Design Optimization of Jib Crane Boom Using Evolutionary Algorithm

Krunal Gandhare[1], Prof. Vinay Thute[2]

[1]ME Student SSGM College of Engineering, Shegaon

[2]Assisant Prof. SSGM College of Engineering, Shegaon, India

Abstract: ***Cranes are the material handling equipment's that are used worldwide. Due the various standards available it is easy for manufacturers to choose dimensions, most of the time they do it on trial and error basis and chooses dimension that are satisfying the conditions provided in standards, and it is often found that the dimensions are not optimum, and lesser attention has been given to optimization of its dimension. In the following paper an attempt has been made to optimize the Boom of 1 ton Jib crane as per Indian Standards using simple and easily available Excel solver's Evolutionary Algorithm.***

Keywords: Jib Crane, Optimization, Indian Standards, Evolutionary Algorithm

1. Introduction

Jib Cranes are used for material handling in many industries. The purpose it serves is to move Loads from one location to other in its circular swept area. There are various parts of Jib Crane like its supporting column or mast, the cantilever beam or a boom which picks up the load and the hoist which moves on the boom of the crane. While in operation the crane and its parts are exposed to various loads like bending loads, compressive load, tensile load and loads due to weather i.e. wind loads etc. While designing the class of operation and classification of the crane has to be known so that appropriate loads can be considered while designing the crane, along with that the standard practices of respective countries has to be followed and design shall conform to the standards given by the authority of countries. The following crane design has been considered according to Indian standards i.e. IS 15419:2004 was followed for Jib crane design, whereas subsequent details of code of practice were taken from IS 3177:1999 which is for EOT overhead crane design, IS 807:2006 (Design, Erection And Testing, Structural Portion of Cranes And Hoists), and IS 800:2007 (General Construction In Steel). Out of the various elements of the Jib crane, the Boom was under consideration for the optimization. The jib crane boom, for design purpose can be considered as a cantilever with its one end fixed. The jib crane boom under consideration is a simple welded box beam having same cross section throughout its span. Similar type optimization was carried out by [4] for the box beam girder for the overhead crane, whereas [5] carried out it for the optimization of I section beam used for overhead crane girder. The optimization technique used here is Evolutionary nonlinear optimization code for various dimension of the box beam cantilever or boom of the Jib crane. Evolutionary nonlinear optimization code is available in MS Excel Spread Sheet Solver under Data tab available in the software (2010 Version), this Paper is focused on carrying out the optimization of the boom with evolutionary algorithm without considering the stiffener design.

2. Design of the Problem

For optimization, objective function has to be defined [6]. The objective for carrying out this optimization was to reduce the mass of the jib crane boom without compromising its strength and keeping design conformed to IS 15419 and IS 800. For reducing mass it was decided to change the

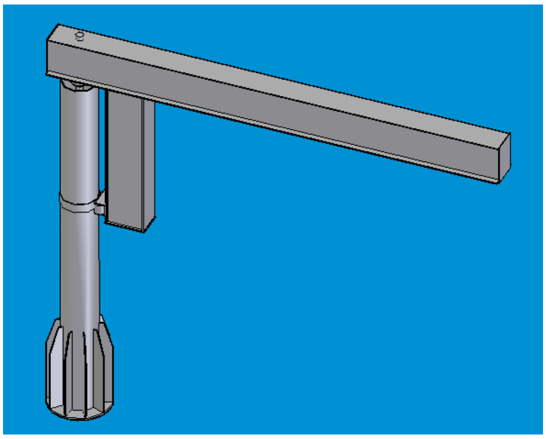


Figure 1: Jib Crane

Cross-sectional dimension of the boom since it has the similar cross section throughout its span unlike [4], and hence the cross-sectional area of the boom was selected as the objective function. And it is defined as:

$$A_b = 2\left(b_{af} \times t_f + h_w \times t_w\right)$$

Where,

A_b	=	Cross sectional area of the boom
b_{af}, t_f	=	Breadth and thickness of top and bottom cover plate
h_w, t_w	=	Depth and thickness of web

Licensed Under Creative Commons Attribution CC BY

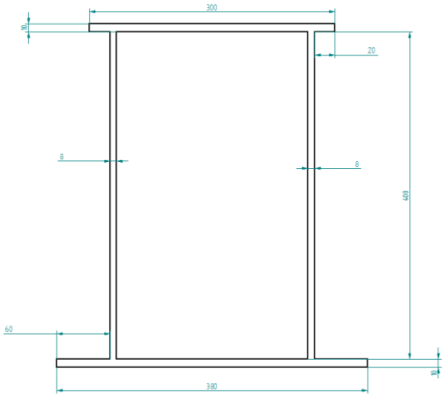


Figure 2: Boom Cross Section

The bottom cover plate on which the hoist mechanism moves has to be greater than the top cover plate and here in this paper for the simplicity of the problem it is kept as same as that of top cover plate. One can consider the bottom cover to be greater and design problem has to be changed accordingly which might yield different results.

For the above objective function the constrained are specified as follows, Constraints were chosen as per the Indian standard code of practice i.e. IS 807, 25.1, the constraints are as:

a) l/h_w Shall not exceed 25
b) l/b_f Shall not exceed 60
c) b_f/t_f Shall not exceed 60
d) h_w/t_w Shall not exceed 62

Where,
l=Length of boom
h_w = Height of boom
b_f = breadth of boom
c = Thickness of cover plate

For constraint, b_f, that is breadth of the boom has to be taken as inner distance between web, and for problem design the actual breath has to be written in terms of b_f i.e.

Breadth of top cover plate
$b_{af} = b_f + 2 \times thickness\ of\ web + required\ outstand$

The h/t_w was restricted to 62 [3][5]so that there is no need of checking the buckling resistance of the cross section and cross section won't be slender.

Figure 2 shows the boom crass section under consideration, but as mentioned earlier, the breadth and thick ness of the top and bottom cover plate is considered same for the simplicity of the problem.

And the deflection of the beam shall not exceed the following [1]:

$$\delta_{max} = \frac{Boom\ Length + Height\ of\ Column}{300}$$

And the allowable stresses were taken as follows [2]from IS 807:2006 Clause 9.7
a) Tensile stress shall not exceed σ_a
b) Compression stress shall not exceed $\sigma_a/1.5$
c) Shear shall not exceed $\sigma_a/\sqrt{3}$
d) (0.6 × Normal plastic shear resistance)Has to be less than maximum shear force [3]
Where,

σ_a = Fundamental allowable stress

It is calculated as,

$$\sigma_a = \frac{Yield\ Point}{\gamma}$$

Or

$$\sigma_a = \frac{Tensile\ Stenght}{\gamma}$$

Value of γ can be chosen from Clause 9 [2].
The weight which has to be applied was calculated as following.

$$W = S_L + W_L \times \psi$$

Where,
W = Total load acting
S_L = Static load due to dead weight of boom
W_L = Working Load
ψ = Dynamic Coefficient or Impact Factor

The dynamic coefficient depends upon the classification of the crane. The detail classification of the crane has to be specified for other constraints that have to be imposed on the problem. Here the crane was identified to be from group M_6 with class of utilization "C" i.e. regular use on intensive duty with moderate state of loading/stress.[2]

The Dynamic coefficient or Impact factor was selected as 1.4 for M_6 was chosen [2],

The Stress calculation was done as follows:

$$Bending\ Stress = \frac{M}{I} \times y$$

Where,
$M = Applied\ moment$
$I = Moment\ of\ Inertia$
$y = distance\ from\ nutral\ axis\ of\ boom$

The bending stress acting on the top cover plate will be tensile in nature while it will be compressive at bottom cover plate, both of them calculated separately and restricted as per the constraints defined.

The Bending moment of the boom,

$$M \leq M_d$$

That is, the M, the bending moment, at any section of the Boom shall not exceed Design bending strength of section M_d**[3],** and

$$M_d = \frac{\beta_b Z_p f_y}{\gamma_{m0}}$$

And to avoid irreversible deformation under serviceability loads M_d shall be less than $1.5 Z_e f_y/\gamma_{m0}$
Where,
β_b = 1.0 for plasic and compact section
$\beta_b = Z_e/Z_p$
Z_e, Z_p = Elastic and plastic section modulus
f_y = Yield stress of the material

γ_{m0} = partial safety factor

Partial safety factor has to be selected as per clause 5.4.1 (IS800)

Licensed Under Creative Commons Attribution CC BY

Here, in this case the resistance to torsional buckling needs not to be checked, by clause (8.2.2)[3]

These all the calculations were done for the actual initial cross section of the boom in a excel sheet.

3. Optimization

For the optimization of the objective function above designed problem was solved using Evolutionary algorithm bundled with Microsoft Excel Spread sheet programmer 2010.The designed problem was written on the Excel sheet and the constraints were fed to the invoked dialog box along with the target cell.

The weight applied to solve this problem was kept fixed to 18604N, which actually changes along with change in cross section of the boom.

For the solver, the integer optimality was 0.5%, and convergence 0.0001, mutation rate 0.075 was used. Then solver was asked to solve the problem. It was found that the solver was exploiting the stress level constraint and giving 110MPa for compressive stress, which was highest limit for compressive stress, and was showing savings in cross sectional area at great extent, which is impractical. Further several trials were made at different stress levels, i.e. the constraint of the compressive stress was reduced from 110MPa to 95, 90, 85 etc. and several optimized Areas for respective stress level were found by running the algorithm.

The obtained various scenarios and obtained solution were compared. Figure 3shows the area for respective stress level.

4. Result and Discussion

The obtained various scenarios and obtained solution were compared. Figure 3 shows the optimized area for respective stress level. Whereas the figure 4 shows the bending moment and deflection at optimized area at various stress level. For the crane under consideration, during the regular use and for the specified life (Fatigue life), the operating stress has to be between 1/3 to 2/3 of the maximum stress P [2] here the maximum stress selected was 110MPa compressive to which the bottom cover plate was reaching even before the Tension i.e. upper cover plate could reach to its maximum stress i.e. 165MPa. Considering this the optimized area for stress of 2/3P i.e. 73.34 MPa (Compressive) was selected as optimized area.

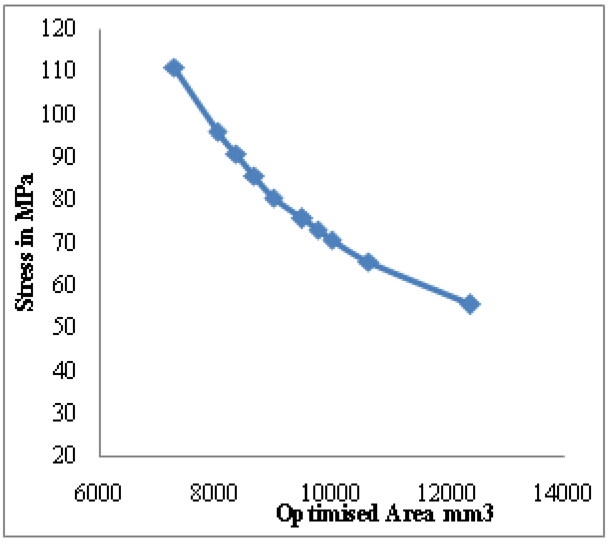


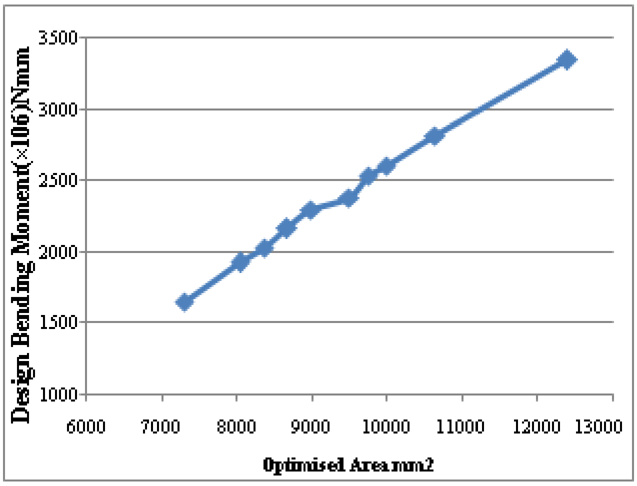
Figure 3: Optimized Area vs. various stress levels

Table 1 shows the comparison between parameters of actual crane. The values of the optimized parameter were rounded off to nearby value. The percentage savings in area without rounding off the values was 21.34% whereas after rounding them off to nearby value it was found to be 18.30%. The savings in the weight of boom was found to be 13%. The results of the optimization model which was fed into the solver did calculation for the cross section which was not the actual one and was considered to be a cross section area with same bottom and top cover plate having same dimensions. If the top and bottom cover plate thickness allowed to change independently, it was found that the savings were higher. Here the results of only one model that was fed to the excel solver i.e. the thickness of the top and bottom flange not changing independently has been shown in Table 1.

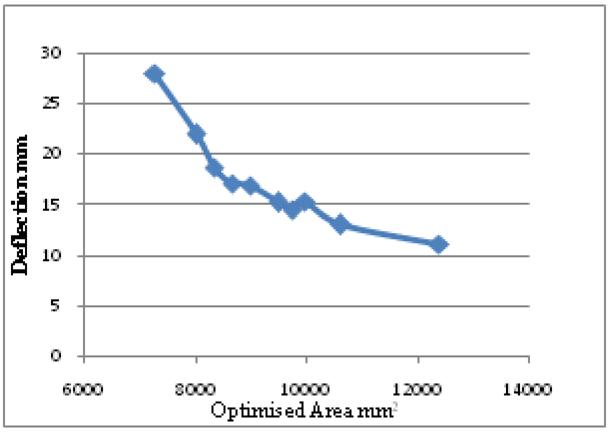
Table 1: Comparison of Boom parameters before and after optimization

Parameter	*Boom Before Optimization*	*Boom After Optimization*
Breadth of top and bottom cover plate	300mm	283.89mm
Thickness of top and bottom Cover plate	10mm	7.79 mm
Height of Web	400mm	398.30 mm
Thickness of web	8mm	6.68 mm
Cross section area of boom	12400mm^2	9752.60 mm^2
Plastic section modulus	1471193.65mm^2	1116379.59 mm^2
Elastic section modulus	1607301.59mm^2	1221961.59 mm^2
Design Bending Moment	334362193Nmm	253722635Nmm
Bending Moment due to applied load	85735828.81Nmm	89299200Nmm
Deflection	9.83mm	14.60mm
Bending stress (Tensile) Top cover plate	53.34MPa	73.07MPa
Bending Stress (Compressive) Bottom cover plate	53.34MPa	73.07Mpa
Weight of boom	447.76kg	390.44kg

Licensed Under Creative Commons Attribution CC BY



(a)



(b)

Figure 4: a. Optimized area at various stress level v/s Design Bending Moment, b. Optimized area at various stress level v/s Deflection

5. Conclusion

Optimization of the jib crane is a nonlinear problem, if this problem was considered to be solved by classical method along Kuhn-Tucker condition it becomes too complex and too difficult to solve, hence automated programming has to be used. In this paper it was found that evolutionary algorithm yields satisfactory results and can be used for obtaining the optimized parameters for the crane and the values of parameter found to be feasible and within limits. There are some of the limitation in the presented optimization model such as the weight applied was kept fixed which actually changes along with change in cross sectional area of the boom, which when removed may give encouraging result. It was also found that by changing the mathematical model relation the results varied a little. The crane dimension obtained has to be tested experimentally to found its validity.

References

[1] Indian Standard 15419:2004, Jib Cranes- Code of Practice
[2] Indian Standard 807:2006, Design, Erection and Testing (Structural Portion) of Cranes and Hoists- Code of Practice.
[3] Indian Standard 800:2007, General Construction In steel- Code of Practice.
[4] Rehan H Zuberi, Dr. Long Kai, Prof. ZuoZhengxing, Design Optimization of EOT Crane Bridge, International Conference on Engineering Optimization, EngOpt 2008,Brazil.
[5] F. Faluyi, C. Arum, Design Optimization of Plate Girder Using Generalized Reduced Gradient and Constrained Artificial Bee Colony Algorithms, International Journal of Emerging Technology and Advanced Engineering, Volume 2, Issue 7, July 2012.
[6] Singiresu S Rao, Engineering Optimization, New Age International Publisher, Third Edition 2008.

Licensed Under Creative Commons Attribution CC BY