Design variations optimization of jib crane 24500 N using I beam 300

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Abstract. A jib crane is a type of lifting equipment that is commonly attached to the walls of factory buildings to raise or lower a load. The lifting mechanism can rotate with a turning angle of 180 degrees. A trolley hoist can be moved manually by chain drive. This research aimed to optimize the design of several variations of the jib crane structure of load lifters that meet the criteria of optimizing safety factor. Firstly, the design concept was made by varying the main beam of the I Beam 300. Then calculated analytically. The 2D and 3D geometry were made in four variants of JC-1, JC-2, JC-3, and JC-4. The strength of the main beam structure and others was analyzed using FEM software. The load of the crane was 24500 N, a range radius of 3 meters, and a turning angle of 180 degrees. The best results were obtained by comparing the yield stress to the maximum stresses that occurred according to Von Mises. Based on the simulation results, the best design is the JC-4 variant. Variant JC-4 simulation results show that the safety factor closed to the optimum point.

1. Introduction
A jib crane is a type of lifting equipment that is commonly attached to the walls of factory buildings to raise or lower a load. The lifting mechanism can rotate 180 degrees with a boom radius of 3 meters. Analyzed the damage to the crane structure found excessive pressure in the jib supporting area that was in contact with the river bed was higher than the simplification of the numerical model created on this part of the jib structure [1]. The explanation about the design problems in mining associated with boom cracks mining machines using the finite element method was used numerically to provide information about pressures for extreme load conditions [2].

Analyzed the pressure near the catastrophic failure of dockside jib crane found the final failure was determined by the collapse of the plastic from a critical cross-section. Furthermore, periodic inspections are needed [3]. Investigation of a gantry scheduling algorithm that could be move optimally, precisely, and free of collisions and optimal motion solution with a very small runtime [4]. A study of forest crane mathematical model created to take into account crane flexibility with the ground and analyze the effect of load flexibility with the drive torque showed a significant effect between flexibility and load useful for the analysis of the strength of components, and their drives [5]. Researched on numerical calculations, the significant effect between flexibility and load for the analysis of the strength of components, and their drives ERTGC showed that could reduce carbon dioxide emissions by diverting energy from diesel to electricity [6].
Analyzed jib cranes using a planar series framework, shown that jib cranes can be modeled and treated as the structure of the framework in analyzed the system [7]. Studied the development of cranes to produce optimal time efficiency, safety, and accuracy of work using a robotics system in automatic operation [8]. The Auction-Based Simulation for Industrial Crane Operations (ASICO) conducted a flexible simulation model to facilitate the lifting of heavy loads in the industry. It was obtained that this model could analyze lifting loads efficiently to save time and costs [9]. A study of elastic vibration was one of the significant problems in gantry cranes. Therefore, it was made a control system to reduce elastic vibrations with a crane model using the finite element method [10]. Evaluation hybrid propolis system based on diesel generators and supercapacitors (SC) as energy storage system (ESS) for rubber tyred gantry cranes (RTGC) shown the technical feasibility, the validity of the proposed control, the strategy would increase in energy efficiency and the consumption of diesel fuel [11].

Analyzed progressive collapse to the maximum extent using the finite element method provided a structure that was economical and safer than used the allowable stress design method [12]. Simulated of a fuzzy overhead crane model used a sliding mode control with a limited time shown the effective and beneficial results [13]. A study about the corrugated web I-beam sections using the hole-drilling method shown the maximum residual stress distribution approved by an increase in the angle of the wrinkle and the radius of curvature, especially for the flange part [14]. Analyzed and calculation to study excessive wear on the crane structure concerning lifting and operating significantly. It was found that the crane had increased bending moment 5 times which cause it to be a major factor of excessive wear. A short-term solution to reduce wear was to provide lubrication of the wheel and railhead flanges.

The focus of this research was to investigate the load structure variation to obtain the most powerful and efficient von mises stress and crane jib safety factors in the industry.

2. Methodology
To get an optimum design to many variants of jib crane using I Beam 300x150x6.5x9 mm [16] with 24500 N load, all data collected as: specification of load capacity, length of the jib crane arm, materials. The next process was a preliminary calculation to get a design concept by varying the main beam of the I Beam 300. The geometry of 2D was drawn with AutoCAD software while 3D and stress analysis simulation processed with FEM of Autodesk Inventor. The geometry was made in four variants of JC-1, JC-2, JC-3, and JC-4. A design concept of JC-1 and JC-3 using the beam profiled as a truss. Whereas for JC-2 and JC-4 models using the square hollow profile 70x70x5 mm as the truss. The results were obtained by comparing the yield stress to the maximum stresses that occurred at the weakest point according to Von Mises. The optimum design would be obtained if safety factor ≥ 3, if not proceed iteration.

The jib crane 4 variants were shown in Figure 1 below:

![Figure 1. 2D geometry variant (a) JC-1, (b) JC-2, (c) JC-3, and (d) JC-4.](image-url)
The effective stress of Von Mises (\(\sigma\)) is defined as uniaxial tensile stress that can produce the same distortion energy by a combination of working stress.

\[
\sigma' = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - \sigma_1\sigma_2 - \sigma_2\sigma_3 - \sigma_3\sigma_1}
\]

Optimization design of all variants will be taken by comparison of the yield strength (\(\sigma_y\)) to the effective stress of Von Mises (\(\sigma'\)) that called a safety factor:

\[
sf = \frac{\sigma_y}{\sigma'} \geq 3
\]

Boundary conditions of jib crane design are shown in table 1, below:

**Table 1. Boundary conditions.**

| Item                  | Description                      |
|-----------------------|----------------------------------|
| Grade Material        | Mild Steel JIS SS400             |
| Mass Density          | 7.85 g/cm\(^3\)                 |
| Yield Strength        | 207 MPa                          |
| Ultimate Tensile Strength | 345 MPa                      |
| Young’s Modulus       | 210 GPa                          |
| Poisson’s Ratio       | 0.3 ul                           |
| Shear Modulus         | 80.7692 GPa                      |
| Load                  | 24500N                           |
| Boom Radius           | 3m                               |

### 3. Results and discussion

#### 3.1. Results

Design result from Autodesk Inventor simulation can be shown in table 2, below:

**Table 2. Design result of jib crane.**

| Design-Load Position | Von Mises Stress | Safety factor | Displacement |
|----------------------|------------------|---------------|--------------|
|                      | Minimum          | Maximum       | Minimum      | Maximum     | Minimum   | Maximum   |
| JC-1 - End           | 0.0057079 MPa    | 129.24 MPa    | 2.128 ul     | 15 ul       | 0 mm      | 1.111 mm  |
| JC-1 - Middle        | 0.0202615 MPa    | 44.27 MPa     | 4.676 ul     | 15 ul       | 0 mm      | 0.56 mm   |
| JC-2 - End           | 0.05566 Mpa      | 78.3 MPa      | 2.643 ul     | 15 ul       | 0 mm      | 1.162 mm  |
| JC-2 - Middle        | 0.000442 Mpa     | 42.64 MPa     | 4.854 ul     | 15 ul       | 0 mm      | 0.359 mm  |
| JC-3 - End           | 0.00947 MPA      | 33.53 MPa     | 6.173 ul     | 15 ul       | 0 mm      | 0.705 mm  |
| JC-3 - Middle        | 0.001092 MPa     | 45.67 MPa     | 4.531 ul     | 15 ul       | 0 mm      | 0.219 mm  |
| JC-4 - End           | 0.01178 Mpa      | 72.53 MPa     | 3.791 ul     | 15 ul       | 0 mm      | 1.100 mm  |
| JC-4 - Middle        | 0.0004174 Mpa    | 40.42 MPa     | 5.120 ul     | 15 ul       | 0 mm      | 0.322 mm  |

From table 2 it can be seen that the greatest Von Mises stress occurred on the JC-1 variant when the load positions at the end. Furthermore, the minimum safety factor occurred on the JC-1 variant when the load positions at the end with \(sf = 2.128\). While the biggest displacement occurred in the JC-2 variant when the load position at the end. The safety factor at JC-4 – End = 3.79 is very close to 3 compare to others, it means optimum.
3.1.1. Von mises stress. The results of the analyzed of Von Mises stress crane variants using Inventor software can be seen in figure 3, below:

**Figure 2.** Von Mises Stress for Load in the Middle and the End of Beam (a) and (b) Variant JC-1 (c) and (d) JC-2, (e) and (f) JC-3, and (g) and (h) JC-4.
3.2. Discussion

Based on table 2 and Figure 3 it can be seen that the safety factor minimum for the JC-1 = 2.128 when the load at the end, but when the load in the middle sf = 4.67. For JC-2 sf = 2.64 when the load at the end but 4.85 when the load in the middle. For JC-3 sf = 4.53 when the load at the end but 6.17 when the load at the end. And the optimum safety factor for JC-4 = 3.79 when the load at the end of the beam but 5.12 when the load in the middle with Von Mises stress = 72.53 MPa. The greatest Von Mises = 129.24 MPa. JC-1 – End, In the above figure 2 effect of load position and truss model will give effect to the strength of the structure.

4. Conclusion

From the results and discussion above it can be concluded that the position of load, material, and type of truss of the structure the jib crane will determine the Von Mises stress. The optimum variant is JC-4, it is shown by the safety factor minimum is 3.79 closed to 3 compared to other variants.

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References

[1] Kovacevic D, Sokovic M, Budak I, Antic A and Kosec B 2012 Optimal Finite Elements Method (FEM) Model for The Jib Structure of A Waterway Dredger Metalurgija. 1 113-116
[2] Kovacevic D, Budak I, Antic A, Nagodeb A, and Kosec B 2013 FEM modeling and analysis in prevention of the waterway dredgers crane serviceability failure Engineering Failure. Analysis 28 328-339
[3] Frendo F 2013 Analysis of the catastrophic failure of a dockside crane jib Engineering Failure Analysis 31 394-411
[4] Briskorn D and Angeloudis P 2015 Scheduling Co-Operating Stacking Cranes With Predetermined Container Sequences Discrete Applied Mathematics. 201 70-85
[5] Urbas A 2016 Computational implementation of the rigid finite element method in the statics and dynamics analysis of forest cranes Applied Mathematical Modelling
[6] Peng Y, Wang W, Song X, Zhang Q 2016 Optimal Allocation of Resources for Yard Crane Network Management to Minimize Carbon Dioxide Emissions J. of Cleaner Productions 1-10
[7] Umar U S, Hamisu M T, Jamil M M, and Sa’ad A 2019 Theorical and Numerical Analysis of a Jib Crane Vibration Science and Education Publishing. 7 33-42 1 DOI:10.12691/jmdv-7-1-5
[8] S Dutta, Y Cai, L Huang, and J Zheng 2019 Automatic re-planning of lifting paths for robotized tower cranes in dynamic T BIM environments Automation in Construction. 110
[9] Taghaddosa H, Eslami A, Hermann U, AbouRizk S, Mohamed Y 2019 Auction-based Simulation for Industrial Crane Operations Automation in Construction. 104 107-119
[10] Golovin L, and Palis S 2019 Robust control for active damping of elastic gantry crane vibrations Mechanical Systems and Signal Processing 121 264-278
[11] Vega P J C, Ramirez L M F, and Triviño P G 2019 Hybrid Powertrain, Energy Management System and Techno-Economic Assessment Of Rubber Tyred Gantry Crane Powered by Diesel-Electric Generator and Supercapacitor Energy Storage System J. of Power Sources. 412 311-320
[12] Lee D H, Kim S J, Lee, M S and Paik J K 2019 Ultimate limit state based design versus allowable working stress based design for box girder crane structures Thin-Walled Structures. 134 491-507
[13] Nguyen V T, Yang C, Du C, and liao L 2019 Design and Implement of Finite Time Sliding Mode Controller for Fuzzy Overhead Crane System ISA Transactions
[14] Wang Z, Zhang T, and Li X 2020 Experimental and numerical study of residual stress distribution
of corrugated web I-beams *J. of Constructional Steel Research* **166**

[15] Kulka J, Mantic M, Fedorko G, and Molnar V 2020 Failure Analysis Concerning Causes of Wear for Bridge Crane Rails and Wheels *Engineering Failure Analysis*

[16] JFE Steel Corporation 2015 *Wide Flange Shapes Catalogue* (Japan)