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Modelling and Analysis of the Crane Hook Problem Using Optimization

***Abstract**. This study's current research, a newly developed optimization algorithms are used to minimize the volume of crane hook. The current study presented here compares 10 modern metaheuristic methods for optimizing the design of the crane hook problem. The performance of these algorithms is assessed both statistically and subjectively. The algorithms' performance is evaluated quantitatively and qualitatively using consistency, simplicity and quality. The experimental results on the crane hook problem shows that PSO produces greater results than EHBMO, whereas CSA and BBCO produce approximately identical results.*

Streszczenie.** W bieżących badaniach w ramach tego studium zastosowano nowo opracowane algorytmy optymalizacji, aby zminimalizować objętość haka dźwigu. Prezentowane tu aktualne badanie porównuje 10 nowoczesnych metod metaheurystycznych do optymalizacji projektowania problemu haka dźwigowego. Wydajność tych algorytmów oceniana jest zarówno statystycznie, jak i subiektywnie. Wydajność algorytmów jest oceniana ilościowo i jakościowo przy użyciu spójności, prostoty i jakości. Wyniki eksperymentalne dotyczące problemu haka dźwigu pokazują, że PSO daje lepsze wyniki niż EHBMO, podczas gdy CSA i BBCO dają w przybliżeniu identyczne wyniki.* (Modelowanie i analiza problemu haka dźwigu za pomocą optymalizacji***)

Keywords: Crane hook, Optimization Analysis, Mathematical Modelling.
Słowa kluczowe: optymalizacja, modelowanie, hak dźwigu.

Introduction

A crane hook is an attachment point on a crane that connects to chains and ropes linked to loads such as containers, construction beams, and machinery. Hooks are available in a range of styles to accommodate a variety of demands, and they, like other crane components, are rated for certain sizes and kinds of weights. It is critical to avoid employing an underestimated crane hook, as this could cause damage to the crane or result in the loss of the load. Crane hooks are components that are commonly used in businesses and construction sites to lift huge loads. A crane is a machine that has a hoist. A crane hook is a mechanism that is used to grab and hoist goods with the help of a crane. It's a hoisting fixture that engages a lifting chain's ring or link, or the pin of a shackle or cable socket. Crane hooks are extremely prone to failure due to the accumulation of significant amounts of stresses, which can eventually result in failure. Rectangular, and triangular cross section crane hooks are often employed. As a result, it must be designed and produced in such a way that it can give maximum performance without failing [3]. Crane hooks are used primarily in the transportation, construction, and manufacturing sectors. Some of the most widely utilised cranes include overhead cranes, mobile cranes, tower cranes, telescopic cranes, gantry cranes, deck cranes, jib cranes, and loader cranes. A crane hook is a device that is used to grab and lift loads using a crane. It's essentially a hoisting fixture that engages a lifting chain's ring or link, or the pin of a shackle or cable socket. Trapezoidal, circular, rectangular, and triangular cross section crane hooks are often employed. As a result, it must be designed and produced in such a way that it can give maximum performance without failing [3].

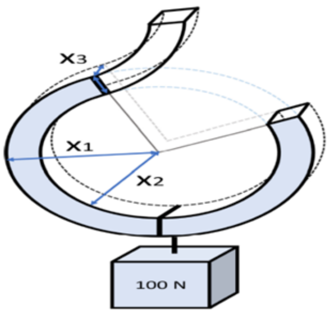

Fig.1. Schematic view of the crane hook design problem

Objective

The aim of the study is to minimize the volume of the crane hook design by optimizing the problem so that it can be minimized by its volume with the same load lifting capacity.

Literature Survey

Ravikanth explains how the hook is designed using an analytical method and for various materials such as forged steel, wrought iron, and high tensile steel [3]. The design of the EOT crane hook has been completed by Sarvesh. For Trapezoidal, Rectangular, and Circular cross-sections, the dimensions of the hook have been established for a load capacity of 9 to 12.5 tones [6]. Yadav investigated the stress distribution of a crane hook in its loaded state and used ANSYS software to create a solid model of the crane hook [7]. Bugra compared the performance of eight new population-based metaheuristic optimisation algorithms on five different mechanical component design issues [2]. Gopichand discusses his work, which involves applying the Taguchi method to optimise design parameters. A total of three factors are examined with mixed levels, and an L16 orthogonal array is constructed [1]. Mahesh presents his work, which aims to investigate the various design parameters and stress patterns of a crane hook in its loaded state for various cross sections. The crane hook will be designed and drafted using ANSYS [4]. He also presented his work, which would use software to design and draught crane hooks in order to analyse the different design parameters and stress patterns of crane hooks in loaded conditions for various cross sections [5].

Mathematical Modelling

The design variables of the crane hook are F – Load, Sy – yield stress, h – depth of the section, R- radius of centroidal axis, rn – radius of the neutral axis, e – distance between centroidal and neutral axis, M – bending moment about neutral axis, co – distance of outer surface from neutral axis, ci – distance of inner surface from neutral axis, Area – cross section area, oA – maximum bending stress at outside surface, oB - maximum bending stress at inner surface, x1 – radius of the outer surface of the crane hook, x2 – radius of the inner surface of the crane hook, x3 – width of the crane hook .

Objective function

$$\text{Minimize} \quad f(x)_{min} = \pi x_1^2 - x_2^2 x_3$$

Subject to:

(1) $g_1(x) = o_A - S_y \le 0,$

(2) $g_2(x) = o_B - S_y \le 0,$

(3) $g_3(x) = x_2 - x_1 \le 0$

where

F = 100,

$S_y = 430,$

$h = x_1 - x_2,$

$R = x_1 + \frac{x_2}{2},$

$r_n = \frac{h}{\log(\frac{x_1}{x_2})},$

$e = R - r_n$

$M = F \times R$

$c_o = x_1 - r_n$

$c_i = r_n - x_2$

$Area = x_3 \times h$

$o_A = M \times \frac{c_o}{Area \times e \times x_1}$

$o_B = M \times \frac{c_i}{Area \times e \times x_2}$

Variable range:

$3 \le x_1 \le 5,$

$1.5 \le x_2 \le 2,$

$0.2 \le x_3 \le 1.5$

Optimization Algorithm

The following are some of the most common problems with traditional gradient methods and direct approaches:

- It converges to an ideal solution based on the original solution; most algorithms have a propensity to limit themselves to the sub-optimal option.
- An algorithm that solves one problem may not be efficient when applied to another.
- When dealing with problems involving nonlinear objectives, discrete variables, and a large number of restrictions, algorithms are inefficient
- On a parallel computer, algorithms cannot be employed efficiently.

Addressing large-scale difficulties with nonlinear objectives functions is difficult using standard techniques like steepest descent, dynamic programming, and linear programming. Traditional algorithms can't address non-differentiable problems since they rely on gradient information. In some optimization problems, there are a lot of local optima. As a result of this issue, more powerful optimization approaches are required, and our non-traditional optimization method has been discovered through research.

The following non-traditional optimization algorithms are used.

- Particle swarm optimization (PSO),
- Crow search algorithm (CSA),
- Enhanced honeybee mating optimization (EHBMO),
- Harmony search algorithm (HSA),
- Krill heard algorithm (KHA),
- Pattern search algorithm (PSA),
- Charged system search algorithm (CSSA),
- Salp swarm algorithm (SSA),
- Big bang big crunch optimization (B-BBBCO),
- Gradient based Algorithm (GBA).

Methodology

The non-traditional algorithm's performance will vary with each run, but the solution will always be global optimal. As a result, twenty trail runs in all algorithms were performed for each problem, and the average value of the answer was calculated from all the trails. Table 1 shows the specific parameters for several techniques, whereas Table 2 shows the Functional Evaluation FEs number and Number of population NP size.

Table 1.Specific Parameter Settings of Used Algorithms

Algorithm	Parameter Settings
PSO	w_{min} = 0.9, w_{max} = 0.4, c_1=2, c_2=2
CSA	$c_1 = c_2 = c_3 = 2$, ω = 0.5, AP = 0.2, fl = 2, V_{max} = $[2]^D$
EHBMO	No. of drones = 40, No. of broods = 10, No. of selected genes in crossover = 8
HAS	HMS=50, HMCR=0.5 fixed, PAR=0.5
KHA	N^{max} = 0.01, V_f = 0.02, D^{max} = 0.005
PSA	Only the common parameters (Fes and NP)
CSSA	rand-Random value between [0,1], c = 0.1, ε = 0.001
SSA	Only the common parameters (Fes and NP)
B-BBCO	N_{pop} = 100, k_{ls} = 30, α = 0.8, N_s = 5
GBA	Only the common parameters (Fes and NP)

w_{min}, w_{max} are respectively the min and max inertia weight 0.4, c_1 and c_2 are acceleration factors. HMS-Harmony Memory Size, PAR-Pitch Adjustment rate, HMCR-Harmony Memory Consideration rate, N_{pop}- Population size, K_{ls}- no. of non-improvement iteration, α- Reduction rate, N_s -no. of neighbours created in each generation, N^{max} - Maximum induced speed, V_f- The foraging speed, D^{max} - The maximum diffusion speed, c_1, c_2, c_3 – acceleration, ω-inertia weight, fl- length of the crow's flight, AP- perceptual probability of crow, V_{max}- upper limit of the particle update velocity

Table 2. FEs number and the NP size for the algorithms

Problem	NP	t_{max}	Fes
Crane hook	20	250	5000

The non-traditional optimization methods are run for 20 trails and the values of the 20 trails, the average value, the maximum and minimum values, the standard deviations of the variables, x1 – radius of the outer surface of the crane hook, x2 – radius of the inner surface of the crane hook, x3 – width of the crane hook are tabulated in table 3, 4, 5 and figure 2,3,4. Table 6 and figure 5 contains the minimized volume of the crane hook.

Radius of the outer surface of the crane hook (x1)

The radius of the outer surface of the crane hook is optimized by using optimization methods for 20 trails

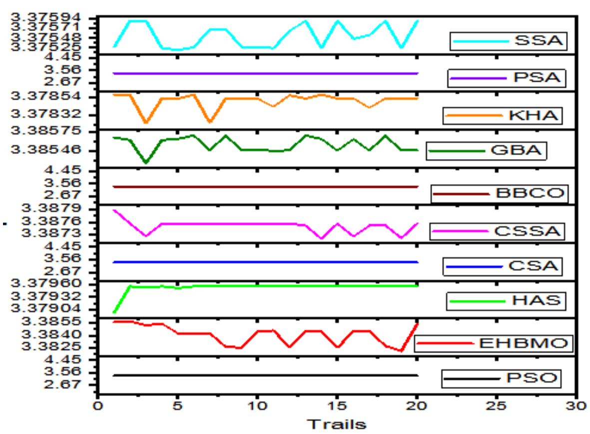

Figure 2. Radius of the outer surface of the crane hook (x1)

Radius of the inner surface of the crane hook (x2)

The radius of the inner surface of the crane hook is optimized by using optimization methods for 20 trails.

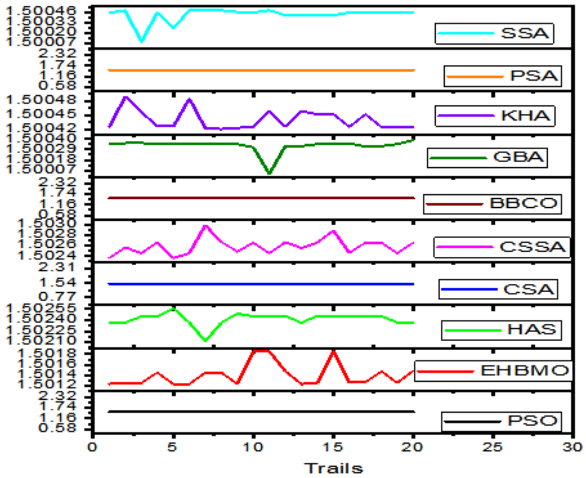

Figure 3. Radius of the inner surface of the crane hook (x2)

Width of the crane hook (x3)

The width of the crane hook is optimized by using optimization methods for 20 trails

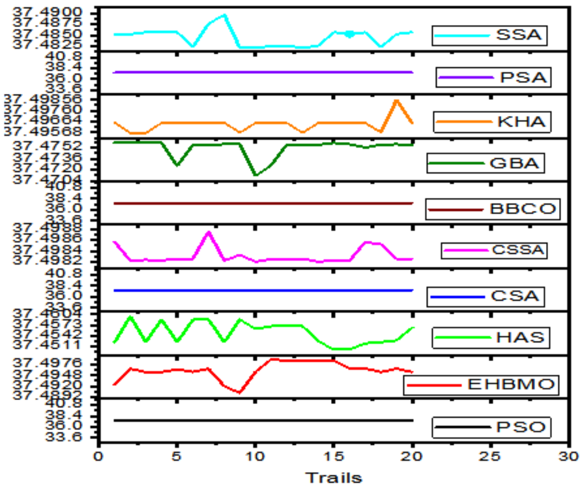

Figure 4. Width of the crane hook (x3)

Volume minimization fmin

Volume of the crane hook is minimized by using optimization methods for 20 trails.

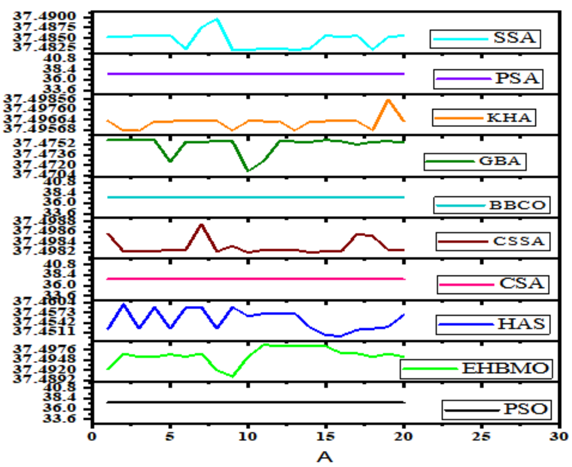

Figure 5. Volume minimization fmin

Table 3. Comparison of the Best Optimum Solution for the Crane hook Problem

	PSO	EHBMO	HAS	CSA	CSSA	BBCO	GBA	KHA	PSA	SSA
x_1	3.4	3.384	3.4	3.39	3.39	3.38	3.39	3.4	3.4	3.4
x_2	1.5	1.501	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
x_3	1.3	1.285	1.3	1.29	1.29	1.29	1.29	1.3	1.3	1.3
fmin	37	37.5	38	37.4	37.5	37.4	37.5	38	37	38

In table 4, a comparison of results for design of crane hook optimization problem are shown. Analysing the table results a conclusion has been drawn that the PSO gives better results in comparison to EHBMO, while in comparison to CSA and BBCO the results are nearly the same

Table 4. Statistical Result of the Used Algorithms for the Crane hook problem

Algo	best	mean	Worst	SD	FEs
PSO	37.42563	37.42563	37.42563	0.00000000	5000
EHBMO	37.49026	37.49604	37.49897	0.002287484	5000
HAS	37.45021	37.4457	37.4457	0.003257023	5000
CSA	37.4457	37.4457	37.4457	0.000000000	5000
CSSA	37.4982	37.49831	37.49876	0.000155588	5000
BBCO	37.42898	37.42898	37.42898	0.00000000	5000
GBA	37.47112	37.47516	37.4759	0.001352185	5000
KHA	37.49563	37.49642	37.49856	0.000634931	5000
PSA	37.4357	37.4357	37.4357	7.29001E-15	5000
SSA	37.4821	37.48454	37.48963	0.002104509	5000

Result and Discussion

Consistency

The consistency table gives the parameters that remain constant for all the trails. All the solvers give the value of PSO, CSA, BBCO and HSA for all the runs, which in turn indicates that the requirements are in the acceptable range.

x1 - PSO (3.37459), PSA (3.37), SSA (3.375534)
x2 - PSO (1.50025), PSA (1.500357), SSA (1.50043)
x3 - PSO (1.284563), CSSA (1.284786), BBBCO (1.284897)
So, we see that the solvers PSO, CSA, BBCO, PSA remains constant throughout their runs.

Simplicity of Algorithm

Of all the algorithm, we have taken PSO is the simplest followed by EHBMO, SSA, HSA, BBCO.

Minimum values of variables

The best optimal solution and statistical simulation results for the crane hook problem are presented in Table 3 and Table 4. Table 3 shows that all of the methodologies used are capable of finding a globally feasible solution. However, with standard deviation values of 0, the PSO algorithm is the most robust in handling this problem, followed by EHBMO, SSA, HAS, CSA, CSSA, BBCO, PSA, GBA, and KHA.

- x1 - PSO (3.37459) is better than PSA (3.37), SSA (3.375534)
- x2 - PSO (1.50025) is better than PSA (1.500357), SSA (1.50043)
- x3 - PSO (1.284563) is better than CSSA (1.284786), BBBCO (1.284897)

Conclusion

The following are some of the most common problems with classic gradient methods and traditional direct approaches:

- It converges to an optimal solution based on the original solution chosen.
- Most algorithms are prone to limiting themselves to a sun-optimal answer.
- A problem solved by one algorithm may not be efficient when applied to another.
- Algorithms are inefficient for solving problems with non-linear objectives, discrete variables, and a large number of restrictions.
- On a parallel computer, algorithms cannot be employed efficiently.

In general, standard techniques such as steepest descent, dynamic programming, and linear programming make it difficult to address large-scale issues with nonlinear objectives functions. Traditional algorithms cannot address non-differentiable problems because they require gradient information. Some optimization problems have a large number of local optima. As a result of this issue, there is a need to build more powerful optimization approaches, and research has discovered our non-traditional optimization [6].

In this paper, we compared 10 meta-heuristic algorithms to solve the crane hook. The algorithms used are particle swarm optimization (PSO), crow search algorithm (CSA), enhanced honeybee mating optimization (EHBMO), Harmony search algorithm (HSA), Krill herd algorithm (KHA), Pattern search algorithm (PSA), Charged system search algorithm (CSSA), Salp swarm algorithm (SSA), Big bang big crunch optimization (B-BBBCO), Gradient based Algorithm (GBA). These algorithm's performance is evaluated statistically and subjectively.

By comparing these methods, we've proved that PSO is the best optimization method comparing with other nine methods which we discussed in the result analysis. To minimize the volume of the crane hook, Particle Swarm Optimization (PSO) got the minimum value comparing with Enhanced Honey-Bee Mating (EHBMO) and Salp Swarm Optimization (SSA). Therefore, for crane hook problem, Particle Swarm Optimization (PSO) is the best method.

Nomenclature

x1 – radius of the outer surface of the crane hook
x2 – radius of the inner surface of the crane hook
x3 – width of the crane hook
F – Load,
Sy – yield stress,
h – depth of the section,
R- radius of centroidal axis,
rn – radius of the neutral axis,
e – distance between centroidal and neutral axis,
M – bending moment about neutral axis,
co – distance of outer surface from neutral axis,
ci – distance of inner surface from neutral axis,
Area – cross section area,
oA – maximum bending stress at outside surface,
oB - maximum bending stress at inner surface

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