Analiza uticaja pogona mehanizma obrtne platforme hidrauličkih bagera na opterećenje aksijalnog ležaja mehanizma

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Rad sadrži rezultate sprovedenih istraživanja koja se odnose na analizu uticaja broja pogona mehanizma obrtne platforme hidrauličkih bagera na opterećenje aksijalnog ležaja mehanizma platforme. Posmatra se opšti model mehanizma obrtne platforme sa transformacionim - hidrosatičkim delom koji čine hidropumpa i hidromotor i prenosno- mehaničkim delom koji grade planetarni reduktor i aksijalni ležaj velikog prečnika. Definisan je opšti matematički model bagera i razvijen softver za određivanje ekvivalentnih opterećenja aksijalnog ležaja na osnovu kojih se vrši izbor veličine ležaja iz skupa raspoloživih, koje proizvode specijalizovani proizvođači. Na kraju rada, kao primer, za hidraulički bager mase 102000 kg sa utovarnim manipulatorom zapremine kašike 6,5m³, dati su uporedni rezultati analize opterećenja aksijalnog ležaja mehanizma obrtne platforme sa jednim i dva pogona.

Ključne reči: pogonski mehanizam obrtne platforme

1. UVOD

Primarna funkcija hidrauličkih bagera, svih veličina, je prekidni transport različitih materijala u prostornom radnom polju. Hidrauličkim bagerima prostornu manipula-ciju, vrlo značajnu za obavljanje manipulacionih zadataka, omogućuje obrtni zglobov kinematičkog lanca bagera, u obliku aksijalnog ležaja velikog prečnika, koji povezuje oslono-kretni mehanizam L_1 (sl.1a) i obrtnu platformu L_2 .

Opšti model pogonskog mehanizma obrtne platforme hidrauličkih bagera se sastoje od: a) transformaciono-hidrostatičkog i b) prenosno-mehaničkog dela.

Transformacioni deo pogonskog mehanizma obrtne platforme bagera čine hidropumpa 2.1 (sl.1b) i hidromotori 2.3, povezani u otvorenom ili zatvorenom hidrostatičkom kolu.

Prenosnom delu mehanizma obrtne platforme hidrauličkih bagera pripada, pored aksijalnog ležaja 2.5, integrisani prenosnik koji čine hidromotor 2.3 i planetarni reduktor 2.4 povezani u jedinstveni modul sa lamelastom kočnicom između izlaznog vratila hidromotora i ulaznog vratila reduktora.

Hidromotor napaja hidropumpa koju pogoni dizel motor 1 preko elastične spojnice 1.1 i zupčastog razdelnika energije 1.2 hidropumpe.

Aksijalni ležaj velikog prečnika mehanizma pogona okretanja platforme hidrauličkih bagera imaju spoljni i unutrašnji prsten između kojih su staze kotrljajnih tela u obliku kuglica ili valjčića. Spoljni ili unutrašnji prsten je ozubljen po celom obimu.

Na izlaznom vratilu planetarnog reduktora, pričvršćenog za obrtnu platformu, nalazi se zupčanik z_{24} koji se spreže sa ozubljenim prstenom z_{25} aksijalnog ležaja čvrsto vezanog za oslono-kretni mehanizam bagera.

U okviru razvijene opšte metodologije [1] za sintezu pogonskog mehanizma obrtne platforme hidrauličkih bagera izvršena je detaljna analiza parametara funkcija, odnosno analiza kinematičkih, dinamičkih i energetskih parametara pogona. Obavljena istraživanja kinematičkih i dinamičkih parametara pogonskog mehanizma obrtne platforme bagera obuhvatila su: a) određivanje vrste, veličine i karaktera promene kretanja i opterećenja mehanizma obrtne platforme,

Slika 1: Pogonski mehanizam obrtne platforme hidrauličkih bagera: a) model bagera b) funkcionalna šema mehanizma

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koja se javljaju pri radu bagera sa različitim manipulatorima i u različitim uslovima rada, b) ocenu uticaja dinamičkih opterećenja pogona u odnosu na statička opterećenja, c) utvrđivanje operacija manipulacionog zadatka bagera pri kojima se javljaju kinematički i dinamički parametri merodavni za sintezu pogona obrtne platforme, d) određivanje spektara ekvivalentnih opterećenja aksijalnog ležaja u celom radnom prostoru bagera na osnovu mogućih sila otpora kopanja i e) analizu uticaja odnosa parametara mehanizma okretanja platforme na energetske efikasnost pogona i dinamičku stabilnost bagera.

Postupcima razvijene metodologije za sintezu pogonskih mehanizma obrtne platforme bagera određuju se komponente pogona (hidropumpa, hidromotor, reduktor, aksijalni ležaj) na osnovu zadatih parametara funkcija pogona uz ograničenja vezana za dozvoljene parametre raspoloživih veličina komponenata koje proizvode u velikim serijama specijalizovani proizvođači.

Dobijeni rezultati sprovedenih istraživanja vezanih za sintezu pokazuju da se mehanizam obrtne platforme, istog modela hidrauličkih bagera, može izvesti da jednim ili više pogona, pri čemu pogon može biti sa hidromotorom manjeg specifičnog protoka i reduktorom većeg prenosnog odnosa i obrtnuto, pri čemu se ostvaruju isti izlazni parametri (broj obrtaja i moment) okretanja platforme.

U ovom radu, kao deo sprovedenih istraživanja, data je analiza uticaja broja pogona mehanizma obrtne platforme bagera na opterećenja aksijalnog ležaja mehanizma.

2. ANALIZA OPTEREĆENJA AKSIJALNOG LEŽAJA

U početnoj fazi postupka sinteze mehanizma obrtne platforme hidrauličkih bagera određuje se aksijalni ležaj pogona. Određivanje se vrši kroz izbor vrste i veličine aksijalnog ležaja iz skupa mogućih raspoloživih modela koje proizvode kao posebne module, specijalizovani proizvođači (Rothe Erde, INA, SKF) [2][3][4].

Kriterijumi izbora veličine aksijalnog ležaja baziraju se na sili F_2 i momentu M_2 opterećenja ležaja određenih jednačinama (sl.2) [1][5]:

$$F_2 = -W - \sum_{i=2}^5 F_{ui} - F_{c2} \quad (1)$$

$$M_2 = ((r_w - r_2) \times W) + \sum_{i=2}^5 ((r_i - r_2) \times F_{ui}) + \sum_{i=2}^5 M_{ui} \quad (2)$$

gde je: W - vektor mogućih sila otpora kopanja [1], F_{c2} - sila reakcije pogona platforme, F_{ui} - ukupna sila vezana za središte mase člana L_i kinematičkog lanca bagera jednaka zbiru inercijalne i gravitacione sile, M_{ui} - moment inercijalne sile člana L_i , r_w -vektor položaja središta rezne ivice kašike, r_i - vektor položaja središta mase člana L_i i r_2 - vektor položaja središta aksijalnog ležaja.

Zavisno od broja pogona mehanizma obrtne platforme i njihovog rasporeda u odnosu na ozubljeni prsten aksijalnog ležaja, mogu se pojaviti dodatna opterećenja aksijalnog ležaja od reakcije pogona platforme usled delovanja sile otpora kopanja, gravitacionih i dinamičkih opterećenja nastalih kretanjem manipulatora bagera tokom manipulacionog zadatka u celom radnom prostoru bagera.

Slika 2: Komponente opterećenja aksijalnog ležaja pogona okretanja platforme bagera: a) sile, b) momenti, c) sile opterećenja ležaja od jednog pogona, d) sile opterećenja ležaja od dva pogona

Sila reakcije pogona kod mehanizma sa jednim pogonom okretanja platforme određena je jednačinom (sl. 2a):

$$F_{c2} = \frac{2|M_{2y}|}{D_{25} - d_{24}} [\sin(\theta_2 + \alpha_2)\mathbf{i} - \cos(\theta_2 + \alpha_2)\mathbf{k}] \quad (3)$$

gde je: M_{2y} - moment pogona okretanja obrtne platforme, α_2 - ugao položaja pogona platforme u odnosu na lokalni koordinatni sistem platforme, θ_2 - ugao položaja platforme u odnosu na apsolutni koordinatni sistem, D_{25} - podeoni prečnik ozubljenog prstena aksijalnog ležaja platforme, d_{24} - podeoni prečnik zupčanika na izla-znom vratilu reduktora pogona, $\mathbf{i}$, $\mathbf{j}$, $\mathbf{k}$ - jedinični vektori apsolutnog koordinatnog sistema bagera.

Kod većih bagera sa dva ista pogona postavljena međusobno pod uglom od $\beta_2 = 180^\circ$ (sl. 2d) sile reakcije pogona platforme se poništavaju i ne opterećuju ležaj.

Uzimajući u obzir dodatno opterećenje od reakcije pogona okretanja platforme, rezultanta i komponente sile u zglobovima O_2 obrtne platforme koje opterećuju aksijalni ležaj pogona okretanja određene su jednačinama:

$$F_{2x} = F_2 \cdot \mathbf{i}_2, \quad F_{2y} = F_2 \cdot \mathbf{j}_2, \quad F_{2z} = F_2 \cdot \mathbf{k}_2 \quad (4)$$

Rezultujuća sila F_2 opterećuje aksijalni ležaj radialnom silom F_{2r} koju, u horizontalnoj ravni ležaja, grade komponente F_{2x} i F_{2z} :

$$F_{2r} = (F_{2x}^2 + F_{2z}^2)^{0.5} \quad (5)$$

i aksijalnom silom F_{2a} koja deluje duž ose O_2y ležaja i jednaka je komponenti F_{2y} :

$$F_{2a} = |F_{2y}| \quad (6)$$

Rezultanta i komponente momenata u zglobovima O_2 obrtne platforme koji opterećuju aksijalni ležaj pogona okretanja određeni su jednačinama:

$$M_{2x} = M_2 \cdot \mathbf{i}_2, \quad M_{2y} = M_2 \cdot \mathbf{j}_2, \quad M_{2z} = M_2 \cdot \mathbf{k}_2 \quad (7)$$

Rezultujući moment M_2 opterećuje aksijalni ležaj momentom M_{2r} koji grade komponente M_{2x} i M_{2z} , čiji vektor leži u horizontalnoj ravni:

$$M_{2r} = (M_{2x}^2 + M_{2z}^2)^{0.5} \quad (8)$$

i pogon okretanja obrtne platforme komponentom M_{2y} , čiji je vektor kolinearan sa osom ležaja.

Veličina aksijalnog ležaja pogona okretanja platforme se bira na osnovu [2]

$$\text{ekvivalentne sile: } F_{es} = (a \cdot F_{2a} + b \cdot F_{2r}) \cdot f_s \quad (9)$$

$$\text{i ekvivalentnog momenta: } M_{es} = c \cdot M_{2r} \cdot f_s \quad (10)$$

gde je: a , b , c - koeficijenti zavisni od vrste ležaja, vrste i veličine mašine i njenih uslova rada, f_s - koeficijent statičke sigurnosti.

Koeficijente koji se koriste za određivanje ekvivalentnih sila i momenata daju proizvođači aksijalnih ležaja u svojim katalogima za svaku vrstu ležaja (kuglični, valjčasti, jednoredni, dvoredni i višeredni), prema nameni i uslovima rada mašine na kojoj se ugrađuju.

3. PRIMER ANALIZE OPTEREĆENJA AKSIJALNOG LEŽAJA

Na osnovu definisanog matematičkog modela, razvijen je softver za dinamičku simulaciju bagera koji omogućuje pored ostalog, određivanje ekvivalentnih opterećenja aksijalnog ležaja mehanizma obrtne platforme bagera zavisno od vremena trajanja pojedinih operacija (kopanje, prenos, istovar, vraćanje) manipulacionog zadatka bagera.

U određenom položaju kinematičkog lanca bagera, ekvivalentna opterećenja aksijalnog ležaja se određuju prema mogućoj sili otpora kopanja koja predstavlja minimalnu vrednost iz skupa graničnih sila otpora kopanja određenih iz uslova stabilnosti bagera i graničnih sila otpora kopanja koje mogu da savladaju pogonski mehanizmi manipulatora pri maksimalnom radnom pritisku pogonskog sistema bagera.

Korišćenjem razvijenog softvera, kao primer, analiziran je uticaj broja pogona mehanizma obrtne platforme na opterećenje aksijalnog ležaja mehanizma za hidraulički bager mase 102000 kg opremljenog utovarnim manipulatorom zapremine kašike 6,5m³. Izvršena je uporedna analiza ekvivalentnih opterećenja aksijalnog ležaja za varijante bagera **A** i **B**. Varijanta bagera **A** je sa jednim, a varijanta bagera **B** je sa dva pogona mehanizma obrtne platforme.

Kod varijante modela bagera **A** sa jednim pogonom okretanja platforme uzeto je da je pogon postavljen, u lokalnom koordinatnom sistemu platforme, pod uglom od $\alpha_2 = 180^\circ$ (sl.3.a) u odnosu na O_2x_2 osu, što odgovara u praksi najčešćem načinu ugradnje, s obzirom na slobodno raspoloživi prostor i blizinu hidromotora, hidropumpi pogonske grupe bagera.

Kod varijante modela bagera **B** sa dva pogona okretanja platforme, pogoni su postavljeni u relativnom položaju pod uglom od $\beta_2 = 180^\circ$ (sl.3.b) u lokalnom koordinatnom sistemu platforme.

Slika 3: Sile reakcije mehanizma platforme sa: a) jednim pogonom, b) sa dva pogona

Dobijeni rezultati analize pokazuju (sl.4) da varijanta modela bagera **A** sa jednim pogonom okretanja platforme ima veće ekvivalentne sile opterećenja ležaja u odnosu na varijantu sa dva pogona. Razlog povećanih ekvivalentnih sila je taj što se kod varijante bagera **A** sa jednim pogonom javlja reaktivna sila pogona okretanja koja dodatno radialno opterećuje aksijalni ležaj. Reaktivne sile pogona se javljaju tokom manipulacionog zadatka pri operaciji kopanja u slučaju ekcentričnog delovanja otpora kopanja u odnosu na podužnu simetričnu ravan manipulatora, i u fazama ubrzanog i usporenog okretanja platforme bagera.

Slika 4: Poređenje ekvivalentnih statičkih ($F_{esA,B}$, $M_{esA,B}$) i dinamičkih ($F_{edA,B}$, $M_{edA,B}$) sila i momenata opterećenja ležaja varijante bagera **A** sa jenim i varijante bagera **B** sa dva pogona mehanizma okretanja platforme

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Kod varijante bagera **B** sa dva pogona reaktivne sile pogona imaju iste intenzitete ali suprotne smerove delovanja tako da ne opterećuju dopunski aksijalni ležaj pogona. Ekvivalentni momenti opterećenja ležaja za obe varijante **A** i **B** pogona okretanja modela bagera su isti jer sile reakcije pogona nemaju uticaja na njih.

Promene statičkih ($F_{esA,B}$, $M_{esA,B}$) i dinamičkih ($F_{edA,B}$, $M_{edA,B}$) ekvivalentnih sila i momenata opterećenja ležaja (sl. 4) tokom manipulacionog zadatka varijanti bagera **A** i **B** pokazuju da se kod varijante **A** sa jednim pogonom platforme javljaju veće ekvivalentne sile i pri operaciji kopanja (crvene linije) i pri svim ostalim operacijama manipulacionog zadatka (plave linije) u odnosu na varijantu **B** sa dva pogona platforme.

5. ZAKLJUČAK

Rezultati sprovedenih istraživanja vezanih za sintezu pogonskog mehanizma obrtno platforme hidrauličnih bagera pokazuju da je za izbor veličine aksijalnog ležaja potrebno je poznavanje parametra članova kinematičkih lanaca i pogonskih mehanizama manipulatora bagera. Veličina aksijalnog ležaja se bira poređenjem datih dijagrama nosivosti ležajeva i ekvivalentnih sila i ekvivalentnih momenata određenih, prema definisanim kriterijumima, na osnovu radijalnih i aksijalnih sila i momenata opterećenja pogona okretanja bagera.

Ekvivalentna opterećenja aksijalnog ležaja zavise od konfiguracije kinematičkog lanca bagera, njegovog položaja u radnom području i pravca i smera delovanja moguće sile otpora kopanja.

Mehanizam okretanja platforme hidrauličkih bagera, zavisno od veličine bagera, može biti sa jednim ili više istih pogona, pri čemu kod mehanizma sa dva i više pogona opterećenje aksijalnog ležaja od reakcije pogona zavisi od njihovog relativnog položaja u odnosu na ozubljeni prsten ležaja.

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Analysis of the Influence of Slewing Platform Drive Mechanism of Hydraulic Excavators on the Load of the Axial Bearing Mechanism

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The paper contains the results of research related to the analysis of the influence number of slewing platform drive of hydraulic excavators on the load of the axial bearing drive mechanism. The general model of mechanism of slewing platform is considered with a transformational - hydrostatics part that consists of a hydro pump and a hydro motor and a transmission - mechanical part with planetary gear and an axial bearing of a large diameter. The general mathematical model of the excavator and the software for determining the equivalent loads of axial bearing on the basis of which the choice of bearing size from the range of available, which produced by specialized manufacturers is defined. At the end of the work, for example, for a hydraulic excavator mass 102000 kg with a loading bucket volume of 6,5m³, comparative results of axial load analysis of the slewing platform mechanism with one and two drives are given.

Keywords: slewing platform drive

1. INTRODUCTION

The primary function of hydraulic excavators, of all sizes, is the intermittent transportation of various materials in a spatial work field. Spatial manipulation of hydraulic excavators, which is very important for carrying out manipulation tasks, is provided by slewing joint of kinematic chain, in the form of a large axial bearing, which connects the support and movement mechanism L_1 (fig.1a) and the slewing platform L_2 .

The general model of the drive mechanism of the slewing platform of hydraulic excavators consists of: a) transformational-hydrostatic and b) transmission-mechanical parts

The transformer part of the drive mechanism of the rotary platform of the excavator consists of hydropump 2.1 (fig.1b) and hydro-motors 2.3, connected in an open or closed hydrostatic circuit.

In addition to the axial bearing 2.5, the transmission part of the hydraulic excavator's slewing platform mechanism belongs to the integrated gearbox comprising the hydro motor 2.3 and the planetary gear unit 2.4 connected in a unique module with a lamellar brake between the output shaft of hydro motor and input shaft of gear.

The hydro motor is powered by a hydraulic pump, driven by a diesel engine 1 via an elastic coupling 1.1 and a toothed energy distributor 1.2 of diesel engines.

The axial bearing of the large diameter of the mechanism of slewing platform of the hydraulic excavators has an outer and inner ring, between which the paths of the rolling bodies are shaped like balls or rollers. The outer or inner ring is toothed all over.

On the output shaft of the planetary gearbox attached to the slewing platform, there is a gear z_{24} that is wrapped with a toothed ring z_{25} of the axial bearing, firmly attached to the support and movement mechanism of the excavator.

Within the developed general methodology [1] for the synthesis of the slewing platform drive mechanism of hydraulic excavators, a detailed analysis of the parameters of the functions was carried out, i.e. analysis of the kinematic, dynamic and energy parameters of the drive. The studies of the kinematics and dynamic parameters of the drive mechanism of the excavator's slewing platform included: a) determination of the type, size and character of the change in the movement and load of the mechanism of the slewing platform,

Figure 1: Slewing platform drive of hydraulic excavator: a) excavator model b) functional scheme of the mechanism

which occur in the operation of excavators with different manipulators and in different operating conditions; b) the assessment of the impact of dynamic loading of the drive relative to the static load, c) the determining of the operation of the manipulation task of excavators in which kinematic and dynamics parameters are relevant for the synthesis of the slewing platforms drive, d) determining of the spectra of equivalent load of axial bearing in the entire working area of the excavator based on the possible forces of digging and e) the analysis of the influence of the parameters of the mechanism of slewing platform on the energy efficiency of the drive and the dynamic stability of the excavator.

The procedures of the developed methodology for the synthesis of the drive mechanism of the excavator's slewing platform determine the components of the drive (hydropump, hydromotor, reducer, axial bearing) based on the given parameters of the drive functions with the limitations related to the allowed parameters of the available sizes of components produced by, in large series, specialized manufacturers.

The obtained results of the conducted investigations related to the synthesis show that the mechanism of the rotary platform of the same model of hydraulic excavators can be carried out to one or more drives, whereby the drive can be with a hydro motor of a smaller specific flow and a gear ratio of a higher transmission ratio and vice versa, whereby the same output parameters (number of rpm and torque) of turning the platform. In this paper, as part of the research carried out, an analysis of the influence of the number of actuators of the mechanism of the slewing platform of the excavator on the load of the axial bearing mechanism was given.

2. ANALYSIS OF AXIAL BEARING LOAD

In the initial phase of the synthesis process of the mechanism of the slewing platform of hydraulic excavators, the axial bearing of the drive is determined. Determination is done by selecting the axial bearing type and size from a range of available models that are produced as special modules, specialized manufacturers (Rothe Erde, INA, SKF) [2] [3] [4].

The axial bearing size selection criteria are based on the force F_2 and the load bearing moment M_2 determined by the equations (Fig.2)[5]:

$$F_2 = -W - \sum_{i=2}^5 F_{ui} - F_{c2} \quad (1)$$

$$M_2 = ((r_w - r_2) \times W) + \sum_{i=2}^5 ((r_i - r_2) \times F_{ui}) + \sum_{i=2}^5 M_{ui} \quad (2)$$

where is: W - vector of possible resistance forces of digging [1], F_{c2} - reaction force of the platform drive, F_{ui} - the total force associated with the center of the member's mass L_i of kinematic chain of the excavator equal to the sum of the inertial and gravitational forces, M_{ui} - moment of the inertial force of a member L_i , r_w - position of the center of the cutting edge of the bucket, r_i - position vector of the center of the member's mass L_i and r_2 - position vector of the center of the axial bearing.

Depending on the number of drive mechanisms of the slewing platform and their arrangement in relation to the axial bearing toothed ring, additional loadings of the axial bearing may occur from the reaction of the platform drive due to the action of the resistance of the digging resistance, gravitational and dynamic loads caused by the moving of the manipulator of the excavator during the manipulative tasks in the entire working area of excavators.

Figure 2: Components of axial bearing load of slewing platform drive of hydraulics excavator: a) forces, b) moments, c) forces of axial bearing loads with one drive, d) forces of axial bearing loads with two drives

The reaction force in mechanism with a one drive of slewing platform is determined by the equation (fig. 2a):

$$F_{c2} = \frac{2|M_{2y}|}{D_{25} - d_{24}} [\sin(\theta_2 + \alpha_2)\mathbf{i} - \cos(\theta_2 + \alpha_2)\mathbf{k}] \quad (3)$$

where is: M_{2y} - moment of slewing platform drive, α_2 - angle of position of the platform drive relative to the local coordinate system of the platform, θ_2 - angle of the platform's position relative to the absolute coordinate system, D_{25} - diameter of the toothed ring of the axial bearing, d_{24} - diameter of the output drive shaft, $\mathbf{i}$, $\mathbf{j}$, $\mathbf{k}$ - unit vectors of the absolute coordinate system of the excavator.

With larger excavators with two same drives positioned at an angle of $\beta_2 = 180^\circ$ (fig. 2b), the reaction force of the platform drive is canceled and the bearing is not loaded.

Taking into account the additional load from the reaction of the slewing platform drive mechanism, the resultant and the components of the force in the joint O_2 of slewing platform, which load the axial bearing, are determined by the following equations:

$$F_{2x} = F_2 \cdot \mathbf{i}_2, \quad F_{2y} = F_2 \cdot \mathbf{j}_2, \quad F_{2z} = F_2 \cdot \mathbf{k}_2 \quad (4)$$

The resulting force F_2 loads the axial bearing with the radial force F_{2r} , which, at the horizontal level of the bearing, builds the components F_{2x} and F_{2z} :

$$F_{2r} = (F_{2x}^2 + F_{2z}^2)^{0.5} \quad (5)$$

and the axial force F_{2a} acting along the axis of the O_{2y} bearing and is equal to the component F_{2y} :

$$F_{2a} = |F_{2y}| \quad (6)$$

The resultant and components of the moment in the joint O_2 of slewing platform, which load the axial bearing of the slewing platform drive, are determined by the following equations:

$$M_{2x} = M_2 \cdot \mathbf{i}_2, \quad M_{2y} = M_2 \cdot \mathbf{j}_2, \quad M_{2z} = M_2 \cdot \mathbf{k}_2 \quad (7)$$

The resulting moment M_2 loads the axial bearing at the moment M_{2r} that builds the components M_{2x} and M_{2z} , whose vector lies in the horizontal plane:

$$M_{2r} = (M_{2x}^2 + M_{2z}^2)^{0.5} \quad (8)$$

and the slewing platform drive with the component M_{2y} , whose vector is a collinear with an axis of bearing.

The size of the axial bearing of slewing platform drive is selected based on [2]:

$$\text{equivalent forces: } F_{es} = (a \cdot F_{2a} + b \cdot F_{2r}) \cdot f_s \quad (9)$$

$$\text{and the equivalent moment: } M_{es} = c \cdot M_{2r} \cdot f_s \quad (10)$$

where is: a , b , c - coefficients dependent on the type of bearing, type and size of the machine and its working conditions, f_s - static safety factor.

The coefficients used to determine the equivalent forces and moments are given by the manufacturers of axial bearings in their catalogs for each type of bearing (balls, roller, single row, double row and multiple row), according to the purposes and operating conditions of the machine on which they are installed.

3. THE EXAMPLE OF LOAD ANALYSIS OF AXIAL BEARING

On the basis of the defined mathematical model, the software for dynamic simulation of the excavator has been developed, which enables, among other, the determination of the equivalent load of the axial bearing of slewing platform drive mechanism depending on the duration of the individual operations (digging, transfer, unloading, returning) of the excavator's manipulation task.

In a particular position of the excavator's kinematic chain, the equivalent loads of the axial bearing shall be determined according to the possible digging resistance, which represents the minimum value from the set of limit values for digging resistance determined from the conditions of the excavator stability and the bordering digging resistance that can overcome the manipulator drive mechanisms at the maximum working pressure of the drive excavator.

Using the developed software, as an example, the influence of the number of drives of slewing platform drive mechanism on the load of the axial bearing mechanism for a hydraulic excavator mass 102000 kg equipped with a loading manipulator and bucket volume of 6.5m³. A comparative analysis of the equivalent load of axial bearing for variants of excavators **A** and **B** has been carried out. The variant of the excavator **A** is with one, and the variant of the excavator **B** is with two drives of the mechanism of the slewing platform.

In the case of a variant of the **A**, model with one slewing platform drive, it was assumed that the drive was placed in the local coordinate system of the platform at an angle of $\alpha_2 = 180^\circ$ (fig.3.a) relative to O_2x_2 axis, which corresponds in practice to the most common mode of installation, considering the available space and the proximity of the hydromotor, the hydropump of the drive group of excavators.

For the version of the excavator **B** model with two slewing platform drive, the drives were positioned in a relative position at an angle of $\beta_2 = 180^\circ$ (fig.3b) in the local coordinate system of the platform.

Figure 3: Reaction force of platform mechanism with: a) one drive, b) with two drives

The obtained results of the analysis show (fig. 4) that the variant of the excavator model **A** with one slewing platform drive has a higher equivalent bearing load compared to a model **B** with two drive variant.

The reason for the increased equivalent forces is that the variant of the excavator **A** with a single drive is the reactive force of the slewing drive which further radially loads the axial bearing. Reactive drive forces occur during a manipulation task during a digging operation in case of

Figure 4: Comparison of the equivalent static ($F_{esA,B}$, $M_{esA,B}$) and dynamic ($F_{edA,B}$, $M_{edA,B}$) equivalent forces and moments of load axial bearing variant of the excavator model *A* with one and model *B* with two slewing platform

eccentric digging force acting in relation to the longitudinal symmetric plane of the manipulator, and in the phases of the accelerated and decelerated of the excavator platform. For the variant of the excavator *B* with two drive units, the reactive force of the drive has the same intensities but the opposite direction of action so that they do not loaded the additional axial bearing of the drive. Equivalent moments of axial bearing for both variants *A* and *B* of the slewing platform drive of the excavator are the same, since the reaction forces of the drive have no effect on them. The changes in the static ($F_{esA,B}$, $M_{esA,B}$) and dynamic ($F_{edA,B}$, $M_{edA,B}$) equivalent forces and moments (fig. 4) of load axial bearing during the manipulation task of the variants of excavators *A* and *B* show that for variant *A* with one drive occurs greater equivalent forces in the digging operation (red line) and in all other operations of the manipulative task (blue line) in relation to variant *B* with two platform drives.

5. CONCLUSION

The results of the investigations carried out in connection with the synthesis of slewing platform drive mechanism of hydraulic excavator indicate that the choice of the axial bearing size requires the knowledge of the parameter of the members of the kinematic chains and the drive mechanisms of the excavator manipulator. The size of the axial bearing is chosen by comparing the given load diagram of bearings and equivalent forces and equivalent moments of certain, according to the defined criteria, based on the radial and axial forces and moments of slewing platform drive of the excavator. Equivalent axial bearing loads depend on the configuration of the kinematic chain of the excavator, its position in the working area and the direction and of action the possible digging resistance.

The mechanism of slewing platform of hydraulic excavators, depending on the size of the excavator, can be with one or more the same drives, whereby in the case of a mechanism with two or more drives, the load of the axial bearing from the reaction of the drive depends on their relative position, relative to the toothed ring of the bearing.

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