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Simulation of Stress-Strain State of Shovel Rotary Support Kingpin

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Abstract. The article presents the sequence of computational simulation of stress-strain state of shovel's rotary support. Computation results are analyzed, the kingpin is specified as the most loaded element, maximum stress zones are identified. Kingpin design modification such as enhancement of fillet curvature radius to 25 mm and displacement of eyebolt holes on the diameter of 165 mm are proposed, thus diminishing impact of stress concentrators and improving reliability of the rotary support.

1. Introduction

The shovel's rotary support (or RS) is one of the critical components determining the safe and reliable operation of the machine as a whole. Therefore, this element requires special attention both in design and in manufacture and operation. However, there is a lack of studies on rotary support loadings.

In domestic engineering estimation of rotary support loadings is performed by mathematical calculations of distributed vertical loads on the roller circle and pull in the kingpin. These approaches are static; wherein the impact of operational loadings is accounted by a dynamic coefficient C_{dyn} , taken equal to two, and by preset safety factors of components.

In general, these methods yield good results, but can not calculate some specific features of loading, such as impacts of maximum cutting force and excavating pressure. In some cases, this leads to calculation accuracy degradation and, as a consequence, diminishing of bearing capacity and reliability of components which adversely affect machines' operations. As for excessive metal consumption, it increases the cost of the machine and hurts its price competitiveness.

2. Description of design and sequence of stress-strain state simulation of the rotary support kingpin

RS layout scheme of EKG-10 shovel (the most common) is a structure with a unilinear roller circle where cylindrical rollers are arranged between upper and lower rails. The kingpin serves to withstand the loadings and avoid tipping if the loss of balance. During operation, the rollers contact with the rails linearly or rectangularly; the kingpin withstands the stresses arising periodically [1]. These impacts will inevitably lead to a wear and tear of conjugate elements and their failure (Figure 1).





Figure 1. EKG-10 shovel's kingpin fracture under operational loadings

Computational model of operational loading impact on stress-strain state of EKG-10 shovel's RS is developed with SolidWorks Simulation. SolidWorks Simulation is widely used for analysis of stress-strain state of structures, including mining machines [2-11]. MathCad software complex was used to obtain quantitative estimation of set loads.

General algorithm of SolidWorks Simulation for solving a static problem in linear formulation is as follows [1, 4].

1. A geometric model of the structure is developed (Figure 2).
2. A finite element grid is constructed, that is, sampling of the volume occupied by a part or assembly is performed. For a solid body the area is divided into tetrahedrons with edges approximated by linear or parabolic coordination functions.
3. Relationship of transformation of grid points translocations to Global Coordinates are determined. Local axial translocations are degrees of freedom for solid finite elements.
4. Finite element stiffness matrices are computed. Coordinates of the points, elastic modulus and Poisson's ratios are used in the formulas for computation of finite element stiffness matrix components.
5. The resulting stiffness matrices transform from Local to Global coordinates, which in turn, are connected into a single Global stiffness matrix.
6. Set boundary (static and kinematic) conditions are converted to loads and points translocations, expressed in Global coordinates.
7. The resulting linear system of equations is solved; displacements in the finite element points are determined. Direct and iterative methods can be used; calculation of strains at the points is performed.
8. Calculation of the equivalent tensions in base of a selected strength criterion is performed from parameters of the stress-strain state and material strength.

To reduce the volume of calculations some of the details were simplified (Figure 2) (the threaded underside of the kingpin nut, the turntable spigot), which effects were offset by the corresponding boundary conditions.

The turntable frame was simulated as an upper rail and a spigot. The sub-frame was simulated as a cast and a bottom rail. Side planes of the components were connected by means of a condition "Rigid connector", which provides stable bonds of selected surfaces and constant distances between them. This condition describes operation of the structure correctly, since the upper rail is fixed to the turntable; the bottom rail and the kingpin cast are fixed to the sub-frame. A kinematic boundary condition "Fixed" was applied to side plane of the bottom rail. This type of fixing limits linear displacements along three coordinate axes taken to zero.

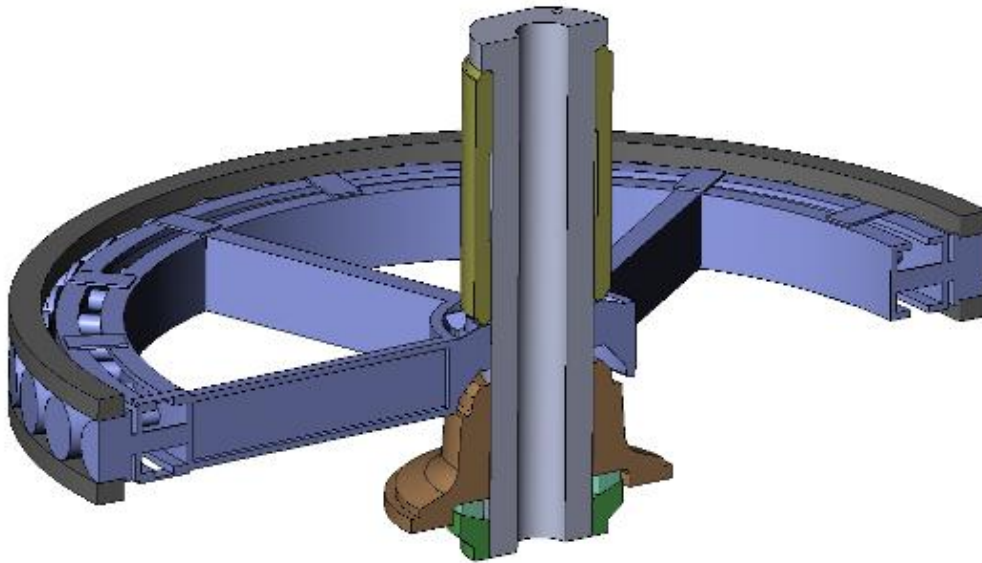


Figure 2. Geometrical model of RS of EKG-10 shovel (section)

Since a geometric model, material properties and imposed loads are symmetrical relative to the vertical plane, a boundary condition "Symmetry" was used. The geometrical model was cut axially; a kinematic boundary condition, inhibiting normal displacements to the cutting plane, was applied to the surfaces of the section. This reduced dimension of the problem; which, in turn, enhanced grid density and accuracy of finite element calculations.

Because of complexity to define boundary conditions of load application on RS elements, boundary forces based on weights of the arm and rock-filled bucket ($G=250$ kN) and on cutting force and pressure ($P_{01}=330$ kN и $P_{02}=100$ kN) were used in the computing. It just is a specific feature of loading, when maximum cutting force and pressure resulting from rock mass excavation are taken into account. The points of force application were adopted in accordance with Figure 3.

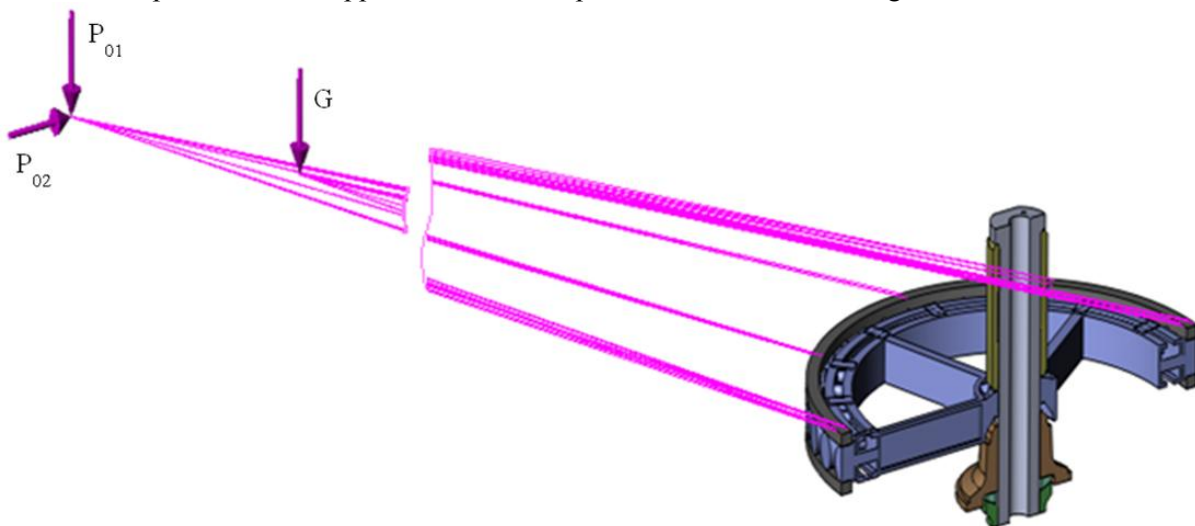


Figure 3. Scheme of rotary support loading

Forces were transferred from the points of application on the upper rail face using the boundary condition "Remote Loading" with the option "Rigid Connector".

Since the calculation was performed for the assembly, conditions of contact interaction of contacting faces were described. The condition "No Penetration", that eliminates interference of

components but admits clearances, was used with the option "Surface to Surface". These contact conditions maximize the accuracy of contact problem's solution, if smooth curvilinear interacting edges, but it requires the greatest computational resources.

The grid with parabolic finite elements (FE) in the form of tetrahedrons was used for geometric model digitizing. Parabolic finite elements provide a better grid description of model geometry and enhance accuracy of computing because of more points, if compared with linear FE. Grid parameters: FE size - from 10 to 50 mm; ratio of element size enhancing - 1.6; automatic grid tightening was not used. For a detailed study of the kingpin the grid was tightened. Maximum size of FE was diminished to 30 mm. A powerful program «FFEPlus», which uses advanced matrix reordering, was used for the computation.

3. Results and Discussion.

We have got an equivalent stress distribution pattern, by Mises criterion, in RS elements of the EKG-10 shovel when exposed to operational loads (Figure 4) [4].

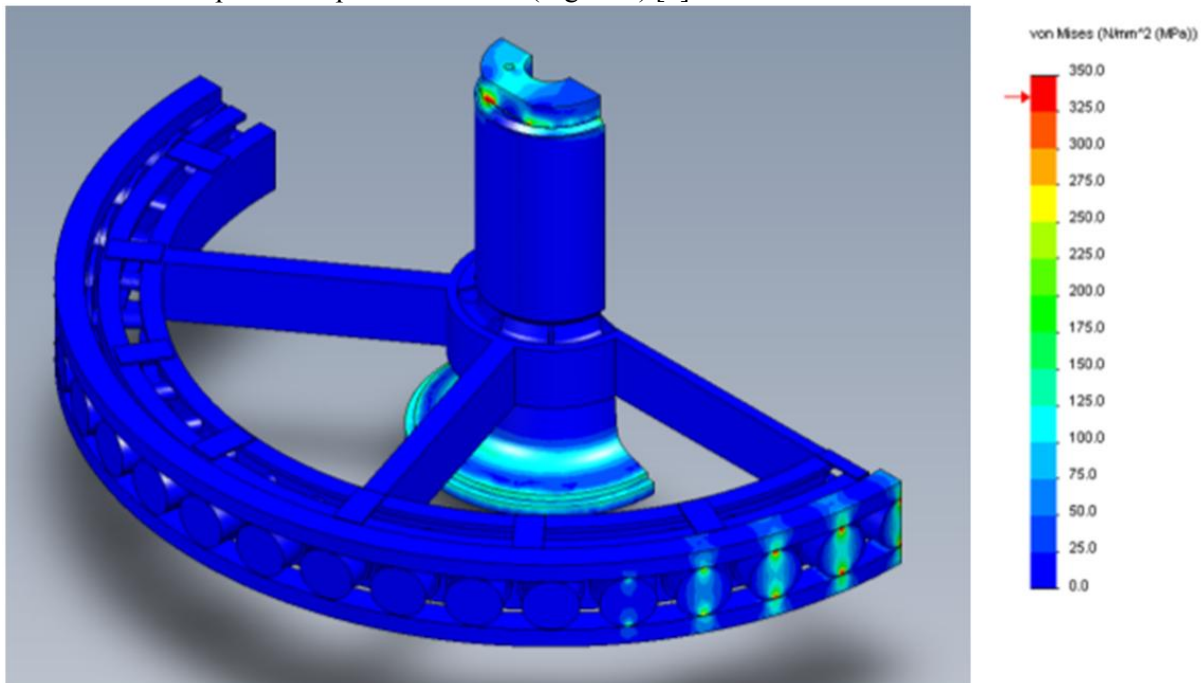


Figure 4. Equivalent stress distribution pattern by Mises criterion in RS elements of the EKG-10 shovel

It was found that the kingpin is one of the most loaded RS elements. Maximum of stress is located in the fillet zone, and the additional stress concentrator is the eyebolt hole (Figure 5a). This figure shows the zone where stresses exceed the kingpin material's yield strength (for Steel 40 - 335 MPa by State Standard 1050-88). This confirms that service loads are destructive and may cause damage to the kingpins. Also, the stress distribution pattern shows the most loaded zones of the upper rail in contact places with seven front rollers.

In order to avoid stress concentration in the kingpin, displacement of eyebolt holes closer to the kingpin axis has been proposed. Initially, the holes were arranged on a diameter of 230 mm; it has been proposed to diminish the distance to 165 mm, with the same depth of the hole. Fillet radius has been enhanced from 10 to 25 mm (Figure 5b). These improvements do not result in significant changes in structure of other (conjugate) elements of the RS, but will significantly diminish maximum stresses (Figure 5b).

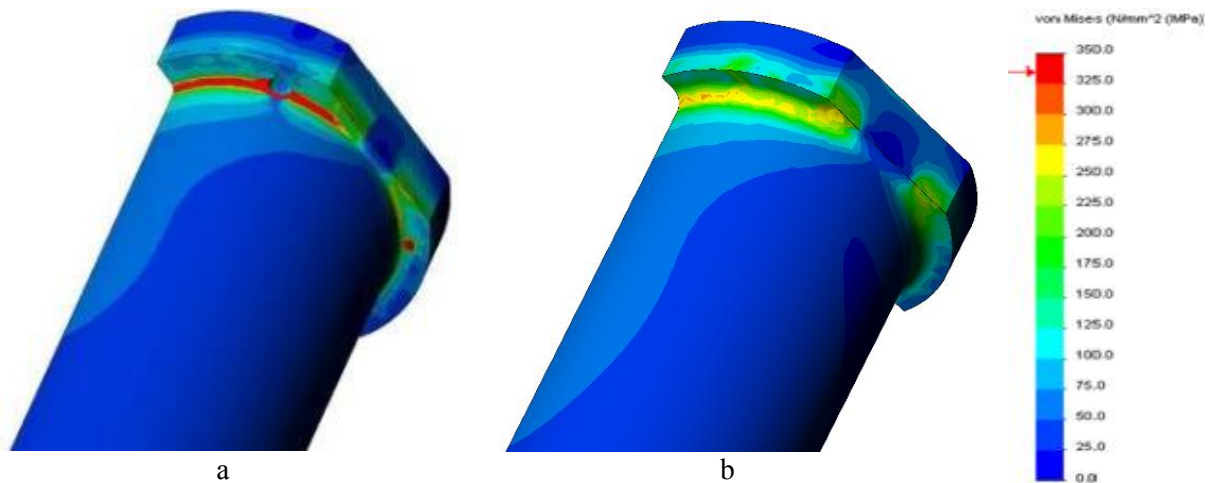


Figure 5. Equivalent stress distribution pattern by Mises criterion in kingpin: a - maximum stress concentration and exceeding of steel 40 yield strength; b - stress concentration after modification

4. Conclusion

The resulting pattern of stress distribution in the RS elements shows how technical condition of the component changes during operation up to the wear and fracture of individual elements. The proposed model of stress-strain state enables to develop both various designs of individual elements and layout diagrams of the RS by simulating maximum loads required for detection of stress concentration, for example, kingpin design modification such as enhancement of fillet curvature radius to 25 mm and displacement of eyebolt holes on the diameter of 165 mm. These improvements can diminish stress concentrations when subjected to operation loadings.

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