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A Study on the Structural Integrity of Lifting Lug without Appendage

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부가물이 미부착된 리프팅 러그의 구조 건전성에 관한 연구

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ABSTRACT

In this study, a multivariate function was applied to the genetic algorithm for D-type lugs currently used in shipyards to closely analyze the behavioral form of weight loss without double plates. An optimal lifting lug structure design without attachments is proposed. MATLAB R2016a was used to design features by applying multivariate functions to genetic algorithms. Furthermore, the design was achieved by deriving the optimal shapes of lugs using genetic algorithms. The shapes of the designed lugs were validated for structural bonding using the structural analysis program ANSYS 2020 R2, and a robust design of lugs with no appendages was developed.

Keywords : Appendage(부가물), Optimization(최적화), Generation(세대), Safety Factor(안전율), Aspect Ratio(종횡비), Mutation(돌연변이)

1. Introduction

Turnover of blocks is essential during the shipbuilding process. The quantity of lifting lugs to handle these processes is increasing as structures become larger and larger in block units of blocks. Generally, the total number of ship lugs used in site is over 3,000. The average weight per lug is 50kg, and about 150 tons of lugs per ship are used and discarded. Lugs are expensive to remove after installation during the fabrication process. Therefore, research on cost reduction through lightweight design is essential. Ham[1-2] proposed a system development for the rationalization of the structural design of the lug. In addition, research has been conducted to reconsider the reuse rate of lugs[3]. There is also a study[4] that presented structural safety by performing a nonlinear finite element analysis on D-type lugs. Lee[5-6] and a like suggested the basis for weight

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reduction through final strength design for T-type lugs that are widely used in shipyards. and study was also conducted to propose weight reduction through local strength analysis by introducing an algorithm to optimize the lug structure[7]. In general, the structural safety evaluation of a lug has been previously studied based on the lug body, a hole in the center of the lug, the size of the ring doubler plate, and the final strength against in-plane and external loads[8-9]. Recently, a lug optimization study based on aspect ratio features has resulted in the conclusion that D-type lugs have the largest weight reduce compared to conventional lugs when aspect ratio is 1:3[10]. These recent studies raise questions about the role of appendage to lugs in their weight. In order to ensure the soundness of the lug, it is necessary to maintain the soundness from a structural perspective.

In this paper, the subject is a type D lug that is currently widely used in shipyards. it is select a multivariate function using genetic algorithms to design an attachment-free lifting lug and through structural analysis, We would like to propose an optimal lug structure design by closely analyzing the behavioral form of lug safety evaluation and weight reduce.

2. Design of D-type Lug without Appendage

D-Type is the lug most commonly used to lift the heaviest ship block used in ships, with a safe load of 100 tons. In Fig. 1. it is a design formed for solving lugs without appendages as multivariate optimization problems. This is a detailed drawing designed to the extent that it does not undermine the original function of the lug.

Dh: diameter of the lug body

y: the toe height

L: the length of the lug longitudinal direction

At1: the length on the vertical line of the lug body diameter

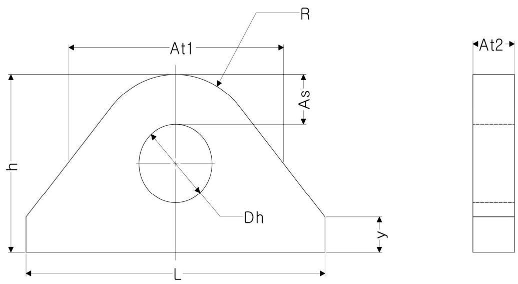

Fig. 1 D-100 type lifting lug without an appendage

At2: thickness of the lug body

As: the shear area

R: the radius of the lug outer diameter

h: lug height

3. Optimization Design System

3.1 Algorithm application and optimization criteria

Applying genetic algorithms is advantageous to find an approximation of the optimization problem when the target we are trying to solve is differentiable, continuous, and has sufficient constraints in the exploration space. According to Goldberg[11], the basic structure of the genetic algorithm is first formed as an initial group, and the properties of chromosomes are evaluated as fitness items. Each chromosome is decryption to provide an objective function, from which fitness calculations are made. Here, reproduction selects more suitable individuals according to their fitness values and forms the next generation of groups. crossover enables information exchange between individuals, and mutations introduce changes to the population by randomly changing genes. New groups formed through reproduction, hybridization, and mutations during this generation are re-evaluated. The sequence of operations performed earlier forms a repeating structure until an optimal solution is found. It establish a random number of multivariate functions with two or more independent variables for optimal shape design that satisfies the functions of existing lugs even in the absence of attachment.

Shown in Equation (1)[12] is a present the criteria for determining optimization of multivariate functions.

$$\begin{aligned} F(X) &= F(X^{*}+\Delta X) \\ &= F(X^{*}) + \nabla F(X^{*})^{T}\Delta X + \frac{1}{2!}\Delta X^{T}\nabla^{2} F(X^{*})\Delta X + O_3(\Delta X) \end{aligned} \tag{1}$$

Here, $\Delta X = X - X^{*}, O_3(\Delta X)$ the equation can be represented by expression (2) by plotting higher-order terms above the third order.

$$\nabla F(X^{*}) = \left[\frac{\partial F(X)}{\partial_{X_1}}\ \frac{\partial F(X)}{\partial_{X_2}} \cdots \frac{\partial F(X)}{\partial_{X_n}}\right]^{T}_{|X=X^{*}} \tag{2}$$

Equation (2) can be represented as a $n\times 1$ vector by Hessian matrix, a symmetric matrix with the following equation (3).

$$\nabla 2F(X^{*}) = \begin{bmatrix} \frac{\partial^2 F(X)}{\partial X_1} & \frac{\partial^2 F(X)}{\partial X_1 \partial X_2} & \cdots & \frac{\partial^2 F(X)}{\partial X_1 \partial X_n} \\ \frac{\partial^2 F(X)}{\partial X_2 \partial X_1} & \frac{\partial^2 F(X)}{\partial X_2^2} & \cdots & \frac{\partial^2 F(X)}{\partial X_2 \partial X_n} \\ \vdots & \vdots & & \vdots \\ \frac{\partial^2 F(X)}{\partial X_n \partial X_1} & \frac{\partial^2 F(X)}{\partial X_n \partial X_2} & \cdots & \frac{\partial^2 F(X)}{\partial X_n^2} \end{bmatrix}_{|X=X^{*}} \tag{3}$$

Ignoring the higher-order term of the optimization judgment equation (1) equals Equation (4), and in order for X^{*} to be the minimum point, the function value $F(X)$ around this point must be greater than $F(X^{*})$, then Equation (5) must be satisfied.

$$\Delta F(X) = F(X) - F(X^{*}) = \nabla F(X^{*})^{T}\Delta X + \frac{1}{2!}\Delta X^{T}\nabla^{2}F(X^{*})\Delta X \tag{4}$$

$$\triangle F(X) = F(X) - F(X^{*}) \geq 0 \tag{5}$$

Here, if the condition of Equation (5) is satisfied for all $X \in \Omega$, then X^{*} is global solution. and if you are satisfied with all X that have relationships $\delta > 0$ and $\|X - X^{*}\| \leq \delta$, then X^{*} is the local minimum. Equation (6)

$$\triangle F(X) = F(X) - F(X^{*}) \leq 0 \tag{6}$$

3.2 Formulation of lugs for GA application

For features that can maintain the functional aspects of a lug, we define each variable at a certain rate to create random numbers with minimum and maximum values. Using these random numbers, the independent variables of chromosome information that to implement optimal formed through crossover are equivalent to equation (7).

$$\begin{aligned} At_2 &= (At_{2max} - At_{2min})rand + At_{2min} \\ AR &= (AR_{max} - AR_{min})rand + AR \\ k_1 &= (k_{1max} - k_{1min})rand + k_{1min} \\ k_2 &= (k_{2max} - k_{2min})rand + k_{2min} \end{aligned} \tag{7}$$

$$AR = (Aspect\,Ratio) \tag{8}$$

Equation (8) is an Aspect Ratio (AR) for applying aspect to algorithms. At_2 is the thickness of the lug and limits it to its maximum value considering the size of the shackle used in the field.

The objective function for optimal design determination is as follows.

$$g_o(X_0), g_o(X_1) = At_1, As \tag{9}$$

Here, the diameter of the lug body At_1 is equal to Equation (10), and the calculation of the variables of the aspect ratio of the lug is equal to Equation (11).

$$At_1 = \frac{P_g}{\eta_1 \times \sigma_0 \times At_2} \tag{10}$$

$$As = \frac{P_g}{\sigma_0 \times \eta_2 \times At_2} \times \frac{\sqrt{3}}{2} \tag{11}$$

η_1, η_2 is usage factor, For tensile, yield strength criterion $\eta_1 = 0.6$ is applied for shear case $\eta_2 = 0.4$. The values of the lug parameters are determined by considering shear stress, and As is determined by considering tensile stress. where P_g is Safety working loads and σ_0 is 235 MPa.

Furthermore, the total lug height can be obtained as shown in Equation (12), by considering the symmetry of the aspect, and aspect ratio, horizontal direction, and proposing a minimum distance to the bottom face of the lug as 50 mm.

$$h = 50 + D_h + As \ , L = \frac{AR}{h} \quad (12)$$

The lug shape parameter y is set to a toe height of more than 50mm, and if it is greater than the height of the entire lug, the shape break occurs.

Therefore, the random variable k_1 is multiplied by the height of the lug, which is shown as Equation (13).

$$y = h \times k_1 + 50 \quad (13)$$

If the outer radius of the lug body is greater than the length of $\frac{L}{2}$, the lug shape break, so the outer radius R of equation(14) is obtained by applying the independent variable k_2.

$$R = k_2 \times \frac{L}{2} \quad (14)$$

3.3 Lug Optimization Geometry Design

The four independent variables of chromosomal information in the genetic algorithm are (At_2, AR, k_1, k_2) and the variables that determine the shape are (As, R, y, L, h). Having high chromosome information in terms of fitness can be seen as approximating the optimal solution. However, if the parent generation of chromosomes is determined by the high fitness ranking, genetic diversity will be lacking as the generation progresses Thus, the solution results in an premature convergence, resulting in a problem that fails to approximate the optimal solution. To solve this problem, we adopt the roulette wheel method, which is based on fitness values and sets the probability that the higher the fitness values can be the parent generation of genetic algorithms. To prevent premature convergence, we implement an algorithm that can be selected as a parent generation, limiting the maximum fitness to 0.25. equation (15) illustrates the equation used in the application of fitness values.

$$fitness = -\frac{0.25}{n-1} \times \frac{(rank - 1) + 0.25}{0.25 \times \frac{n}{2}} \times 100 \quad (15)$$

Rank is currently a lightweight ranking of lugs in a group based on chromosomes. The size of the group here is pop size. Table 1 summarized the parameters of the genetic algorithm.

Since there are four genetic information applied to the algorithm, the difference between multiple-point hybridization and simple hybridization was not clearly seen, so simple hybridization was applied like Fig. 2. There was no singularity in convergence from the size of the group above 100, and it converged to the optimal shape in the 87th generation. For genetic diversity, two mutations with 1% genetic information were generated. and use elite conservation strategies using crossover and mutation, which are factors that affect changing the superior factors of all generations. This strategy conveys chromosome information of the best factors to the next generation.

Table 1 Parameters of genetic algorithms

Variable name	Initial value
Pop size	100
Gen(k)	100
σ	235
p_1	59
P_g	981000

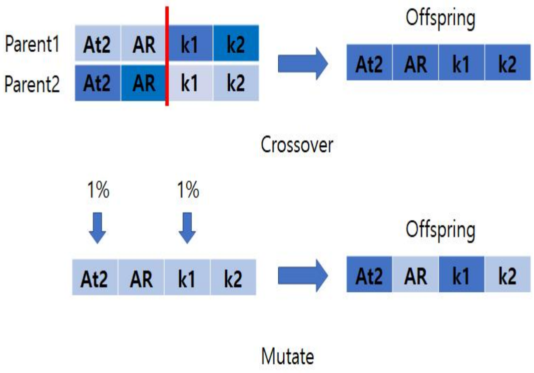

Fig. 2 Single-point hybridization

3.4 Lug Optimization Geometry Design

Using genetic algorithms, candidates close to convergence were selected as roulette wheel methods suitable for optimization in this study. Table 2 uses MATLAB R2016a to show the results of the genetic algorithm. We were able to obtain more satisfactory feature ratios from nine candidates than the conditions of lugs to which conventional appendages were attached, without the need to select a crystal sample that compensated for the disadvantages of roulette wheels. Prior to the 10th generation, the larger the spacing of as affecting the shear stress of the lugs, the smaller the thickness of the lugs. And the overall weight of the lug increased on average. As the number of generations progresses backward, we can see that as has significantly reduced lug weight since the 18th generation as it begins to converge features of lug thickness and optimal ratio.

Fig. 3 presents a graph of the lug weight relative to the feature ratio of the lug without the additive attached.

The y-axis direction represents the weight of the lug, and the x-axis direction represents the number of generation. Optimization behavior was carried out until generation 100th. The optimal shape ratio and minimum weight satisfying the load conditions of the lug remained constant from generation 87th to converge.

Table 2 Results of lug parameters according to generation

Generation	1	2	4	8	10	18	32	84	87
As	227.66	192.93	185.72	203.88	185.72	185.72	182.22	182.22	181.03
At_2	51.61	60.90	63.27	57.63	63.27	63.27	64.48	64.48	64.90
AR	1.65	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62
h	365.66	330.93	323.72	341.88	323.72	323.72	320.22	320.22	319.03
L	602.59	535.42	523.75	553.14	523.75	523.75	518.09	518.09	516.17
y	143.25	134.05	132.22	105.67	102.71	52.46	52.44	51.37	51.36
R	64.12	83.77	81.94	86.54	81.94	81.94	81.06	81.06	80.75
Dh	88.00	88.00	88.00	88.00	88.00	88.00	88.00	88.00	88.00
weight	61.64	59.35	59.05	56.88	55.94	50.91	50.76	50.65	50.60

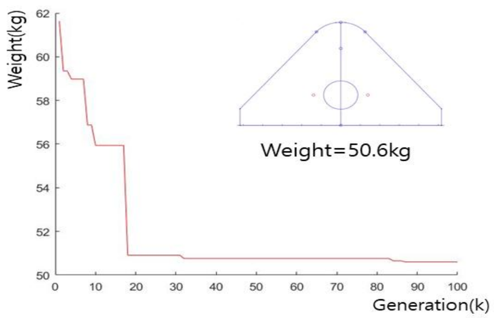

Fig. 3 Lugs geometry of generation

4. Target Lug Selection and Structural Analysis

Using genetic algorithms, the optimization aspect ratio for weight reduction while satisfying the functional aspects of the lug without attachments was selected and modeled from the nine candidates mentioned above. We use ANSYS 2020 R2, a commercial finite element structural analysis program, to execute strength analysis of selected 100-ton D-type lugs. Fig. 4 presents existing D-type lug design drawings and analytical results.

Conventional lug analysis results in a yield strength of 207.16MPa, which meets the allowable range when the most severest load in the lug is 45°. However, it

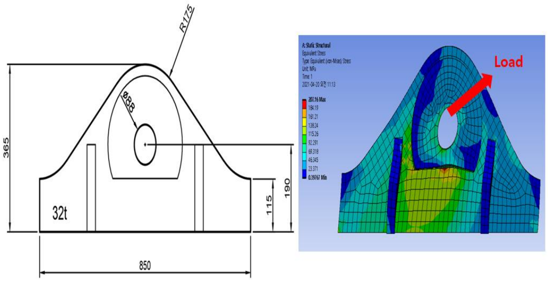

Fig. 4 Existing D100 lifting lug design drawing

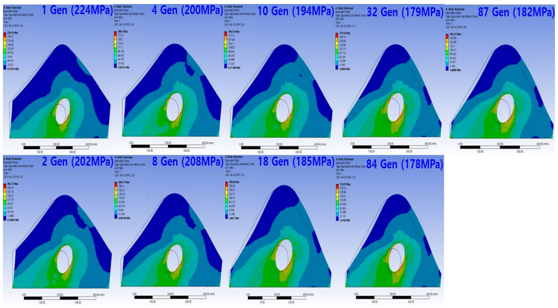

Fig. 5 Stress distribution plot by 9 cases

is accompanied by a secondary process due to bracket and double ring operation, and its total weight is 91.6kg, which has a heavy disadvantage. Fig. 5 is a structural analysis plot of nine lug candidates with optimal features without attachments. We analyze the behavior of the actual stress relative to the allowable stress of 235MPa for each generation by adding a tensile load of 100 tonnes at the most severest 45° of the loading range of D100 lug.

In Table 3, each of the nine selected candidates conducted a structural analysis based on proportion of shapes of each generation. The results are then summarized by weight and actual stress and safety factors.

The average weight of the nine cases was 55kg, 36kg less than that of the previous lugs, and It weighed 50.60kg in 87 generation and recorded optimum lightweight. The safety factor was also significantly higher than the standard of 1.3, with an average of 8.2. Overall, it can be seen that the heavier the weight, the higher the safety rate, and the optimal shape ratio compared to allowable stress is between the 18th generation and the last 87th generation.

Table 3 Structural analysis results and safety factor

Generation	Weight	Actual stress (MPa)	Safety factor
1	61.64	224.16	8.72
2	59.35	202.72	8.70
4	59.05	200.1	8.59
8	56.88	208.37	8.42
10	55.94	194.76	8.40
18	50.91	185.66	7.71
32	50.76	179.74	7.82
84	50.65	178.78	7.77
87	50.60	182.74	7.71

5. Discussion

In this paper, was applied the genetic algorithm as a multivariate function for the lifting lug D100 currently used in shipyards, resulting in optimal aspect ratios for lugs with no additives attached. Among them, nine types of candidates suitable for optimization were selected as the final candidates and structural design was carried out. A comparative analysis of existing lugs and developed lugs without appendages are obtained to draw the following conclusions.

1. According to the genetic algorithms, the shape ratio of the lugs in this study averaged 55kg, much smaller than the existing lugs weight of 91.6kg, which withstand a tensile load of 100 tons.
2. Developed nine cases selected as optimization candidates showed that the safety rate was significantly higher than the existing lugs.

3. Considering the safety rate, yield strength, and weight, we can finally see that shape ratio of candidates formed after generation 18 is close to optimization.
4. It is believed that the cost reduction of steel consumed annually can be secured through the design proposal for lug soundness without additional parts attached.

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