Approach for Measuring a Ship to Shore Crane Actual Wheel Load
Maksym Starykov and Evgenii Kokoshko

ABSTRACT

Knowing the real crane deadweight, center of gravity (COG) and wheel loads instead of nominal ones is crucial for many reasons. One of the reasons relates to the checking the quay strength where the crane is going to be installed and it should be based on the crane maximum real wheel loads. Another example could be the crane transportation by sea on the deck of the vessel (Starykov & Van Hoorn, 2017). In this case predicting the precise value of the crane deadweight and its COG plays a key role in accurate calculation of the vessel stability, acceleration calculation from the ship motions and the vessel’s deck strength.

This paper demonstrates a new approach to finding the crane wheel load and in the result the deadweight and COG position. This method does not need special arrangement and uses combination of strain gauge measurements and Finite Element (FE) analysis only. The application of the method is demonstrated on example of the ship loader for which the possibility of capacity increase has been assessed.

Keywords: quay crane, ship-to-shore crane, strain gauge, weight measurement, wheel load.

I. INTRODUCTION

One of the main limitations to the crane design is the maximum allowable wheel load, which mainly comes from a quay structure strength. Usually, this parameter is obtained from the crane FE model. The main source of mismatching with reality is that the model provides the nominal wheel loads, i.e., corresponding to the nominal dimensions and nominal weights of the structure elements. But in reality, the tolerances for weight and dimensions introduce the difference in position of COG and crane dead weight. As the wheel load is a crucial characteristic it should be controlled more precisely. If the crane was a smaller structure it would be possible to weigh it directly using a special platform or using a heavy lift to determine the real COG position and weight. For the contemporary quay cranes, which weight comes up to 1500 tones (Bartošek & Marek, 2013), using direct weighing would be a challenging task.

Another area where the value of the crane deadweight and COG could be used are for the crane sea transportation. In this case knowing the dead weight and COG is critical for the ship stability and vessel acceleration calculation.

II. APPROACH DESCRIPTION

This work is proposing an approach that allows measuring the crane wheel load magnitude using strain gauges (Tutak, 2014) with further processing with FE analysis (Werkle, 2021). The method could be described as crane ‘weighing’ using the strain gauges.

The approach’s main steps are:

Step 1. The stress in the crane travel wheels appears in the area between the wheel pin/shaft and the contact of the rail with the wheel, see Fig.1 and the rest of the wheel is unloaded. Using this observation, a strain gauge is attached to the crane travel wheel at pos. 1 (Fig. 1. a) to the area with no stress.

Step 2. Start crane moving and as the result of wheel rotation the area with the strain gauge becomes loaded by the wheel load (pos. 2, Fig. 1. b) and during the further rotation the stress there disappears again.

Step 3. The measured signal is proportional to the wheel load magnitude, but in order to find out the load in tons the additional step, calibration, is needed that would allow to transfer the original signal of mV/V to tons. The calibration is created using calibration beam and the FE analysis of the wheel model.
III. APPLICATION TO THE SHIP LOADER

The described approach is demonstrated for project of ship loader modification, when its capacity had been increased twice from 2000 t/h to 4000 t/h. One of the milestones of this project was to assess the increased magnitude of the wheel load with its further comparison with the maximal allowable load on the quay.

This approach could be extended to the different types of cranes, like boom level-luffing cranes, quay cranes (ship-to-shore cranes) that have the same travel arrangement, when the crane moves along the rails laying along the quay.

Due to the lack of data on the ship loader structure element weights and its total COG the proposing experimental approach utilizing strain gauge measurement has been developed.

The ship loader has four supports: two sea side (labeled A and B) and two land side (labeled C and D), see Fig. 2. Each sea support has 4 wheels, and each land support has 3 wheels, see Fig. 3. The strain gauges have been attached to the outmost wheels of each support.

Step 1. Strain gauges are attached to the wheels in the “unloaded” area, away from area with stress from wheel / rail contact, see Fig. 4.

Step 2. Firstly, the crane is put into position for which the wheel load is measured. In case of ship loader, the boom has been put in horizontal position and all the sections are pulled out. According to the port authority the experiment was allowed without any cargo on conveyor belt only. The effect of cargo has been added to the wheel loads later by hand calculations. Secondly, the crane is moved using gantry travel so that the wheel rotates approx. 160 deg. allowing the strain gauge to pass the “stressed area”. The moment of the time during the wheel rotation when the strain gauge is in “stressed area” shows the maximum strain. The signal from strain gauge during the wheel rotation comes to the amplifier and then to the “analog to digital convertor” (ADC) which converts electrical voltage to the digital signal. An example of a typical signal from a strain gauge is shown in Fig. 5.

The strain gauge maximal strains during wheel rotation are obtained using calibration beam and are shown in Table I and II.
TABLE I: MAXIMAL STRAIN GAUGE RELEVANT DEFORMATIONS FOR THE BOOM UP POSITION

<table>
<thead>
<tr>
<th>Support label</th>
<th>Maximum strain gauge relevant strain, x10,000</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>left wheel</td>
</tr>
<tr>
<td>A</td>
<td>-1.9</td>
</tr>
<tr>
<td>B</td>
<td>-2.0</td>
</tr>
<tr>
<td>C</td>
<td>-2.1</td>
</tr>
<tr>
<td>D</td>
<td>-2.3</td>
</tr>
</tbody>
</table>

Step 3. Measured signal transformation into wheel load.
In order to obtain the correlation equation between the measured strain and the wheel load, the finite element model has been created using FE analysis, Fig. 6 a. During this analysis a set of calculations has been performed in which the wheel load varied from zero to 40 tons with the increments of 1 ton. The result of one of the analyses is shown in Fig. 6 b. In order to reduce the scope of the problem only the half of the model has been created using symmetry boundary conditions.

![Fig. 6](image)

The analytical form of correlation curve is shown in Fig. 7. is:

\[ P = -77662.5 \cdot \varepsilon_z \]  

where

\[ P \] – wheel load, tons;

\[ \varepsilon_z \] – vertical relevant deformation of the strain gage location.

The result of the relevant deformation recalculation to the wheel load is shown in Table III and Table IV.

TABLE III: WHEEL LOAD IN TONS AND THE UNEVENNESS OF ITS DISTRIBUTION AMONG WHEELS FOR THE BOOM UP POSITION

<table>
<thead>
<tr>
<th>Support label</th>
<th>Left wheel</th>
<th>Right wheel</th>
<th>Load unevenness between wheels, %</th>
<th>Mean</th>
<th>Support total load</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>14.7</td>
<td>6.6</td>
<td>38*</td>
<td>10.7</td>
<td>42.7</td>
</tr>
<tr>
<td>B</td>
<td>15.9</td>
<td>10.1</td>
<td>25*</td>
<td>13.0</td>
<td>51.8</td>
</tr>
<tr>
<td>C</td>
<td>16.4</td>
<td>19.1</td>
<td>16</td>
<td>17.7</td>
<td>70.9</td>
</tr>
<tr>
<td>D</td>
<td>18.1</td>
<td>16.8</td>
<td>5</td>
<td>17.4</td>
<td>69.7</td>
</tr>
</tbody>
</table>

* The significant difference in wheel load magnitude may be a result of a poor equalizer joints’ conditions.

The maximum wheel load values, acting during the cargo being on the conveyor belt, have been determined by combination of the calculation data and measured wheel loads.

TABLE IV: WHEEL LOAD IN TONS AND THE UNEVENNESS OF ITS DISTRIBUTION AMONG WHEELS FOR THE BOOM DOWN POSITION (WITHOUT MATERIAL ON THE BOOM BELT CONVEYOR)

<table>
<thead>
<tr>
<th>Support label</th>
<th>Left wheel</th>
<th>Right wheel</th>
<th>Load unevenness between wheels, %</th>
<th>Mean</th>
<th>Support total load</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>19.1</td>
<td>11.9</td>
<td>55*</td>
<td>15.5</td>
<td>61.9</td>
</tr>
<tr>
<td>B</td>
<td>18.3</td>
<td>13.7</td>
<td>37*</td>
<td>16.0</td>
<td>64.1</td>
</tr>
<tr>
<td>C</td>
<td>11.1</td>
<td>12.9</td>
<td>17</td>
<td>12.0</td>
<td>48.0</td>
</tr>
<tr>
<td>D</td>
<td>12.6</td>
<td>12.0</td>
<td>7</td>
<td>12.3</td>
<td>49.3</td>
</tr>
</tbody>
</table>

* The significant difference in wheel load magnitude may be a result of a poor equalizer joints’ condition.

Nominal weight of the ship loader is 247 352 kg. According to the measurements the ship loader weight for boom up position is 235 069 kg and for boom down position is 223 321 kg.

Thus, the total measurement error: for boom up position is 5.0% and for boom down position is 9.7%. To minimize this error the strain gauges should be used for each wheel which would eliminate the effect of the poor equalizer joints’ conditions on the measured value.

IV. CONCLUSION

In this study, a new approach was proposed to calculate crane weight, COG and wheel loads based on strain gauge measurements and FE analysis. The key advantages of this method are summarized below:

- The method allows to find the real wheel load distribution, which is critical for the quay and also for the whole crane transportation on the deck of a vessel.

- The method has a potential to be utilized for validation of a crane’s nominal weight and nominal position of its COG that have been obtained during the crane design stage using hand calculation or FE analysis.

- Wheel load measurement time is moderate, which makes the procedure effective.

Regarding the limitation of the presented method, the following aspects could be pointed out:
• The wheel drawings are needed for the analysis.
• The method allows to measure the wheel load for the cases that could be reproduced (i.e. it is impossible to force the wind to blow with different speed and different directions to allow to find the worst wind attack angle etc.). But these effects could be considered in addition using hand calculation.

REFERENCES