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# ANALYSIS AND METAHEURISTIC OPTIMIZATION OF RAMSHORN HOOK WITH DIFFERENT CROSS-SECTIONS

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***Key words**: crane hook, curved beam, metaheuristic algorithm, MATLAB, optimal design*

***Abstract:** This paper presents the optimization problem of the cross-sectional area of Ramshorn hook at its most critical place. The geometric parameters of different profiles (triangular, parabolic and I cross-sections) are taken as optimization variables. The maximum stresses at the inner and outer fibers of a crane hook are taken according to Winkler-Bach theory (the constraint functions). The minimization of the cross-sectional area of Ramshorn hook is the main goal of this research (the objective function). As a method of optimization, one physics-inspired algorithm is taken to solve this optimization problem, called Improved Ray Optimization (IRO) Algorithm. The algorithm was applied in its source code, without modifications, using MATLAB software. The optimization results for all cross-sections are compared to show which achieves the best performance (savings in material).*

## 1. INTRODUCTION

A hammer-forged trapezoidal Ramshorn hook is a standard type of crane hook. Ramshorn hook is a very important and used component in lifting and grabbing heavy parts. It should be designed and manufactured to deliver the best performance under all working conditions without function cancellation and failure. Because of its responsibilities and functions, problems of analysis and optimization of crane hooks is the subject of research in many research papers.

The analysis and optimization of crane hooks are most often performed using some of the software for the Finite Element Method (FEM). Analytical methods are also often applied, and various optimization algorithms. In the paper [1], authors analyzed using ANSYS software lifting hooks with square, circular and trapezoidal cross-sections for the considered materials. The paper [2] analyzed the optimization of different cross-sections of crane hooks, where, besides typical cross-sections, parabolic and elliptic cross-sections were considered, also. The main goal of [3] is to identify the stress concentration areas of different cross-sections of crane hook (trapezoidal, rectangular and triangular cross-sections) for selecting the cross-section with minimum induced stresses. After that, the shape of this cross-section was modified (parametric optimization) to increase its working life and reduce the failure rates.

Comparison between T and I cross-sections of crane hook was done in the paper [4], where the analytical results were compared with those obtained by FEM. The paper [5] showed the advantage of T cross-section by comparing it to trapezoidal and circular cross-sections. The paper [6] showed optimization and comparison of T and I crane hook's cross-sections using two metaheuristic optimization algorithms.

The paper [7] presents the FEM analysis of Ramshorn hook using ANSYS, where a comparison of circular cross-section with T and I cross-sections was performed. Ramshorn hook. Analysis in [8] has been performed on a forged Ramshorn hook with trapezoidal cross-section to study the behaviour under different grades of steel and to determine the proof load under each case. The paper [9] presented the optimization of Ramshorh hook's cross-sectional area (trapezoidal and T cross-sections) by applying two nature-inspired algorithms, Water Cycle Algorithm (WCA) and its modified version, called Evaporation Rate based Water Cycle Algorithm (ER-WCA).

Considering the importance of analyzing and optimizing the geometrical parameters of a crane hook, in this research the optimization of triangular, parabolic cross-section and I cross-sections of Ramshorn hook will be carried out. The Improved Ray Optimization (IRO) Algorithm was chosen as the optimization method.

## 2. MODEL OF OPTIMIZATION PROBLEM

The following figure (Fig.1) shows one standard Ramshorn hook with the position of the load forces, according to [10] and [11]. Also, Fig.1 shows the most critical place (Section *A–A*) where the analysis and optimization of the cross-section are performed, which is the topic of this study.

The main goal of the research for this optimization problem is to minimize the cross-sectional area (the objective function) subject to critical stresses (the constraint functions).

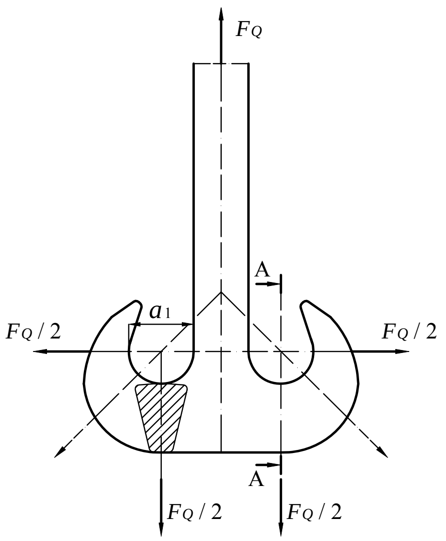



**Fig. 1. – A forged trapezoidal Ramshorn hook**

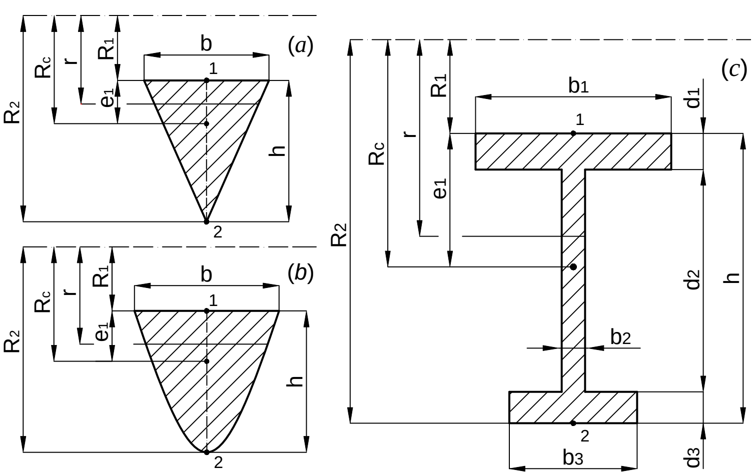



**Fig. 2. – Different cross-sections (Section *A-A*)**

Fig.2 shows different cross-sections (triangular cross-section, Fig.2a, parabolic cross-section, Fig.2b and I cross-section, Fig.2c) with optimization variables (depending on the type of cross-section) and other necessary geometric parameters, where $F_Q$ is the lifting force, according to [10], $e_1$ is the position of the center of the cross-section (Fig.1), $a_1$ is the inner diameter (Fig.1), according to [11], $h$ is the radius of inner fiber (Fig.2), $R_1$ is the radius of inner fiber (Fig.2), $R_2$ is the radius of outer fiber (Fig.2), $R_c$ is the radius of the centroidal axis (Fig.2), and $r$ is the radius of the neutral axis (Fig.2):

$$R_1 = a_1 / 2 \tag{1}$$

$$R_2 = a_1 / 2 + h \tag{2}$$

$$R_c = a_1 / 2 + e_1 \tag{3}$$

## 3. THE OBJECTIVE FUNCTION

The objective function is represented by the cross-sectional area ($A_p$) of Ramshorn hook at its most critical place (Fig.1 and Fig.2).

The mathematical formulation of the objective function is:

$$f(X) = A_p(x_1, \dots, x_n) \tag{4}$$

where $X$ is the vector of $n$ optimization variables $x_i,\ i = 1,\dots,n$ (Ramshorn hook's cross-sectional geometric parameters).

Depending on the cross-section, in the Chapter 5, there will be a presentation of the optimization variable.

### 3.1 The objective function for triangular cross-section

The area for triangular cross-section $A_p$, i.e. the objective function, is:

$$A_p = \frac{b \cdot h}{2} \tag{5}$$

The geometric parameters for this cross-section are determined as follows:

$$e_1 = h/3 \tag{6}$$

$$r = \frac{h}{2 \cdot \left( \frac{a_1 + 2 \cdot h}{2 \cdot h} \cdot \ln \frac{a_1 + 2 \cdot h}{a_1} - 1 \right)} \tag{7}$$

### 3.2 The objective function for parabolic cross-section

The area for parabolic cross-section $A_p$, i.e. the objective function, is:

$$A_p = \frac{2 \cdot b \cdot h}{3} \tag{8}$$

The geometric parameters for this cross-section are determined as follows:

$$e_1 = 2 \cdot h / 5 \tag{9}$$

$$r = \frac{2 \cdot h \cdot \sqrt{h}}{3 \cdot \left( \sqrt{R_2} \cdot \ln \frac{2 \cdot \left( \sqrt{R_2} + \sqrt{h} \right)^2}{a} - 2 \cdot \sqrt{h} \right)} \tag{10}$$

### 3.3 The objective function for I cross-section

The area for I cross-section $A_p$, i.e. the objective function, is:

$$A_p = b_1 \cdot d_1 + b_2 \cdot d_2 + b_3 \cdot d_3 \tag{11}$$

The geometric parameters for this cross-section are determined as follows:

$$e_1 = \frac{b_1 \cdot d_1^2 + 2 \cdot b_2 \cdot d_1 \cdot d_2 + b_2 \cdot d_2^2 + 2 \cdot b_3 \cdot (d_1 + d_2) \cdot d_3 + b_3 \cdot d_3^2}{2 \cdot A_p} \tag{12}$$

$$r = \frac{A_p}{b_1 \cdot \ln \frac{a_1 + 2 \cdot d_1}{a_1} + b_2 \cdot \ln \frac{a_1 + 2 \cdot (d_1 + d_2)}{a_1 + 2 \cdot d_1} + b_3 \cdot \ln \frac{a_1 + 2 \cdot (d_1 + d_2 + d_3)}{a_1 + 2 \cdot (d_1 + d_2)}} \tag{13}$$

## 4. THE CONSTRAINT FUNCTIONS

The strength criterion in tensioned and compressed fiber at the critical section of Ramshorn hook (Fig.1) must be satisfied. The stress check is based on Winkler-Bach theory, where a hook is treated as a curved beam.

The constraint functions, subject to maximum stresses at the characteristic points (point 1 and point 2, Fig.2), have the following form:

$$g_1 = \sigma_z - \sigma_{1d} = \frac{F_Q}{2 \cdot A_p} + \frac{M_s}{S_x} \cdot \frac{r - R_1}{R_1} - \sigma_{1d} \le 0 \tag{14}$$

$$g_2 = \sigma_p - \sigma_{2d} = \left| \frac{F_Q}{2 \cdot A_p} - \frac{M_s}{S_x} \cdot \frac{R_2 - r}{R_2} \right| - \sigma_{2d} \le 0 \tag{15}$$

$$M_s = \frac{F_Q \cdot R_c}{2} \tag{16}$$

$$S_x = A_p \cdot (R_c - r) \tag{17}$$

where $M_s$ is the bending moment, $S_x$ is the static moment of the area, $\sigma_z, \sigma_p$ are maximum stresses (maximum tensile stress and maximum compressive stress, respectively), and $\sigma_{1d}, \sigma_{2d}$ are critical stresses (critical tensile stress and critical compressive stress, respectively), according to [10].

Depending on type of cross-section, geometrical conditions were considered as additional constraints, too.

## 5. OBTAINED RESULTS

The optimization procedure was performed using the MATLAB code for the IRO algorithm, according to [12]. A detailed description of this algorithm can be found in the mentioned literature.

The mark of the standard Ramshorn hook whose cross-sectional area is optimized is: DIN 15 402 – RF20 – M. The cross-sectional area of that hook, in comparison to which the optimal results are compared is: $A_s$ = 97,944 cm$^2$ (dimensions of standard trapezoidal profile: $b_s$ = 10,6 cm – the base of profile and $h_s$ = 13,2 cm - the height of profile), according to [11].

The optimization variables are *b*, *h* for triangular and parabolic cross-sections, and $b_1$, $d_1$, $b_2$, $d_2$, $b_3$, $d_3$ for I cross-section (Fig. 2).

Input parameters for optimization are: $F_Q$ = 200 kN (for Ramshorn hook capacity: $Q$= 20 t, drive group: 3m, and strength class: M), according to [10], and $a_1$ = 12,5 cm, according to [11]. The permissible stresses are taken according to [10], and their values are: $\sigma_{1d}$ = 8,6 kN/cm$^2$ and $\sigma_{2d}$ = 3,7 kN/cm$^2$.

Some geometrical constraints (maximum height $h_{\max} \le h_s$ and maximum width $b_{\max} \le b_s$) for I cross-section were taken. Also, in this analysis is adopted that minimum value of thickness of I profile is 0,6 cm.

For the IRO algorithm, control parameters for the optimization process are: the population size is 20 (the number of light rays) and the number of objective function evaluations is 20000.

The following tables present the optimization results (optimal geometric parameters, areas, savings, and the time necessary for optimization processes) for triangular cross-section (Table 1), parabolic cross-section (Table 2) and I cross-section (Table 3). Subscript *o* marks optimal values.

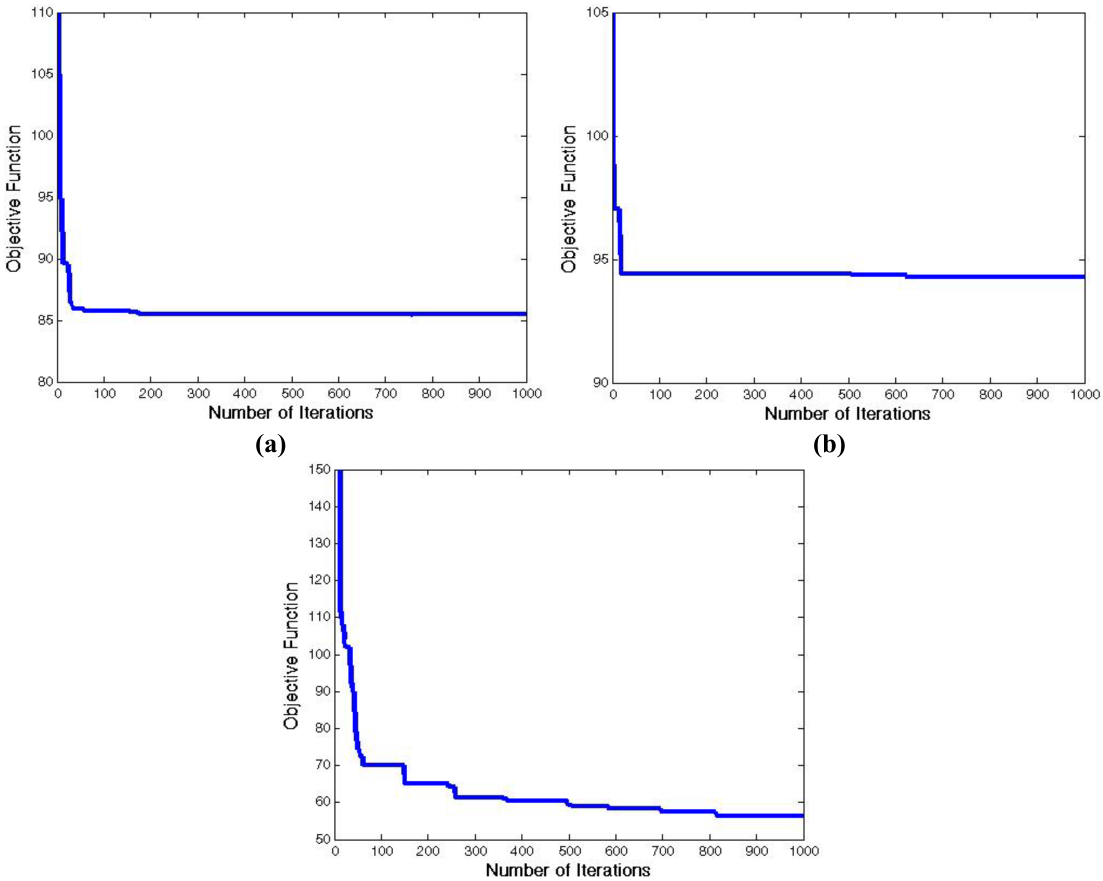
**Table 1**

| Cross-section | $b_o$ (cm) | $h_o$ (cm) | $A_o$ (cm$^2$) | Saving (%) | time (s) |
|---|---|---|---|---|---|
| Triangular | 5,4954 | 31,1015 | 85,457 | 12,75 | 1,0995 |
| Parabolic | 5,4935 | 25,7373 | 94,258 | 3,76 | 1,2231 |

**Table 2**

| $b_{1o}$ (cm) | $d_{1o}$ (cm) | $b_{2o}$ (cm) | $d_{2o}$ (cm) | $b_{3o}$ (cm) | $d_{3o}$ (cm) | $A_o$ (cm$^2$) | Saving (%) | time (s) |
|---|---|---|---|---|---|---|---|---|
| 10,5331 | 3,0830 | 0,6125 | 8,2689 | 10,2779 | 1,8263 | 56,308 | 42,51 | 1,1542 |

The following figures (Fig.3) present convergence graphs for triangular cross-section (Fig.3a), parabolic cross-section (Fig.3b) and I cross-section (Fig.3c).




(c)

**Fig.3 – Convergence graphs**

## 6. CONCLUSION

This research presents analysis and optimization of geometric parameters of different cross-sections of Ramshorn hook (triangular, parabolic and I profile), subject to stresses according to Winkler-Bach theory. The Improved Ray Optimization (IRO) Algorithm was chosen for the optimization process, using MATLAB. The minimization of the cross-sectional area was the goal in this research.

The saving achieved with a triangular cross-section is 12,75% (Table 1), while the optimal profile height is much higher, compared to the standard, with a trapezoidal cross-section (more than twice). For parabolic cross-section, the value of the optimal area is slightly smaller than the one defined by the standard (saving of 3,76%, Table 1). In this case, optimal the profile's height is higher than the standard (about twice). Both cross-sections are not suitable for the observed conditions, regardless of the savings achieved.

In the case of I cross-section, savings of as much as 42,51% were achieved (Table 2), where limitations were set regarding the height and width of the profile (compared to the standard). By choosing this cross-section, a large saving in a material was achieved.

The IRO Algorithm solved in a relatively short time (Table 1 and Table 2), and it can be successfully applied to different engineering problems, where optimal results are obtained quickly and successfully, regardless of the number of variables and constraint functions.

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