform L_2, connected by a rotary joint in the form of a large-diameter axial bearing *7*, where the support-movement mechanism resting on the ground is a relatively fixed member in relation to a slewing platform which can achieve unlimited rotation, in both directions, about the vertical axis of the joint [1].

Members of kinematic pairs connected to hydrostatic actuators (hydraulic cylinder and hydraulic motors) build drive mechanisms, which strengthen the kinematic chain of the machine, turning it into an active mechanism.

Depending on the conditions of support and movement, excavators are equipped with support-movement mechanisms on caterpillar L_1 (Fig. 1a) and L_1 wheels (Fig. 1b). In this case, the variants of the support-movement mechanisms on the caterpillar can be with different lengths of fit, the range of the caterpillar and the width of the slippers. It is similar with a support-movement mechanism with wheels, the same model of excavator can be with a moving mechanism that has one or two pairs of stabilizers or one pair of stabilizers and a bulldozer board.

For all possible configurations of the excavator model, the drive mechanism of the rotating platform remains the same. The correct choice of the size of the axial bearing of the rotating platform drive is made on the basis of the equivalent bearing load for all possible configurations of the excavator model [2].

This paper presents the procedure for selecting the axial bearing of hydraulic excavators based on the spectrum of equivalent loads of bearings of a certain size of hydraulic excavators, equipped with a crawler support-movement mechanism and a support-movement mechanism on wheels.

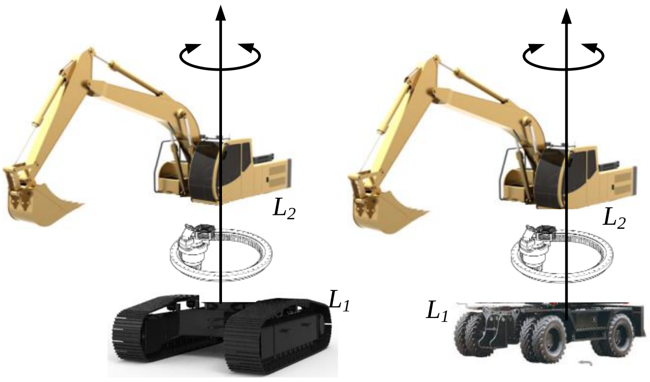

***Fig.** 1 Slewing platform drive mechanism of hydraulic excavators with: a) crawler support and movement member, v) support and movement mechanism on wheels*

2 MATHEMATICAL MODEL OF EXCAVATOR

For realization its spatial manipulation, kinematic chain of hydraulic excavators have slewing member (platform) L_2 (Fig. 2a), which is for support and movement member L_1 linked slewing joint O_2, of fifth class, with vertical kinematics axis O_2y_2 in relation to substrate reliance. Joint O_2 is axial bearing *7* (Fig. 2.b), which is internal toothed ring *7.1* with screws *7.4* linked for support-movement mechanism L_1, and not-toothed outer ring *7.2* is with screws *7.3* linked for slewing platform L_2. Driving mechanism of slewing platform build hydromotor *5*, reductor *6* coupled over the output gear *6.1* with toothed ring of axial bearing *7.1*.

Each member of the kinematic chain L_i model is defined in its local coordinate system $O_ix_iy_iz_i$ with values set [3]:

$$L_i = \left\{ \vec{e}_i, \vec{s}_i, \vec{t}_i, m_i \right\} \quad \forall \quad i = 1,2,3,4,5 \qquad (1)$$

where: $\vec{e}_i = \left\{ e_{ix}, e_{iy}, e_{iz} \right\}$ - joint axis unit vector O_i by which are segment L_i linked for previous segment L_{i-1}, $\vec{s}_i = \left\{ s_{ix}, s_{iy}, s_{iz} \right\}$ - the position vector of the joint center O_{i+1} by which are segment L_i linked for to the following segment L_{i-1} (the vector intensity s_i represent kinematic length of segment), $\vec{t}_i = \left\{ t_{ix}, t_{iy}, t_{iz} \right\}$ - the position vector of center of mass segment, m_i - segment mass.

Mathematical model of excavator driving system are includes driving mechanisms of boom L_3, arm L_4 and bucket L_5 which for actuators have bidirectional hydro-cylinders c_3, c_4 and c_5 (Fig 2b). Each driving mechanism C_i of excavator manipulator determined by a values set:

$$C_i = \left\{ d_{i1}, d_{i2}, c_{ip}, c_{ik}, \vec{a}_i, \vec{b}_i, c_i, m_{ci}, n_{ci} \right\} \quad \forall \ i = 3,4,5 \quad (2)$$

where: d_{i1},d_{i2} –diameter of the piston and piston rod of hydro-cylinder, c_{ip},c_{ik} - start and final length of hydro-cylinder, $\vec{a}_i, \vec{b}_i$ - vectors of joint center position in which the hydro-cylinders linked to the segments of the kinematic chain, c_i - length of transmission levers if drive mechanism has, m_{ci} - mass of hydro-cylinder, n_{ci} - number of hydro-cylinder driving mechanism.

The assumptions of a mathematical model of kinematic chain excavator are:

- The substrate reliance and members of excavator kinematic chain are modeled with rigid bodies,
- During manipulative task, excavator work is stable, ie. possible displacement in zero-joint does not occur,
- kinematic chain excavator is an open configuration with the fact that during the digging operation, when has a closed configuration, is viewed as an open chain configuration, on which the last segment-bucket acting resistance to digging ***W*** at the center of the cutting edge O_w,
- During manipulative task on kinematic chain excavator operating gravitational forces and resistance to digging. Vector of digging resistance is determined by the equation [2]:

$$\vec{W} = W_{xy} cos\varphi_w \vec{i} + W_{xy} sin\varphi_w \vec{j} + W_z \vec{k} \quad (3)$$

where: W_{xy} - potential resistance to digging, which operates in the plane of the manipulator, W_z - lateral resistance to digging, φ_w - angle directions of possible digging resistance.

For a certain direction and course activity, size of possible digging resistance is defined by equation [1]:

$$W_{xy} = min\{W_s, W_3, W_4, W_5\} \quad (4)$$

where: W_s - maximum limit value digging resistance determined from the condition of stability of the excavator, W_3, W_4 ,W_5 - maximum limit values for digging resistance that can overcome the driving mechanisms boom, arm and bucket manipulators with influence the maximum pressure of the hydraulic system of excavator.

For a certain position of kinematic chain excavator, the size of the lateral digging resistance is defined by the equation:

$$W_z = \frac{m \cdot g \cdot L}{4 \cdot x_w} \mu_o \quad (5)$$

m - mass of the excavator, L - length of adjacent caterpillar, μ_o - resistance coefficient swivel of caterpillars in relation to the substrate reliance excavator, x_w - the horizontal coordinate the center of cutting bucket.

2.1 The load bearing

Fictitious break of kinematic chain excavator in the joint O_2 slewing platform L_2 and reduction of all load, of the rejected parts, in its center, are obtained of the resultant force (Fig.1b) [2]:

$$\vec{F}_2 = \vec{W} - g\sum_{i=2}^{5} m_i \vec{j} - g\sum_{i=3}^{5} m_{ci} \vec{j} - gm_z \vec{j} \quad (6)$$

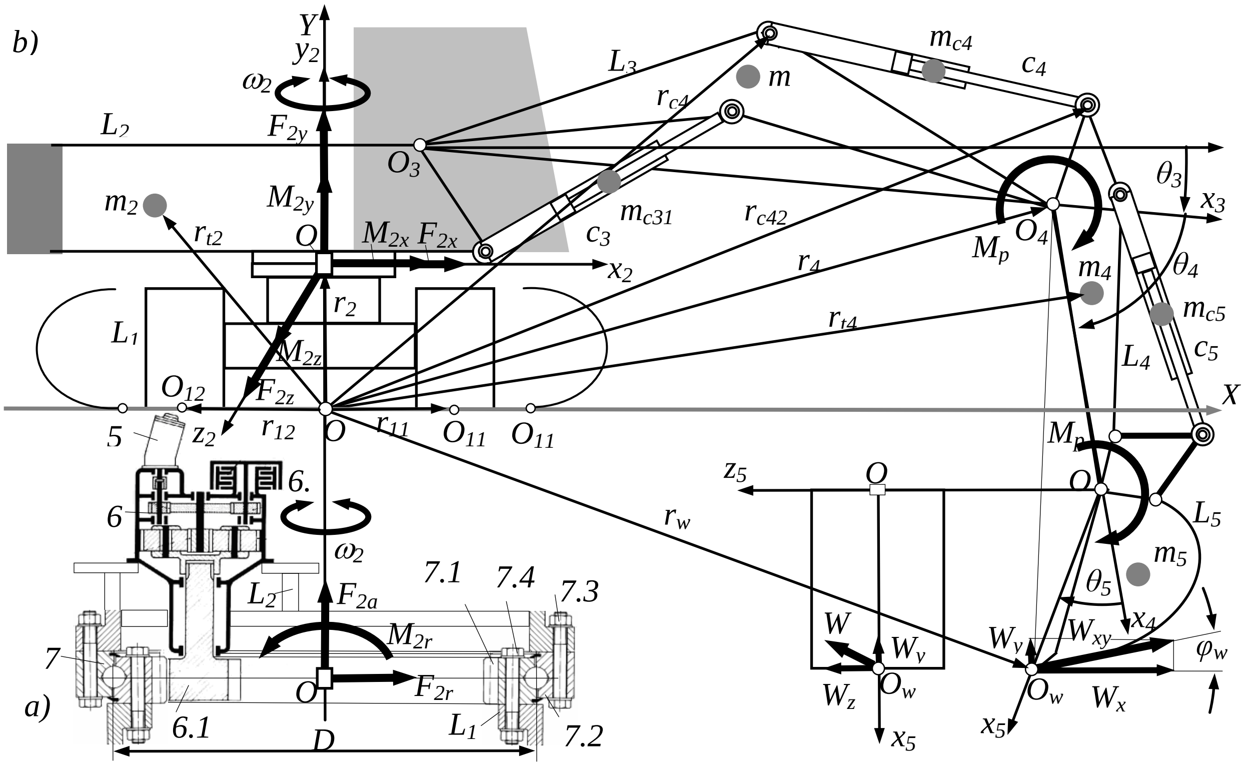

Fig. 2 *Determining the load of axial bearing slewing platforms of hydraulic excavator: a) driving mechanism of slewing platforms, b) mathematical model of excavator*

and the joint moment:

$$\vec{M}_2 = ((\vec{r}_w - \vec{r}_2)\times\vec{W}) - g\sum_{i=2}^{5} m_i((\vec{r}_{ti} - \vec{r}_2)\times\vec{j}) - gm_z((\vec{r}_{t5} - \vec{r}_2)\times\vec{j}) - g\sum_{i=3}^{5}\frac{n_{ci}m_{ci}}{2}((\vec{r}_{ci1} - \vec{r}_2)\times\vec{j}) - g\sum_{i=3}^{5}\frac{n_{ci}m_{ci}}{2}((\vec{r}_{ci2} - \vec{r}_2)\times\vec{j}) \qquad (7)$$

where: $\vec{r}_w$ - position vector of the center of the cutting edge of bucket, $\vec{r}_2$ - position vector of the center joint (axial bearing) O_2, r_{ti} - position vector of the center of mass the segments of the kinematic chain, $\vec{r}_{cij}$ - position vector of the joint in which are linked hydro-cylinders of driving mechanisms for kinematic chain segments of excavator, m_z - mass of material seized by bucket (where it is assumed that the center of mass of the material coincides with the center of mass of bucket). The components of force F_2 and moment M_2 of joint O_2 along the coordinate axes:

$$F_{2x} = \vec{F}_2 \cdot \vec{i}, \quad M_{2x} = \vec{M}_2 \cdot \vec{i}$$
$$F_{2y} = \vec{F}_2 \cdot \vec{j}, \quad M_{2y} = \vec{M}_2 \cdot \vec{j} \qquad (8)$$
$$F_{2z} = \vec{F}_2 \cdot \vec{k}, \quad M_{2z} = \vec{M}_2 \cdot \vec{k}$$

Load components of axial bearing slewing platforms of excavator are (Fig. 1b): a) axial force F_{2a}, b) radial force F_{2r} and moment M_{2r}:

$$F_{2a} = F_{2y} \qquad (9)$$

$$F_{2r} = \left(F_{2x}^2 + F_{2z}^2\right)^{0,5} \qquad (10)$$

$$M_{2r} = \left(M_{2x}^2 + M_{2y}^2\right)^{0,5} \qquad (11)$$

Moment M_{2r}, whose vector lies in the horizontal plane strain axial bearing, while the moment M_{2z}, whose holder vector coincides with the axis of the bearing, balancing the drive moment M_{p2} of platform slewing mechanism.

3 SELECTION OF BEARING

Manufacturers of bearings in their catalogs define the equivalent load according to which are selected the size of bearing.

According to the manufacturer's catalog ROTE ERDE bearing load equivalent amounts [4]:

a) Equivalent static force F_{es}:

$$F_{es} = \left(a \cdot F_{2a} + b \cdot F_{2r}\right) f_s \qquad (12)$$

б) Equivalent static moment M_{es}:

$$M_{es} = f_s \cdot M_{2r} \qquad (13)$$

where: a - factor of influence the axial force, b - factor of influence the radial force, f_s - conditions factor of bearing. Values of factors a,b,f_s are given depending on the type bearing (single-row, double-row, ball, roller), types and sizes of machines and their working conditions.

For example, in the diagrams of permissible bearing capacities (Fig. 3 - curves AL7, AL8 AL9 AL10), shows the spectra of

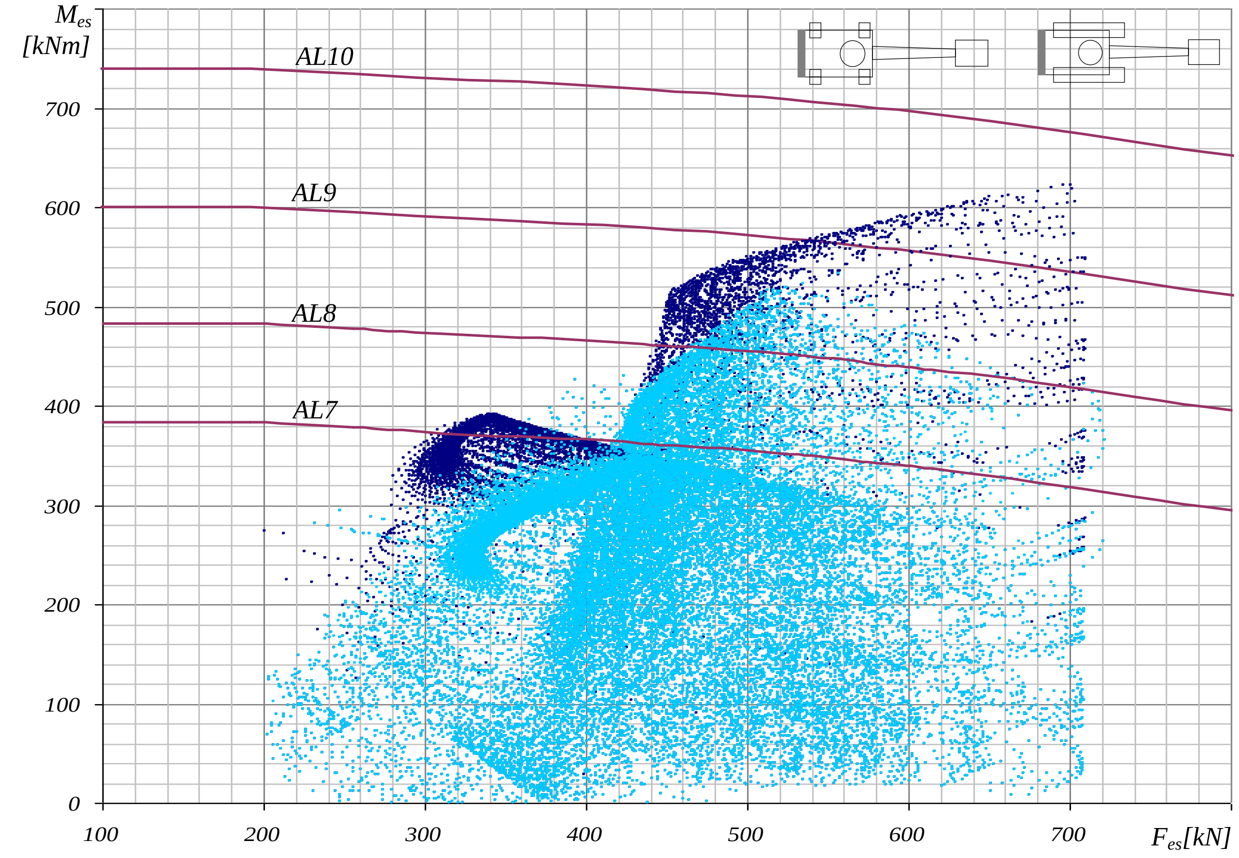

Fig. 3 *Comparison of the axial bearing load spectrum of the excavator model E with a crawler movement mechanism (light blue color) and the model of the excavator model F with a movement mechanism on wheels (dark blue) and the same depth manipulator bucket*

the load bearing, in the form of constellations, which make the coordinates of equivalent forces F_{esi} and equivalent moments M_{esi} load bearing excavator.

Two models of excavators *E* and *F* that have the same slewing platform and the same configuration of the kinematic chain of the depth manipulator but different support-movement mechanisms: model of excavator *E* has a crawler support-movement mechanism, and model excavator *F* a support-movement mechanism on wheel with four stabilizers.

The load spectra of the axial bearing were determined for the same kinematic chain of the manipulator with an boom length $s_3 = 5m$, arm length $s_4 = 1.8m$ and bucket volume $V = 0.6m^3$ for digging a material of density $\rho = 1800\ kg / m^3$. A comparison of the load spectra of models *E* and *F* shows that the equivalent loads, relevant for the choice of bearing size, are significantly higher for the model of excavator *F*. According to the diagrams of permissible bearing capacities, the larger bearing *AL10* would correspond to the excavator model *F* and the smaller bearing *AL9* to the excavator model E.

The difference in equivalent loads for bearing selection occurs due to the higher moment of stability of the excavator model *F* in relation to the potential overturning lines of the excavator. With the support-movement mechanism on wheels, model *F*, by pulling and lowering the stabilizer on the support base, the polygon that forms potential transverse and longitudinal rollover lines is significantly larger than the polygon that forms potential rollover lines of the crawler support-movement mechanism of excavator model *E*.

With the *F* excavator model, the distance of potential overturning lines is greater from the directions of action of the gravitational forces of the platform and the support-movement mechanism, so the moment of stability is higher for the positions of the excavator kinematic chain in most of the working space. As the moment of stability of the excavator increases, they are also larger limit digging resistances determined from the stability conditions which also enable higher limit digging resistances that can be overcome by the driving mechanisms of the excavator manipulator. With the increase of the limit digging resistances, higher possible digging resistances occur, which cause higher loads of the axial bearing of the excavator platform drive.

4. CONCLUSION

The results of previously conducted research related to the choice of the size of the axial bearing of the mechanism of the rotating platform of hydraulic excavators show:

• to select the size of the axial bearing of the mechanism of the slewing platform of the excavator, it is necessary to know the parameters of the members of all possible configurations of kinematic chains and drive mechanisms of the excavator manipulator,

• axial bearings, as ready-made modules, for the mechanisms of the slewing platform of hydraulic excavators of all sizes, are produced by specialized world manufacturers with accompanying documentation prescribing the criteria and conditions for the selection, installation and maintenance of bearings,

• the basic indicator of available axial bearings is a diagram of permissible loads that represents, for each bearing size, the dependence of the permitted equivalent moments and the permissible equivalent load forces of the axial bearing,

• the size of the axial bearing is selected by comparing the given diagrams of bearing capacity and equivalent forces and equivalent moments determined, according to defined criteria, based on radial and axial forces and load moments,

• for reliable selection of the axial bearing size, it is necessary to determine the axial bearing load spectra for all possible variants of the support-movement mechanism and possible configurations of kinematic chains of manipulators with which the same model of excavator is equipped.

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