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RESEARCH AND DEVELOPMENT OF CARRYING STRUCTURE OF RADIAL-AXIAL BEARING OF CONSTRUCTION AND TRANSPORT MECHANIZATION MACHINES

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Abstract: *Choice of geometric values of support structure of radial-axial bearing can influence the defining of necessary stiffness of construction and transport mechanization carrying structure. This parameter has a dominant influence on functionality and reliability of radial-axial bearing function.*
Apart from using the theoretic relations of geometric values which influence the reduction of bearing structure support surface deformation, it is not possible to completely eliminate the above mentioned occurrence.
The paper gives the systematization of theoretic and experimental results in realized solutions research, and in the end it gives a constructive solution which eliminates the influence of terrain roughness on radial-axial bearing support surface deformation.

Key words: *radial-axial bearing, carrying frame, mechanization, deformation, structure*

1. INTRODUCTION

While excavator is in function, due to roughness of leaning surface, it is not possible to accomplish the complete contact between the caterpillar running machine and the leaning surface so a torsion of carrying structure occurs. Excavator carrying structure torsion deforms the support surface of the radial-axial bearing bond structure.
Choice of geometric values of radial-axial bearing carrying construction can influence the structure stiffness of construction and transport mechanization machines. This parameter has a dominanat influence on functionality and reliability of radial-axial bearing function. In numerous manuscripts there has been done the analysis of load transfer from revolving platform to carrying structure over the radial-axial bearing and further to leaning surface, regarding excavators, portal cranes or other machines of construction and transport mechanization [1]. Long life and functionality of these bearings greatly depends on support surface stiffness to bearing bond. As the contact between terrain and running machine is not possible, either for ground deflection or production error, there occurs lifting or descending of some of machine supports, that is the redistribution of vertical reactions in supports and by itself the deformation of carrying structure.

Fig.1. Types of excavator running machine realizations

2. MODEL DEFINING

Analytic defining of stiffness dependence and influence of geometric values of support structure relations would enable the geometric structure parameters solutions which would provide the successful track supervision and proper bond function by radial-axial bearing. Supposing that one of the supports (support C –figure 2) is declined for Δ value, the basic system is formed in a way that in support D the unknown force X_1 is introduced, and instead of the rejected bonds, the unknowns X_i $(i=2,3,...,7)$ are introduced [1], [2], [3],[9].

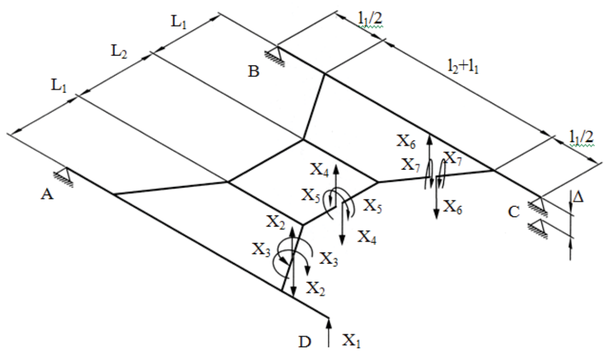


Fig.2. Excavator carrying frame model

In case that values relations for excavator carrying frame model are introduced (figure 2) [1], [2]:

$$\psi = L_1/L_2\,;\eta = I_5/I_2\,;\beta = I_4/I_2\,;$$

$$\varphi = I_3/I_2\,;w = l_1\,/\,l_2;I_2 = I_1$$

applying canonic equations:

$$\sum_{j=1}^{10}\delta_{ij}\cdot X_j + \Delta_i = 0 \quad ; \quad i = 1,...,7 \qquad (1)$$

we come to theoretic dependences:

$$\frac{C_{ki}}{C_{kj}} = \left(\frac{k_i}{k_j}\right)^{\sqrt{3}} \quad \text{i} \quad \frac{C_{Li}}{C_{Lj}} = \left(\frac{L_j}{L_i}\right)^3 \qquad (2)$$

where:

δ_{ij} - moving of point i because of unit load functioning

$\overline{X_j} = 1$;

X_j - real value of the unknown parameter;

Δ_i - moving of point i because of outer load functioning.

In considerations there has been used the relation between flexural and torsional stiffness for box-like cross section carriers of steel plates:

$$\mu = \frac{EI_x}{GI_{0\,1}} = \sqrt{3}k\lambda^{0,4} \qquad (3)$$

where:

k – relation quotient of cross section carier height and width

λ – relation quotient of horizontal and vertical cross section carrier plates thickness

2.1. Solving the given problem

By solving the system of canonic equations by the unknown X_1 with knowing the value of support Δ "descending", it is possible to determine the stiffness [2], [8], [9].

On the base of these analyses, we come to a conclusion that it is possible by choosing the relations of carrying structure geometric values to influence the:

increase of carrying structure stiffness,

better supervision of the track where the machine goes, that is proper functioning of the bond between the revolving and nonrevolving part.

However, even if the relation is defined in this way, it is not possible to provide the stiffness where the deformation of support surface would be smaller than allowed. Ingredient element, whose mounting considerably influences the effect of stiffness increase in support surface of radial-axial bearing, is cylindric cross section carrier (figure3 – position 4).

Realization of cylindric cross section carrier function depends above all on its geometric characteristics. By defining the necessary height *l* and the wall thickness of cylindric carrier (δ) it is possible to reduce deformation of support surface of radial-axial bearing with big diameter.

For determining the necessary height of cylindric carrier we use the relation:

$$\beta\cdot l \geq 3 \Rightarrow \sqrt[4]{\frac{3\left(1-\nu\right)^2}{r^2\cdot\delta_z^2}}\cdot l \geq 3 \qquad (4)$$

where:

ν - Poisson quotient,

δ - cylindric carrier wall thicknes,

R – curve radius of cylindric carrier.

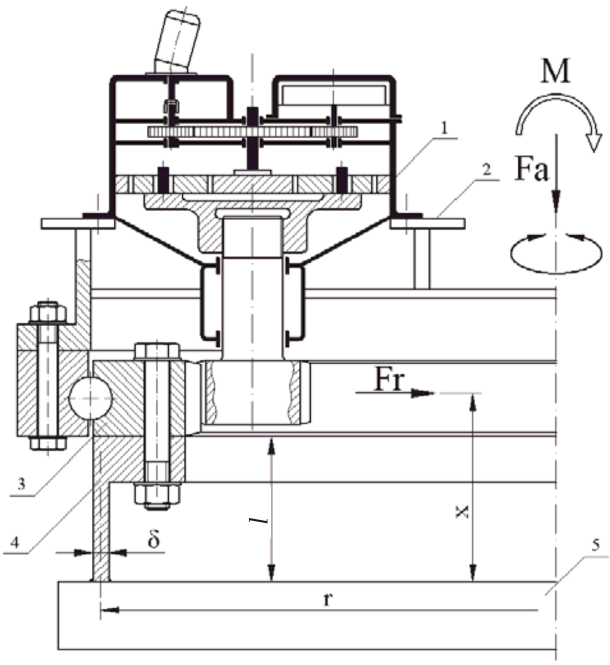


Fig.3. Radial-axial bearing with cylindric cross section carrier

On the base of realized solutions we can conclude that the relation of radius and cylindric carrier thicknes is found within $r/\delta_z = 20\div30$, so the smallest height l for $\nu=0,3$:

$$l \geq \left(0.45 - 0.56\right)\cdot r \qquad (5)$$

Wall thickness has a considerable influence on deformations in support surface of cylindric carrier. Having in mind the loads which radial-axial bearing conveys during function, in order to determine the wall thickness, we need to determine the moving of points of support surface which are a consequence of action of radial force and knock over moment.

Out of condition that such calculated moving is less than allowed we get:

$$\delta_z \geq \frac{2\cdot M\cdot l + F_r\cdot l^2}{2\cdot\pi\cdot r^2\cdot E\cdot\delta_{doz}} \qquad (6)$$

For model (figure 4) with geometric values for two realized solutions, with and without indirect element between radial-axial bearing and carrying structure (position 4, figure 3), there has been done a comparative analysis of moving the characteristic points of support surface.

Also, the experimental research has been done in order to verify the theoretic results. Memi feeders are set on appropriate places of carrying structure of radial-axial bearing (figure 4).
Characteristic positions of revolving platform, considered in the experiment, follow:

a) Carrying frame leans on all the supports, when they are in horizontal plane, loaded with its own weight and extra load. Turning has been done with stopping at every 45° and without stopping.
b) Carrying frame leans on the supports, where one of them is lowered for value Δ loaded with its own weight and extra load. Turning has been done with stopping at every 45° and without stopping.

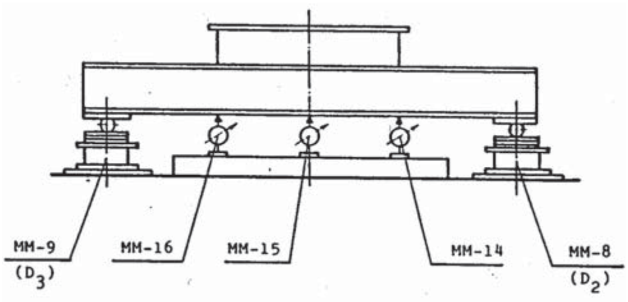


Fig.4. Experimental model

Comparative results of stiffness, obtained by calculation and research, show a high level of matching (deviation less than 13%).

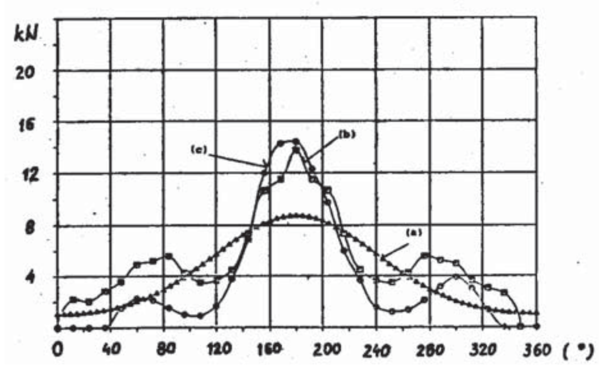
Table 1. Comparative display of theoretic and experimental results

	Force on the support O_2 (kN)	Deflections on the support O_2 (mm)
Calculation value	57.79	2.3
Eksperimental value	56.98	2.0

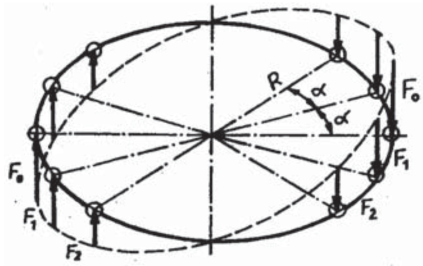
Radial-axial bearings have small stiffness. Moment loads are different by bearing sizes and cause pressure increase on one group of balls (cylinders), and decrease on the other one. If the support surfaces of revolving and nonrevolving parts are stiff; that is if movements of some of the points are smaller then allowed values, than it can be taken that the distribution of forces from the moment is a straight line.
Results of the analysis of load distribution for different calculation models are shown in figure 5a [5],[7].
Load distribution from the moment, at equal distance of balls by defined angle α (figure 5b), can be determined by the following equation:

$$M = 2F \cdot r = 2F_0 \cdot r + 4F_1 \cdot r \cdot cos(\alpha) + 4F \cdot r \cdot cos(2\alpha) + + 4F_x \cdot r \cdot cos(x\alpha) \quad (7)$$

where:
$\alpha = 2\pi / z$ – angle between two adjacent balls
$x = (z-4)/4$ – number of angles on one quarter of bearing
r – radius of the ball's path
z – number of balls



a)



b)

curve – a – stiff model
curve – b – final elements model
curve – c – experimental results

Fig.5. Load distribution at radial-axial bearing

If the force F_0 causes deformation δ_0, then the deformation from the force is F_x, $\delta_x = \delta_0 \cdot cosx\ \alpha$.
It shows that the relation is:

$$\frac{F_0^2}{\delta_0^3} = \frac{F_1^2}{\delta_1^3} = \frac{F_2^2}{\delta_2^3} = ... = \frac{F_x^2}{\delta_x^3} = const \Rightarrow$$

$$F = F_0 \left(1 + 2\,cos^{2.5}\,\alpha + 2\,cos^{2.5}\,2\alpha + ... + 2\,cos^{2.5}\,x\alpha\right) \quad (8)$$

Expression in brackets depends on the number of balls z. For different values of balls number, we get relations $z/(F/F_0)$ shown in table 2.

Table 2. Relation $z/(F/F_0)$ in function of number of balls z

Number of balls z	Angle between the balls α	Number of angles x	Relation $z/(F/F_0)$
12	30	2	4.36
16	22.5	3	4.37
36	10	8	4.37
72	5	17	4.40

It can be seen that these relations have value of about 4.37, which says that 1/4 of 1/5 balls convey the load from the moment, or that the bearing is loaded on the part which is limited by angle of 72° to 90°. Considering also the elastic deformations, load distribution from the moment does not follow a straight line. Deviations for the real model reach the values higher than the theoretical up to 30%. Load from the moment is conveyed over a part of the ring, limited by angle of 45^0 from both sides of the moment action plane, which points to a fact that this segment of revolving part must have higher stiffness.

bearing support surface deformation is decreased. Change in support surface deformation, with and without cylindric carrier, is shown in picture 8.

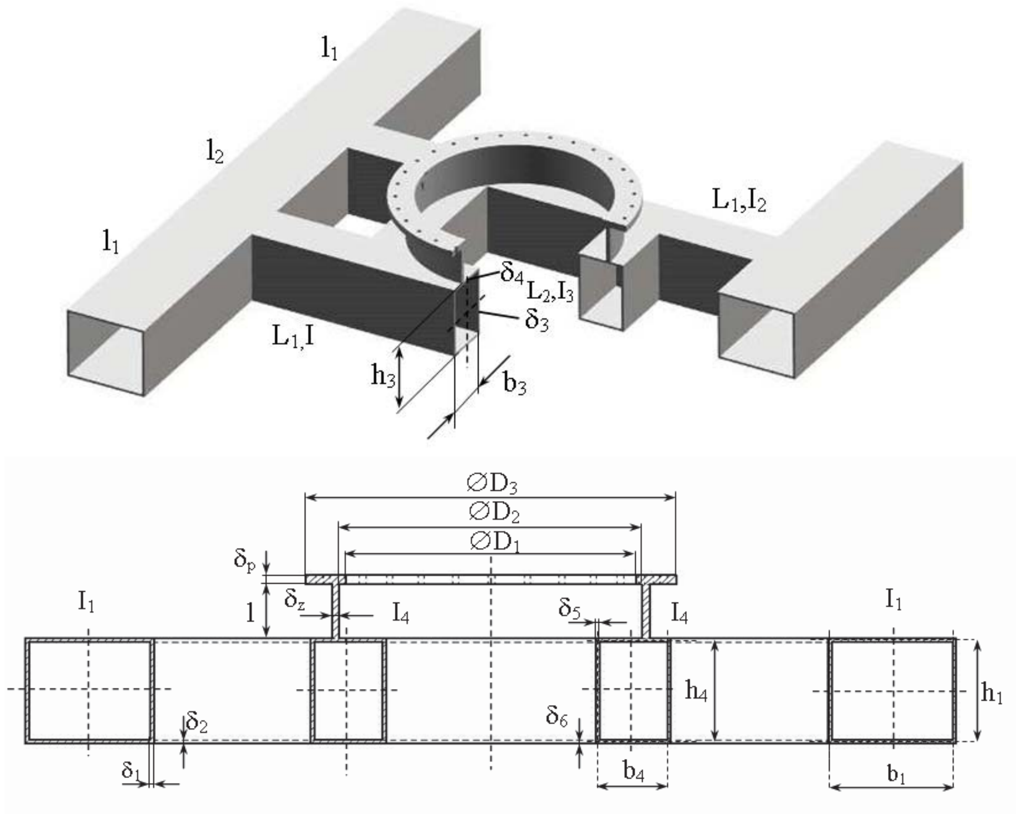


Fig.6. Realised solution of carrying frame of radial-axial bearing

Further analysis of carrying frame of radial-axial bearing and determining the performance of revolving and nonrevolving parts bond, can be done by final elements method. We start with the realized solution and determine the movement of points of longitudinal and transversal carriers.

Realized solution of carrying frame of radial-axial bearing with geometric parameters (Table 3) is shown in figure 6.

In order to understand the influence of roughness of terrain where machine goes on support surface deformation, as well as the verifications of formerly obtained conclusions, the movements of characteristic points of support surface are obtained by considering the carrying frame with and without cylindric carrier. Necessary movements of support surface of both variants of carrying structure obtained by final elements method are shown in figure 7.

Aim of analysis is reduction of influence of terrain roughness where construction and transport mechanization machines go. Shifting of one of supports Δ was taken as outer load. Lower shifting values are bound to transport machines (cranes), while higher shifting values are characteristic for construction machines.

By mounting the indirect element between the carrying structure and the radial-axial bearing, the effect of stiffness increase in the bearing support surface is realized, that is the influence of terrain roughness on the

Table 3. Geometric parameters of realized solutions of radial-axial bearing carrying structure

Excavator carrying structure realization type - H			
Parameter	Parameter value	Parameter	Parameter value
L_1 (mm)	725	δ_1 (mm)	10
L_2 (mm)	800	δ_2 (mm)	10
l_1 (mm)	1000	δ_3 (mm)	10
l_2 (mm)	800	δ_4 (mm)	16
I_1 (cm^4)	20270	δ_5 (mm)	10
I_2 (cm^4)	16126	δ_6 (mm)	16
I_3 (cm^4)	16126	h_1 (mm)	300
I_4 (cm^4)	16126	b_1 (mm)	350
h_2 (mm)	300	D_1 (mm)	815
b_2 (mm)	200	D_2 (mm)	850
h_3 (mm)	300	D_3 (mm)	1040
b_3 (mm)	200	δ_p (mm)	30
h_4 (mm)	300	δ_z (mm)	20
b_4 (mm)	200	l (mm)	160

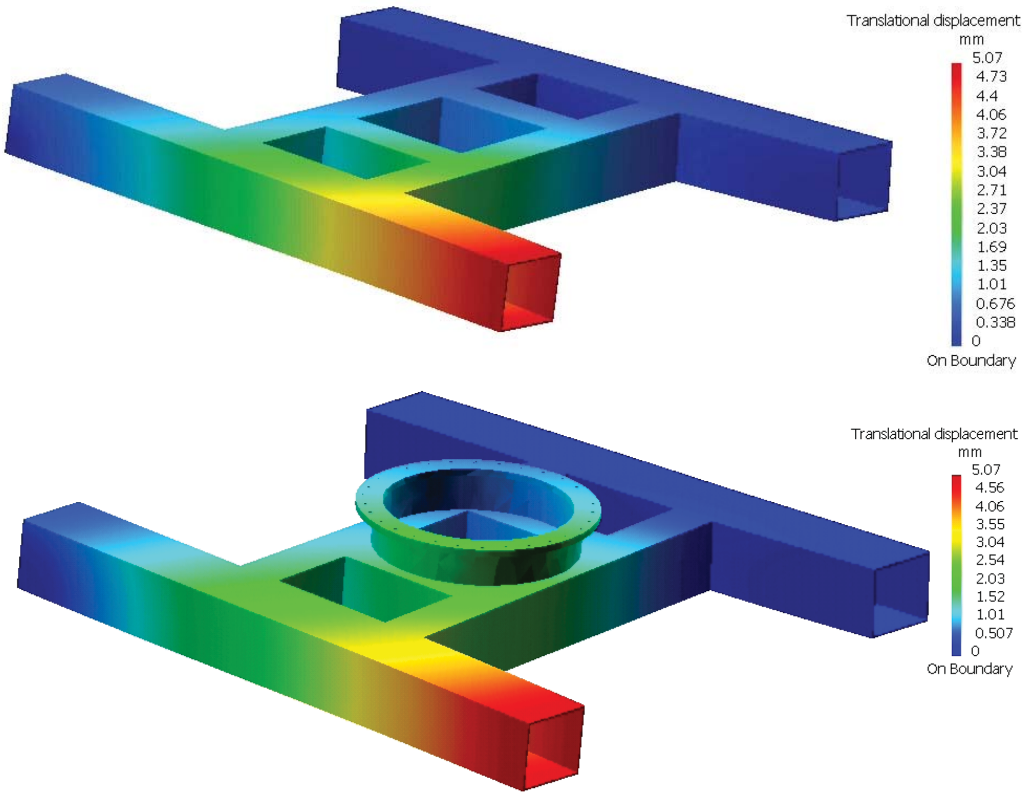


Fig.7. Movements of carrying frame points,with and without cylindric carrier

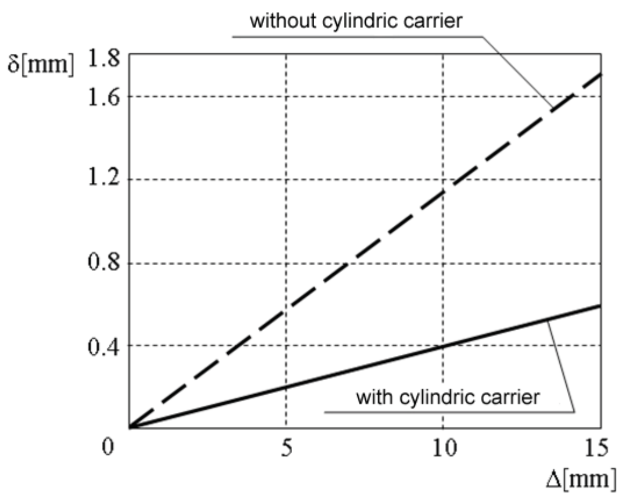


Fig.8. Comparative diagram of carrying structure support surface deformation with and without cylindric carrier

Stiffness increase effect by mounting the indirect element, having in mind the bearing producer's references and proper functioning of revolving and nonrevolving parts bond is given in figure 9.

By value analysis for characteristic point deformation of support surface for variants with and without cylindric carrier, it's decrease can be seen, that is carrying frame stiffness increase at indirect element mounting. Having in mind the preconditions of reliable and safe function of revolving and nonrevolving parts bond, as well as the appropriate choice of carrying frame geometric values relations, it is noticeable that the necessary stiffness of support surface can be realized by mounting the indirect element and also by the right choice of bearing type.

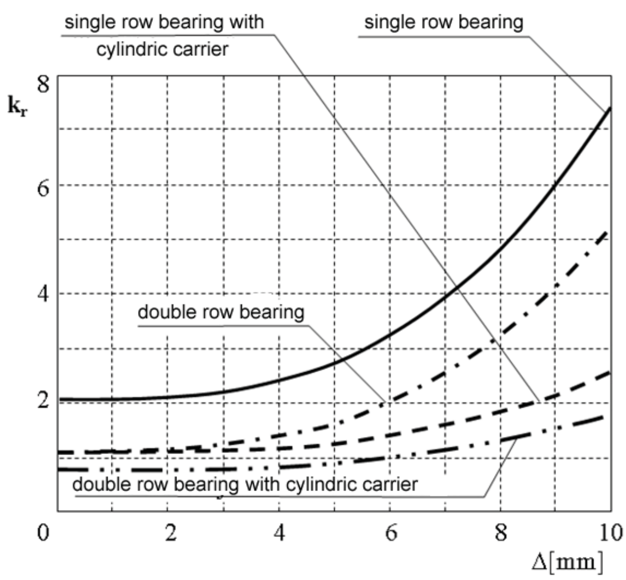


Fig.9. Comparative diagram of stiffness difference quotient dependence k_r

Bearing structure influence effect, that is the bearing type, is smaller for structure variant with cylindric carrier as indirect element. At that, we should also bear in mind the fact that the choice of radial-axial bearing depends on the load that it conveys during its exploitation. By appropriate choice of geometry of structure itself and the indirect element, it is not always possible to realize smaller points movements of support surface than allowed.

3. ANALYSIS OF NEW SHAPE OF RADIAL-AXIAL BEARING CARRYING STRUCTURE

By realizing the influences of certain parameters on support surface deformation, which is based on former analyses, we came to a new shape of carrying structure (figure 10) which would almost completely disable the support surface deformation of bearings with big diameters caused by the terrain roughness.

In this way a better machine adaptability to the terrain would be realized, that is contact of all the wheels with the terrain.

Deformations and roughness of the ground, defined by the angle in relation to referent plane, by rule do not overcome values $\gamma = \pm 10^0$ in over 80% function situations. If the structure solution of the bond between the main carrier and the bearing carrier is done in joint shape (figures 11 & 12) the influence of ground deformation and roughness on deformation of support surface for bearing bond can be eliminated.

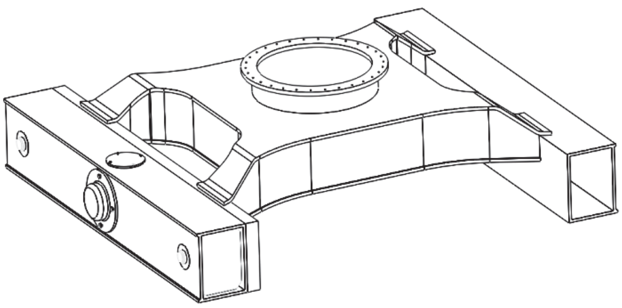
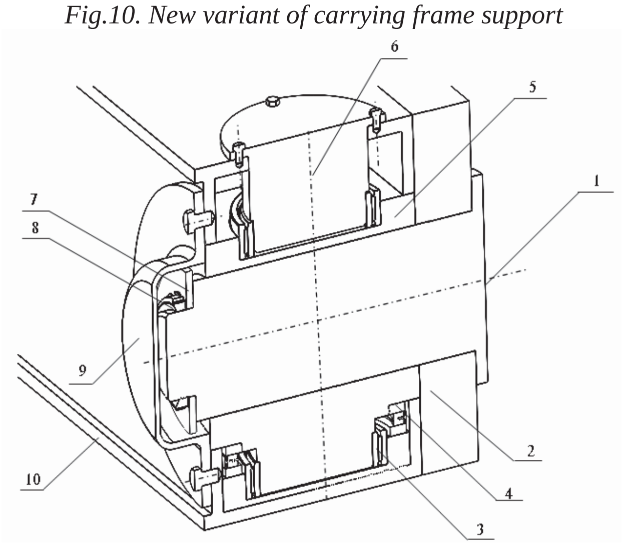


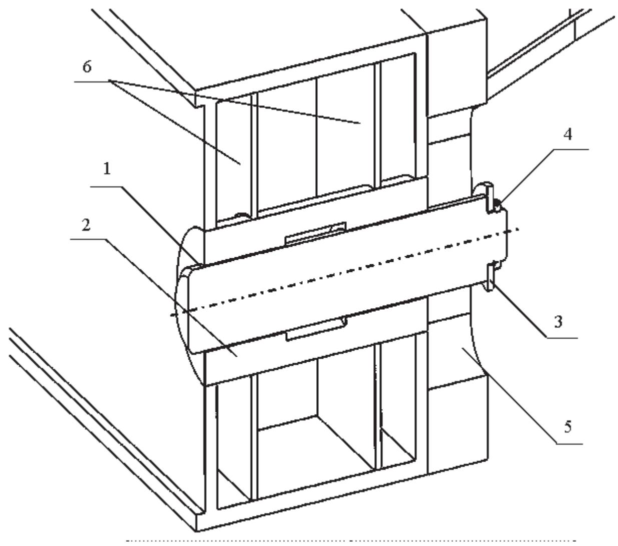
Fig.10. New variant of carrying frame support



1. Central axle *2. Sliding plate*
3. Axial bearing *4. Radial bearing*
5. Bush *6. Upper lid*
7. Limiter *8. Safety nut*
9. Lid *10. Longitudinal carrier*

Fig.11. Joint bond of longitudinal carrier's central part

Joint bond is placed in the central part of longitudinal carrier, while at its ends are axles which form sliding pairs. More detailed display of suggestion for new solution of carrying structure, by which the deformation of bearing support surface is eliminated, having in mind the size of real load during the construction machine's work, is shown in figures 12 – 14 [8].



1. Axle *2. Bush* *3. Limiter*
4. Nut *5. Lead* *6. Stiffness*

Fig.12 Final bond of longitudinal carrier and carrying structure frame

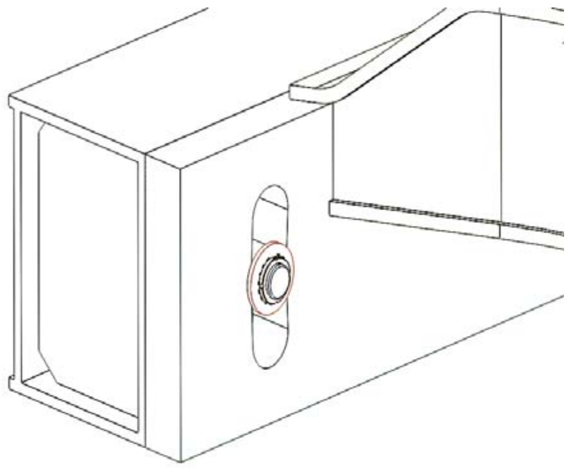


Fig.13. Sliding plate

Loads (axial force F_a, radial force F_r and moment M) are carried over radial-axial bearing. In case of total stiffness of support surface of revolving and nonrevolving parts, the law of distribution of pressure forces from the moment is a straight line, which is not the case when the elastic deformations of support elements are taken.

Confirmation to these facts, as well as the development of models which would consider numerous influences on load distribution, are given in a great number of papers [4],[5],[6],[7]. Values of forces or loads depend on calculation method type, but they are within the limits acceptable for engineering practice, while further progress in this field is realized thanks to wide range of FEM use. Example of results for deviation in tension values on the

FEM outer ring surface and by experimental measuring, at support surfaces rotation of 30° one in relation to another and the load F_a = 123.3 kN, M=555.3 kNm [5], is shown in figure 15.

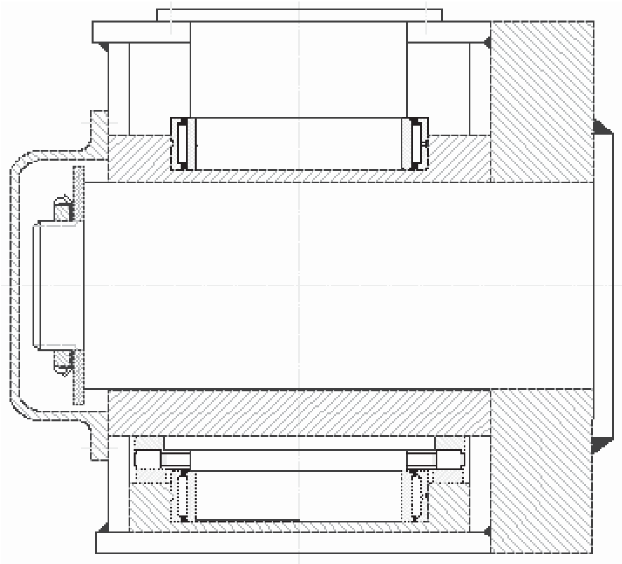


Fig.14. Joint bond of longitudinal carrier

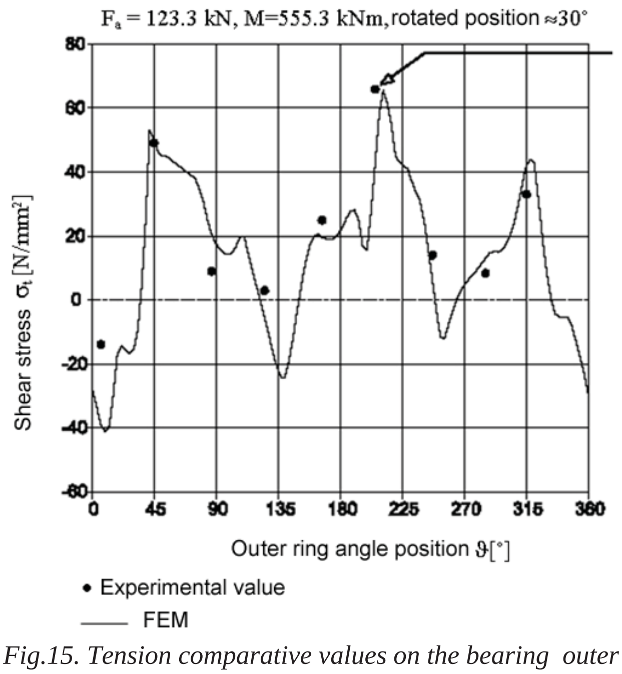


Fig.15. Tension comparative values on the bearing outer ring surface obtained by FEM and measuring; support surfaces rotated 30° one in relation to the other and given load

4. CONCLUSION

Special attention in this paper is directed to further development and improvement of revolving and nonrevolving bonds in construction and transport mechanization machines, concretely to proper functioning of revolving and nonrevolving parts bond over radial-axial bearings with big diameters. Basically, studying the influential parameters on the bond is of complex nature, therefore it is necessary to reduce the number of influential parameters without disturbing the generality of considered problem.

Easy mounting of bearing's assembled elements and increased stability of the whole structure with own boundary parameters, make an advantage compared to other ways of supporting, and by that the justified analysis and research of influential parameters on revolving and nonrevolving parts bond.

Justifiableness of the analysis and researches with the aim of life prolonging and safety in function of named machines is the greater the more we have in mind the problems at transfer of load from revolving to nonrevolving parts of carrying structures in construction and transport mechanization machines.

By comparative analysis of movement values of characteristic points of support surfaces for the first and second variant (figure 7), the influence of cylindric carrier mounting on reduction of deplanation and on movements of support surface points for radial-axial bearing bond can be determined.

By mounted cylindric carrier, it is not always possible to realize movements that are smaller than allowed, and partially the stability of excavator during work is reduced.

That is why we should research the shape of carrying structure without cylindric carrier. The solution is in joint carrying structure (figures 10 & 11) which in great part will eliminate the influences of terrain roughness on deformation of bearing support structure.

REFERENCES

[1] JEVTIĆ, D., GAŠIĆ, M., *The influence of relation between elements geometric dimensions of a dredger supporting structure and the connection with the rotating platform,* International conference on engineering design, IECD, Dubrovnik 1990, pp 23-43

[2] GAŠIĆ, M., MARKOVIĆ, G., SAVKOVIĆ, M., *Supplement to development of new solution of bond between revolving and nonrevolving parts of construction and transport mechanization machines,* IMK 14 Research and development, 2009, Vol. 16, No. 4, pp 399-412

[3] GAŠIĆ, M., PETROVIĆ, D., *Geometric identification of cylindric carriers of radial-axial bearings with big diameters,* International conference on transport in industry, Belgrade 1992, pp 23-43

[4] AMASORRAIN, J.I., SAGARTZAZU, X.,DAMIAN, J., *Load distribution in a four contact-point slewing bearing*, Mechanism and Machine Theory,2003, Vol 38, No. 4, pp 399-412

[5] ZUPAN, S., PREBIL, I., *Carrying angle and carrying capacity of a large single row ball bearings as a function of geometry parametars of rolling contact and the supporting structure stiffness*, Mechanism and Machine Theory, 2001, Vol 36, No. 4, pp 399-412

[6] PREBIL, I., ZUPAN, S., *Influence of actual loose fit upon carrying angle of axial bearings,* Strojniški Vestnik, 1990, Vol.36, No. 3, pp 399-412

[7] PREBIL, I., ZUPAN, S., LUČIĆ, P., *Load distribution onto rolling elements of a rotational connection*, Third International Congress on Air-and Structure Borne Sound and Vibration,Montreal 1994, VDI-Berichte, pp 23-43

[8] GAŠIĆ, M., MARKOVIĆ, G., SAVKOVIĆ, M., *Influence of excavator carrying structure constructive solution on increase of functionality and reliability of radial-axial bearing for the bond with rotating platform (In Russian)*, International Conference on Interstrojmeh, Voronež 2004, pp 23-43

[9] GAŠIĆ, M., KARAMARKOVIĆ, V., SAVKOVIĆ, M., MARKOVIĆ, G., *Research and development of new solution to the connection of excavator carrying construction*, International Conference -Heavy Machinery HM 2002, Kraljevo, 2002. p.p. A3÷A5,

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