Modeling the stress-strain state of crane metal structures

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Abstract. The intensification of construction production imposes very strict requirements on the safety of construction machines. When carrying out lifting and hoisting operations using overhead cranes, production safety is primarily determined by the technical condition of the undercarriage and crane runways, as well as metal constructions. The authors deal with the issues related to modeling and research of the stress-strain state of metal structures of an overhead crane. A model of the crane metal structure is proposed, which includes the main and end box-section crane girders. To study possible geometric movements of the crane, a model of an overhead crane was designed in KOMPAS-3D software environment. The model contains main and end box-section girders. The model allows determining the maximum possible misalignment of the crane and runout of one of the sides. To determine the bending, tensile and compressive stresses in the bridge truss and the deformations of the crane metal structures, depending on the working loads, a 3D model of the bridge crane was created in the ADW Winmachine software environment. With its help, the bending stiffness of the crane bridge was established. These values are necessary to compile a mathematical model of an overhead crane as a control object in the synthesis of an automatic control system.

1. Introduction
The intensification of construction production imposes very strict requirements on the safety of construction machines. When carrying out lifting and hoisting operations using overhead cranes, production safety is primarily determined by the technical condition of the undercarriage and crane runways. Malfunctions in the operation of the undercarriage or changes in the geometry of the crane metal structures due to imprecise control significantly reduce the service life of the rail track from the design life of 8 years (on average) to overhaul - down to 2-3 years. Travel wheels have lower performance properties and their service life is further reduced. In addition to high economic costs, such violations in crane operation are associated with the occurrence of emergency situations - crane derailment [1].

The effective elimination of these problems is associated with the automation of an overhead crane - the development of automatic control systems [2]. The synthesis of automatic control systems is preceded by the stage of modeling the dynamics of an overhead crane as a control object, the parameters of the computational model of which must fully correspond to the actual operating crane [3, 4].

2. Materials and methods
At the Samara Stroyfarfor LLC enterprise (Samara), a double-girder overhead crane is operated at the raw material unloading process area. It has the following main technical characteristics:
1. Crane dimensions: crane span – 34500 mm, crane base – 5000 mm, wheel diameter – 500 mm, distance between bumpers (extreme points of the crane) – 6710 mm;  
2. Characteristics of the drive of the travel mechanism: Electric motor - MTF-311-6, 11kW, 945 rpm - 2 pcs. Reducer - 1I2Y-250-12.5-12/21 reduction ratio - 12.5 - 2 pcs.  
3. Crane mass (design) - 31.5t, trolley mass - 3.5t, cab mass - 1t, grab mass - 1.9t, lifting capacity - 5t.  
4. Maximum load of the crane wheel on the rail (calculated) - 185 kN.  

To study possible geometric movements of the crane, a model of an overhead crane, used at Samara Stroyfarfor LLC, was designed in KOMPAS-3D software environment (Fig. 1). The model is built on a scale of M1:1 and contains two main and two end box-section girders. Traveling wheels are installed on the end girders (wheel flanges are shown by rectangles). The model allows determining the maximum possible misalignment of the crane (when the flanges of the diagonally located wheels touch the rails) - in the angular dimension of 16', while the runout of one side is 165mm.

Figure 1. Overhead crane model

Figure 2 shows a model of a running wheel for determining the working clearances between the flanges of traveling wheels with a diameter of 500 mm and the side surfaces of the rail head of the KP-70 brand. Under normal operating conditions of an overhead crane, if the crane runway is in good condition, there should be no contact between the flange and the side surface of the KR-70 rail. The model is also designed to determine the contact area between the flange and the side surface of the rail.
3. Computational experiment
To determine the bending, tensile and compressive stresses in the bridge truss and the deformations of the crane metal structures, depending on the working loads, a 3D model of the bridge crane was created in the ADW Winmachine software environment [5, 6].

In addition to the dead weight of the crane metal structures, the following loads were used in calculations:
1. The load from the trolley weight, grab bucket and the mass of the material being lifted (60-100 kN) is applied to the rails of the cargo trolley on the upper part of the main girders;
2. Load from the weight of the crane operator's cab (10kN), applied to the main girder;
3. Bending moment (9kN·m), creating the maximum possible runout of one side of the crane 165mm from the uneven operation of the crane bridge drives.

The calculations show that the maximum misalignment of the crane (165 mm) occurs under the action of an additional force of 265 N applied to one of the end girders.

When the mass of the crane grab is varied, a load is created in the range from 60 kN (empty bucket) to 100 kN (full bucket), which causes deformation of the main girders by 37 mm and 60 mm, respectively (Fig. 4).
The results obtained make it possible to determine the deflection stiffness of the crane bridge $C = \Delta N / \Delta Z$, where $\Delta N$ - change in the applied load; $\Delta Z$ - travel of the crane bridge in the vertical plane:
C=1.76·10^6 N/m. Table 1 shows the deflection of the bridge from the applied load in the operating range.

### Table 1. The deflection of the crane bridge depending on the applied load.

| Load (kN) | Bridge deflection (mm) |
|-----------|------------------------|
| 60        | 37.29                  |
| 80        | 49.57                  |
| 100       | 60.07                  |

#### 4. Discussion

The main reason for the increased wear of the wheels of cranes with a separate movement mechanism is the non-parallelism of the axes of the crane rails [3, 4]. Unfortunately, even a perfect rail installation will not eliminate the bend of the crane bridge while traveling. This situation is caused by a mismatch in the characteristics of the drive motors and the predominantly off-center position of the transported load. Moving the load away from the center of the crane increases the load on the corresponding motor and it reduces its rotation speed. Rotation of the left and right motors at different angular speeds leads to runout of one side of the crane relative to the other. When the crane moves with a bend, the flanges of the traveling wheels constantly rub against the rails. This leads to intense wear of the flange and rail side surfaces.

Using a 3D model of an overhead crane, it was experimentally established that the maximum possible misalignment of the crane is in an angular dimension of 16°, while the runout of one side is 165 mm. When the mass of the crane grab is varied, a load is created in the range from 60 kN (empty bucket) to 100 kN (full bucket), which causes deformation of the main girders by 37 mm and 60 mm, respectively. The results obtained make it possible to determine the deflection stiffness of the crane bridge C=1.76·10^6 N/m.

#### 5. Conclusion

The computational experiments carried out and the results obtained make it possible to assess the nature and level of the bridge deflection from the applied load in the operating range, to determine the deflection stiffness of the crane bridge. These values are necessary to compile a mathematical model of an overhead crane as a control object [3, 4] in the synthesis of an automatic control system [2, 7, 8].

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