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Laboratory Model of the Joint Connection in the Carrying Structure of the Excavator Undercarriage

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The laboratory model presented in this paper covers the formation of a new concept of connection between the revolving and non-revolving parts of transportation and earth-moving machinery. The new concept of connection is oriented toward providing better adaptability to the path along which the machine is moving and improvement of the function of indirect elements made in the form of large diameter bearings (type Rothe Erde) with the increased reliability in operation and speed of operations. The connections between revolving and non-revolving structures of transportation and earth-moving machinery have developed under the influence of different operation and structural requirements. However, the conceptual solutions so far (realized in the shape of "X" and "H" types) do not provide reliable and long operation of indirect elements (large diameter bearings) inserted between the revolving and non-revolving parts. The problem set for the model is a requirement how to structurally provide relief and reliable operation of the indirect element (large diameter bearings) inserted between the revolving and non-revolving parts of the excavator carrying structure. Unlike the existing solutions with a rigid connection, the new solution is based on the joint connection for the purpose of torsional relief of the carrying structure of the excavator undercarriage. The solution is conceived in such a way that, in addition to excavators, it can be applied to other transportation and earth-moving machinery.

Keywords: laboratory model, radial-axial bearing, torsional stiffness, underframe, deplanation

1. INTRODUCTION

It is widely known that it is not possible to realize a full contact between the path and the excavator undercarriage. The problem of realizing contacts can occur, almost as a rule, due to terrain roughness or, more rarely, faults made during manufacturing. As a consequence, during exploitation there occurs lifting or lowering of a machine support, i.e. redistribution of vertical reactions at the supports, which leads to deformations of the carrying structure [1, 2, 3]. The consequence of this phenomenon is the fact that the underframes of the existing solutions of radial-axial bearings cannot completely provide the necessary rigidity of the support surface for the bearing connection and, therefore, normal functioning of the connection between the revolving and non-revolving parts in such machines (Figure 1).

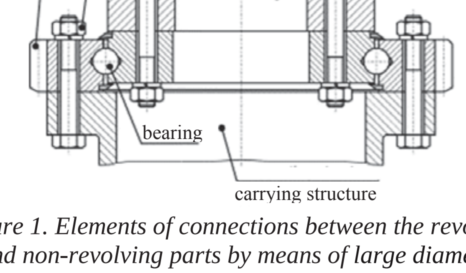

Figure 1. Elements of connections between the revolving and non-revolving parts by means of large diameter bearings [4]

Starting from a wide application of such a type of support and the problems which appear in transferring loads from revolving to non-revolving parts of the carrying structures of transportation and earth-moving machinery, the analysis and research for the purpose of increasing the life and safe operation of the mentioned machinery are imposed as an imperative. The solutions of the connection have been improved in the course of time by inserting a mid-element – cylindrical carrier, for the purpose of reducing deplanation of the support surface of the large diameter radial-axial bearing [4].

Normal functioning of transportation and earth-moving machinery, with revolving and non-revolving parts, depends on the parameters influencing the value of pressure at the supports. In other words, the results of research into the transfer of loads from the revolving part to the connection with the non-revolving part should define the parameters influencing the proper functioning of the mentioned connection.

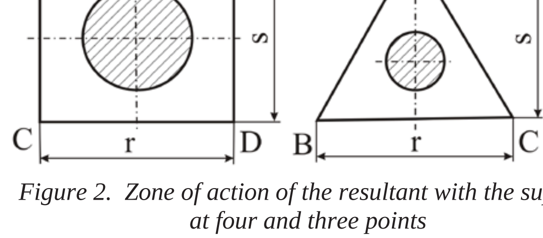

Figure 2. Zone of action of the resultant with the support at four and three points

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Generally, the existing solutions of the carrying structures of transportation and earth-moving machinery are such that deformations are mostly received by the support structure of large diameter bearings (support plate, carriers to which the plate is connected and the rigid ring).

The statically determined scheme of support at three points is mainly applied in high-productivity mining machines, modern portal cranes with horizontal displacement of loads and some jib cranes. The support at four points is applied in all other cases. The reason for larger application of the statically indefinite scheme of support at four points lies in the fact that the resultant of vertical forces can be distributed in a wider zone than with the support at three points with the same width of support. This is obviously seen in a comparative scheme of machines with a revolving part (Figure 2) [5]. With the support at four points, the forces at the supports depend on the state of the support surface (roughness and deformations) as well as on the structural solution and elasticity of the undercarriage of machines.

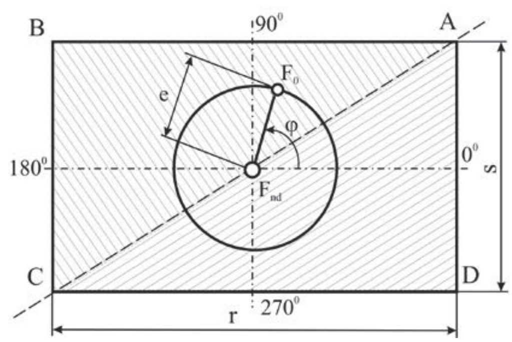

Figure 3. Zone of action of the resultant with the support at four and three points

So, if deformations of the base or faults in manufacturing and mounting of tracks occur, the support rectangle can be divided into two triangles (Fig. 3). If the resultant passes through one of the two triangles, e.g. ΔABC, the opposite support D, of the unloaded triangle ΔACD, detaches from the base or the track. By further rotation of the upper part of the machine, the resultant moves and the machine overturns around AC, and in that case the support is accomplished through ΔACD, i.e. the support B detaches from the base or the track.

All this shows that it is necessary to eliminate such an undesired effect, i.e. achieve uniform support on all wheels. The analysis of this problem with the influence of the previously stated phenomena is comprehensive because it also requires the introduction of parameters of the revolving parts (undercarriage) and the path along which the machine moves. The evaluation and influence of roughness of the path are often connected with certain difficulties, so that approximate methods of calculation are used [6]. In accordance with the equilibrium equations and with the assumption that ΔABC appears as the carrying one (Fig. 3), the forces at the supports F_A and F_C will have maximum values for the position of the boom in the direction of the diagonal AC:

$$F_{A\max} = \frac{F_{nd} + F_0}{2} + F_0 \frac{e}{\sqrt{r^2 + s^2}} \qquad \ldots\ldots(1)$$

whereas for the boom position in the direction normal to AC, the force at the support FB will have the maximum value:

$$F_{B\max} = F_0 \frac{e}{rs} \sqrt{r^2 + s^2} \qquad \ldots\ldots(2)$$

A better and more detailed analysis was performed by Herrnbrodt [16], and then he compared the obtained experimental results with the results of approximate methods. Namely, in that way he pointed to simple formation of the diagram F_A/F_0 in polar coordinates as a function of the angle of rotation of the boom φ around the point of rotation O, where the force F_A is presented in the form:

$$F_A = c + a\sin\varphi + b\cos\varphi = r_1 + r_2 \qquad \ldots\ldots(3)$$

or graphically in the form of two circle lines with the centre at O. The maximum value of the force F_A is at the boom position in the direction normal to the diagonal BD. The graph (Fig. 4) shows the curves of change of loads obtained by the different methods, as well as for the cases of support at three points.

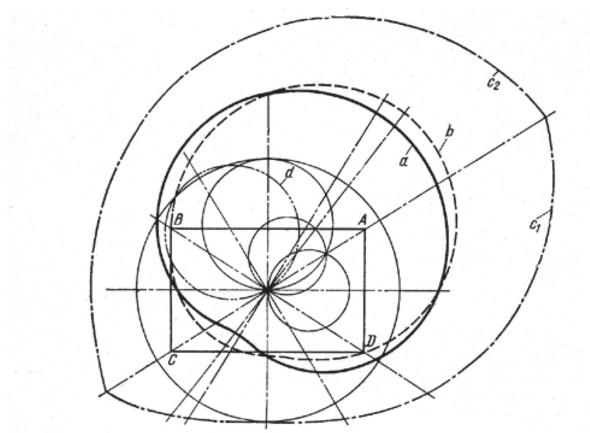

Figure 4. Polar diagram of the change of loads at the supports as a function of the angle of rotation
a-force F_A according to Montagnon; b- force F_A according to Andre; c_1-force F_A with the support at three points (ΔACD); c_2-force F_A with the support at three points (ΔABC); d-force F_B with the support at three points (Δ ABC);

In further exploitation, and for the purpose of providing the necessary rigidity of the support surface, the existing solutions with the rigid connection of the cylindrical carrier, i.e. the bearing support structure and the longitudinal carriers of the caterpillar assembly have been improved. In order to improve the solutions, the manufacturers of excavators have performed optimization of the geometry of the cross section of the bearing support structure and changed the relationship between its bending and torsional stiffness [7, 8, 9, 10].

Despite the optimization of the relationship between geometrical values of the carrying structure elements and installation of a cylindrical carrier, as an indirect element between the bearing and the underframe, the problem has not been entirely solved, i.e. the support surface of radial-axial bearings still do not have the necessary rigidity. This problem is the reason for finding a new solution that will allow tracking of roughness while the excavator is moving, which will at the same time relieve the structure [11, 12, 13].

In spite of careful searching through the available patent documentation and considering solutions made by all relevant world manufacturers of excavators, no solution with a joint which will allow tracking of roughness while the excavator is moving has been found.

2. CONCEPT OF THE LABORATORY MODEL OF THE JOINT CONNECTION

Torsional relief of the carrying structure of the excavator undercarriage, which significantly solves the problem of deplanation of the support surface of the radial-axial bearing, is based on the concept of the new way of support of the undercarriage. Formation of the theoretical calculation method for the carrying structure of the bearing allowed a certain degree of reduction of influential parameters and establishing of theoretical dependencies of the corresponding geometrical characteristics of the carrying structure. Without disturbing the generality of the considered problem, it resulted in the creation of a database for research and development of a new concept of connection between the revolving and non-revolving structures. Verification of the defined theoretical dependencies significant for the quality of connection was done experimentally, on a physical model of the excavator carrying structure [14, 15].

The universal element of the joint connection for torsional relief of the carrying structure of the excavator undercarriage consists of the main central joint and two auxiliary joints (Figure 5). The joints are placed on one caterpillar carrier. They can be installed either on the left one or the right one.

The central joint is placed in the central part of the box girder of the caterpillar and it allows the reception of vertical load. It is installed from the lateral side of the box girder of the caterpillar. Vertical support on the box girder of the caterpillar is realized through a pair of bolts (upper and lower) which are connected to a ring welded to the upper or lower plate of the box girder of the caterpillar. The central joint allows rotation of the box girder in the vertical plane – in both directions, that is, it allows maximum adjustment to terrain roughness. This rotation leads to torsional relief of the carrying structure of the excavator undercarriage, which solves the problem of deplanation of the support surface of the radial-axial bearing.

The auxiliary joints allow rotation of the box girder in the vertical plane – in both directions up to the prescribed angle as well as guidance in the vertical plane.

Prescribing of the angle of rotation is defined by the position of the installed limiters. Simultaneously, the mentioned elements prevent the rotation of the box girder around the vertical axis (in the horizontal plane) during the change of direction of motion of the excavator.

The novelty is seen in the increased quality of the connection between revolving and non-revolving parts of transportation and earth-moving machinery which are connected to radial-axial large diameter bearings [16, 17]. Also, the presented model has the following advantages over the existing technical solutions:

- prevention of the appearance of deplanation of the support surface for the bearing connection,
- increased reliability and life of the radial-axial bearing,
- increased reliability and life of the radial-axial bearing support structure, and
- improved efficiency in the operation of excavators and other transportation and earth-moving machinery.

2.1 Detailed description of the technical solution of the joint connection for torsional relief

The carrying structure of the undercarriage consists of the central welded carrier 1, whose constituent element is the support ring for the connection with the radial-axial bearing 2. As for the central carrier 1, on one end it has a welded fixed box girder of the caterpillars 3, while on the other end the support plate and the central joint serve for the removable connection with the other carrier of the caterpillars 4, which rotates in the vertical plane.

The structural solution of the central joint, which accomplishes the adaptability of the carrying structure of the undercarriage to terrain roughness, is shown by the cross section in Figure 5.

The box girder of the caterpillars, which consists of the upper (1) and lower (2) web plate and the external (3) and internal (4) webs, can simultaneously rotate around its horizontal and vertical axes.

The universal element of the joint connection for torsional relief of the carrying structure of the excavator undercarriage consists of the central joint (5) made of a hub (20), which is placed in the central part.

On its upper and lower sides, it provides support to the bolts (12), through the bearings (19), and by means of two bearings (32) it leans on the central bolt (26), which can rotate around its horizontal axis (23). It thus alows turning of the rotary caterpillar carrier (4) in relation to the carrying plate (24), which is supported on the central bolt (26) by means of the radial surface (28), where the carrying plate (24) and the central bolt (26) are joined by the screws (29).

The hub (20) is connected, through the bolt (12) and the bearings (13), with the rings (11), which are welded to the upper web plate (7) and the lower web plate (8) and thus make a whole with the rotary caterpillar carrier (4).

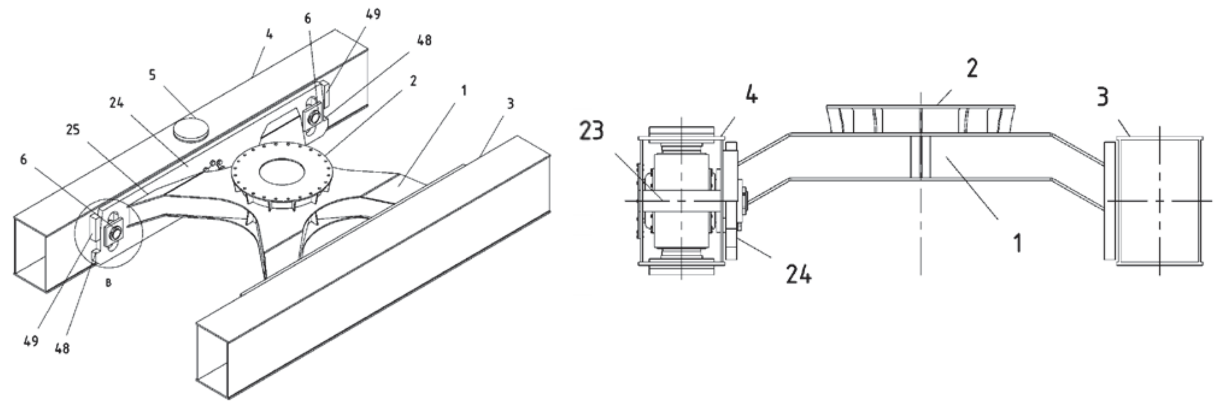

Figure 5. Isometric view and the cross section of the carrying structure of the excavator undercarriage with the universal element of the joint connection [16]

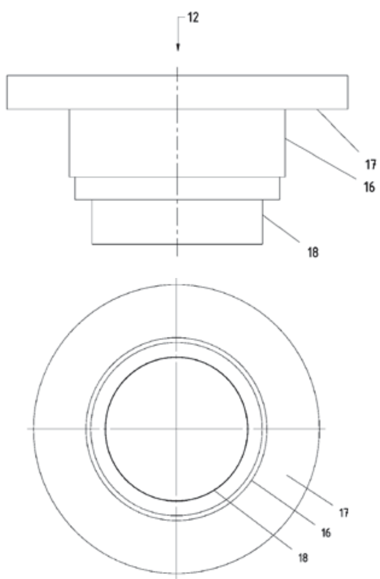

Figure 6. Bolt

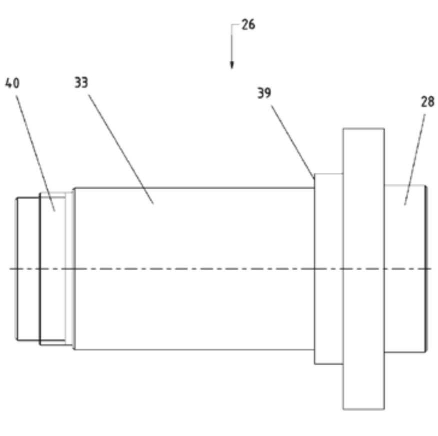

Figure 7. Central bolt

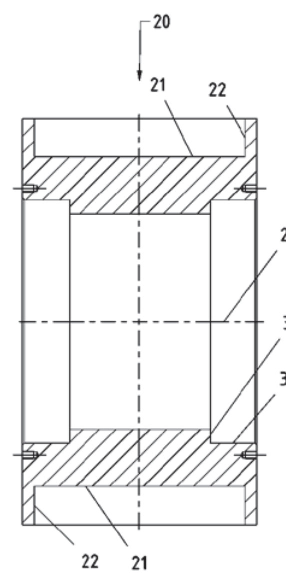

Figure 8. Hub

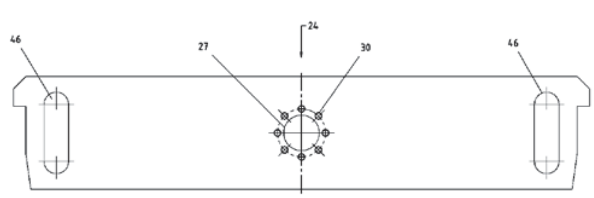

Figure 9. Carrying plate

Within the assembly of the auxiliary joint (6) (Figure 10), there is a pin (47) welded to the inner (10) and outer webs (9), which thus allows its motion along the groove (46) of the carrying plate (24), restricted in the space. The restriction is defined by the tooth of the plate (48) and the limiter (49). The pressure plate (51), together with the nut (52), allows restricted rotation of the rotary caterpillar carrier (4) around the carrying plate (24).

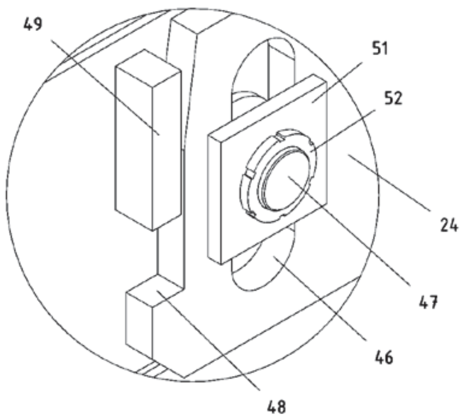

Figure 10. Auxiliary joint [15]

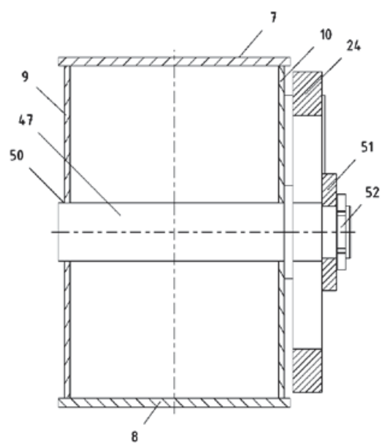

Figure 11. Cross section of the auxiliary joint

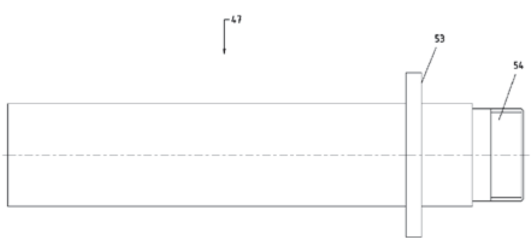

Figure 12. Pin

2.2 Realized technical solution of the joint connection for torsional relief

The new solution of the joint connection for torsional relief would considerably increase the quality of connection between the revolving and non-revolving parts of transportation and earth-moving machinery connected by radial-axial large diameter bearings [16].

In other words, such a conceptual solution prevents the occurrence of deplanation of the support surface for the bearing connection, which considerably increases its reliability, life of the structure and efficiency in operation. Also, the manufacturers of large diameter bearings could define new conditions of installation, guaranteeing a longer life, when, if potential users recognize all advantages of these results, it will be possible to use this solution in serial production.

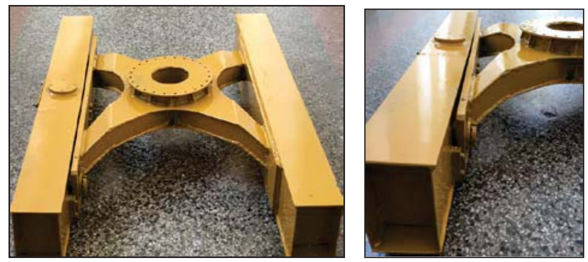

Figure 13. Laboratory installation of the joint connection [17]

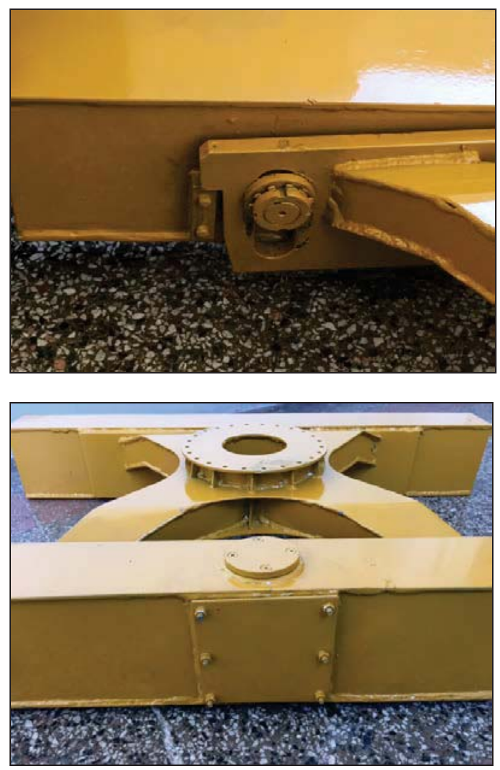

Figure 14. Central and auxiliary joints of the laboratory model of the joint connection [17]

3.CONCLUSION

Special attention within this paper is directed toward the presentation of results of development and improvement of revolving and non-revolving connections in transportation and earth-moving machinery, i.e. proper functioning of the connection between the revolving and non-revolving parts by the large diameter radial-axial bearing.

Research and development of the new conceptual solution of the connection between the revolving and non-revolving structures of machines is based on the analysis of torsional stiffness of various variant solutions and formation of the theoretical calculation model of the bearing support structure. The influence of installation of the cylindrical carrier on the reduction of deplanation and displacements of points of the support surface for the connection of the radial-axial bearing has been defined based on the theoretical dependency of the corresponding geometrical characteristics of the carrying structure and the comparative analysis of the values of displacements of characteristic points of the support surfaces. It has been established that the installed cylindrical carrier does not always produce displacements which are smaller than the allowed ones, and the stability of the excavator in operation is partly reduced, too.

The solution developed prevents the appearance of deplanation of the support surface for the the bearing connection, which considerably increases its reliability, the life of the structure and the efficiency in operation.

Easy mounting of the assembled elements of the bearing and the increased stability of the whole structure with its own boundary parameters provide an advantage over the other manners of support and, therefore, justify further analysis and improvement of the new solution.

Justification of analysis and research for the purpose of increasing the life of the mentioned machines and their safety in operation is even greater if the problems of transferring loads from revolving and non-revolving parts of carrying structures of transportation and earth-moving machinery are taken into account.

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