Experimental analysis of the self-erection mechanism of self-erecting cranes

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Abstract. In this paper is presented the experimental analysis of the self-erection mechanism of the self-erecting cranes for the erection process from the transport to the building site state to the normal working state. The force in the rod of the erection hydraulic cylinder and the stress and strain on one of the mechanism’s bars were determined experimentally. Measuring the stress and strain was carried out by using strain gauges bonded to the measured element and by using data acquisition equipment. The measurements were carried out in real working conditions on a Potain Igo 18 in a working building site.

1. Introduction
Object of experiments was the self-erecting crane Potain IGO 18 which is presented in figure 1.a in folded state and in figure 1.b in erected state, prepared for work.

As a method of experimental investigation of the crane’s self erection mechanism was chosen the resistance strain gauge measurement method and was chosen taking into account that the results of experimental measurements can be compared easily with the results of the mathematical model, namely: forces in kinematic joints and respectively driving force of the hydraulic cylinder drive, especially since the measured bars are subjected to simple loads (tension - compression).
2. Measurements objectives
In order to fulfil the purpose presented previously and having in mind the 2 types of theoretical results, meaning joints reactions and driving force, the following objectives are setup for experimental analysis of the mechanism:

- Determining the force in one of the mechanism’s bars with axial loading, bar 1 (AJ).
- Determining the force in the rod of the driving hydraulic cylinder.

These 2 categories of theoretical results which are driving force and joint reactions correspond to the type of kinematic element of the mechanism and therefore it is necessary that the experimental measurements to be carried out to at least one type of element namely driving element and driven element. For placing the strain gauges were chosen the hydraulic cylinder as driving element of the mechanism and the rocker bar 1, AJ, which is only axially loaded since it has only 2 revolute joints A and J and was considered that the weight of the element is negligible in relation to the joints reactions.

Another reason for choosing the rocker bar AJ as investigated element is its placing into the structure, meaning that is placed on the revolving platform, is easily accessible and needs a shorter cable to connect the strain gauges to the data acquisition system.

3. Placing strain gauges and building the measuring circuits
There were placed two measuring points on the investigated mechanism: one on the rocker bar AJ, and the other on the hydraulic cylinder’s rod. The measuring point placed on the rocker bar AJ was
mounted in a section to 1500 mm from the A joint, figure 2. The measuring point on the hydraulic cylinder’s rod was placed to a distance of 150 mm from the rod’s joint, figure 2. Also the measured elements are bars that don’t have variations in their dimensions.

Every one of the measuring circuits was built as half Wheatstone bridge having one active strain gauge and one temperature compensating strain gauge. The strain gauges were applied as follows:

- the rocker bar AJ, the active strain gauge was applied on the smaller sized side of a rectangular profile (150x100x6 mm), and the temperature compensating strain gauge was placed perpendicular to the active strain gauge, measuring point M1, figure 2;
- on the rod of the hydraulic cylinder, the active strain gauge was applied on the generator of the rod with a diameter of Φ80 mm, and the temperature compensating strain gauge was applied on the circumference near the active strain gauge, measuring point M2, figure 2.

![Figure 2. Placement of measuring points on Igo 18 self-erecting crane.](image)

In figure 3 is presented the mounting spot of the strain gauges for measuring point M1.

![Figure 3. Applying the strain gauges in measuring point M1.](image)
In figure 4 is presented the mounting spot of the strain gauges for the measuring point M2, the rod of the hydraulic cylinder.

![Figure 4. Applying the strain gauges in measuring point M2.](image)

4. Experimental setup, equipment and materials

The testing setup is presented in figure 5 and includes:

- Strain gauge measuring circuits;
- Connecting cables;
- Data Acquisition System [6];
- PC (laptop);
- Stabilized continuous current power source.

![Figure 5. Testing setup and components.](image)
Measuring circuits were built using strain gauge model EA-06-250BG-120 [3]. The strain gauges were mounted using cyanoacrylate based adhesive [4] and were protected using protective coating [5].

5. Carried out experiments and obtained results
The experiments were carried out on a self-erecting crane Igo 18 from POTAIN in working state and deployed in a working site and are presented in table 1.

After the testing setup was finished and verified and before starting the experiments, some folding and unfolding actions were done in order to reduce as much as possible the hysteresis effect which appears to fresh bonded strain gauges because of the fresh adhesive.

The working cycle was as follows:
- balancing the circuits with the crane in folded state;
- starting the recording of acquired data from known position of the initial length of the hydraulic cylinder CH=1900 mm;
- beginning the unfolding, from the radio remote control of the Igo 18 crane, to full speed of the cylinder;
- finalising the unfolding and stopping the mechanism;
- ending the recording of acquired data;

| Experiment                                   | Result                                                      |
|----------------------------------------------|-------------------------------------------------------------|
| Measuring strain on rocker bar 1 AJ          | Chart of strain variation of the rocker bar 1 AJ             |
| Measuring strain on the rod of the hydraulic |                                                             |
| cylinder                                     | Chart of strain variation of the rod of the hydraulic cylinder (figure 7) |

Table 1. Carried out experiments

![Figure 6. Strain variation of the rocker bar 1 AJ, while unfolding.](image-url)
6. Comparison between the theoretical and experimental results

Strain charts [µm/m] in figures 7 and 8, were transformed in charts representing force variation of the measured bars in [N]. The transformation is done using the following relations [1]:

\[ \sigma = E \cdot \varepsilon \]  
\[ F = \sigma \cdot A \]  

where:
- \( \varepsilon \) - axial strain in direction of gauge;
- \( E \) - Young’s modulus (Modulus of elasticity);
- \( \sigma \) - axial stress;
- \( F \) - axial force;
- \( A \) - cross sectional area.

From equations (1) and (2) the force in the bar is [1]:

\[ F = \varepsilon \cdot E \cdot A \]  

where \( \varepsilon = \varepsilon_{\text{read}} \cdot C \) and \( C \) gauge factor (sensitivity) of any strain gauge \( C = \frac{1}{1+\mu} = \frac{1}{1.3} \) where \( \mu \) is Poisson’s ratio.

6.1 Forces analysis of rocker bar AJ

Bar AJ is built out of closed rectangular shape profile and the force is determined using equation (3). Cross sectional area is \( A = 2784 \text{ mm}^2 \) and by introducing the previously acquired values of \( \varepsilon \), the force variation in rocker bar AJ is determined and presented in figure 8.

The axial force is determined theoretically in the rocker bar AJ with the following equation [2]:

\[ F_x = \frac{1}{2} \left[ F_x \cdot \cos(\alpha_x) + F_y \cdot \sin(\alpha_y) \right] \]  

where \( \frac{1}{2} \) - is there because the mechanism is composed of 2 similar rocker bars (AJ);
- \( F_x, F_y \) – are the projections of the resultant force in the joint;
$\alpha_1$ - is the angle of the bar in relation to the Ox axis.

In figure 9 is represented in the same chart, the measured axial force, figure 8, and the theoretical axial force.

![Figure 8. Force variation in rocker bar AJ; acquired data (red).](image)

![Figure 9. Axial force variation for rocker bar AJ; determined theoretically (square - green) and measured axial force (circle - red).](image)
6.2 Forces analysis of the piston’s rod

The piston’s rod is a cylindrical rod profile, having a diameter of: $\Phi_{rod}=80$ mm. Cross sectional area is $A=5027$ mm$^2$. The force in the piston’s rod is determined with the equation 3 and by introducing the previously acquired values of $\varepsilon$, the force variation in the piston’s rod is determined and presented in figure 10.

![Figure 10. Force variation for piston’s rod; acquired data (red).](image)

![Figure 11. Axial force for piston’s rod; determined theoretically (square - blue) and measured force (circle - red).](image)
In figure 11 is represented in the same chart, the measured force in the piston’s rod, figure 10, and the axial force determined theoretically [2].

7. Conclusions
The experiments were carried out on a working self-erecting crane and in a working site.

The experiments were carried out in optimal temperature and weather conditions ≈ 24°C, humidity ≈ 60% Rh etc.;
Data acquisition was done in real-time;
For the experiments were carried out using state of the art equipment, specialised software for digital data acquisition.
The strain gauges were optimally chosen for the range of loads to which the measured element was subjected (EA-06-250BG-120), and also the measuring circuit was chosen accordingly.
Strain gauges mounting operations (strain gauge bonding, cable posing, etc.) were carried out in the work site on the workplace of the crane. In this situation the balance of the measuring bridges does not coincide with the no load state of the measured elements.
Also in these conditions the measuring circuit determined the surplus of load which can be positive or negative in relation to the unknown initial load already present in the element (The measurements are relative to the actual load already present in the element).
From comparison of the obtained results with the experimental ones the following conclusions appeared:

- the shape of both diagrams experimental and theoretical coincide over the whole working cycle of the mechanism;
- the periods of the working stages of the mechanism coincide;
- By overlaying the diagrams a very good similarity of the results is observed. Very small differences between the results are due to the fact that in reality the elements are elastic and in the theoretical study the elements were considered rigid and friction and damping in the kinematic joints were neglected;

The coincidence between the diagrams sows that the mathematical model is correct both in its parts and in its entirety respectively synthesis, kinematics and dynamics studies.
Also from the same good coincidence in the diagrams, another conclusion is that the experiments were carried out correctly.
Also it should be pointed out the fact that theoretical data was determined in [2] and in the literature there isn’t any publicly available data, since it’s a closed industrial field.

8. References
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