Optimal Design of Lifting Mechanism of Linkage Hydraulic Lifting Dam Based on MATLAB

Yuanlong Chen¹,a,*, Zhuangzhuang Cheng¹,b, Zhendong Huang²

¹School of Mechanical Engineering, Hefei University of Technology, Hefei, 230009, China;
²Anhui Lu'an Hengyuan Machinery Corporation Limited, Lu'an, 237000, China.

Abstract. The muti-link lifting mechanism in hydraulic dam was briefly introduced. The optimization model of the lifting mechanism is established, and the stroke of the hydraulic cylinder is taken as the optimization objective. The genetic algorithm and fmincon function in MATLAB are used to optimize the connecting rod parameters. The results show that the genetic algorithm can obtain the optimal value in a small number of iterations, but it takes a long time; while the fmincon function can obtain the optimal value in a short time under suitable initial value conditions, but the number of iterations is more. It provides a basis for further research on the multi-link lifting mechanism.

1. Introduction
The hydraulic lifting dam is a new type of movable dam that adopts the principle of dump trucks and combines the hydraulic structure of the buttress dam. It is composed of dam surface, hydraulic rods, support rods, hydraulic cylinders and hydraulic pump stations [1]. In the hydraulic lifting dam lifting mechanism, the six-bar linkage structure based on the Mallery lifting mechanism integrates the hydraulic cylinder and the support rod into a whole, which ingeniously solves the problems of gate opening and closing and support locking [2]. However, there is a complicated non-linear relationship between the motion law of the six-bar linkage lifting mechanism and the connecting rod parameters. There are still many difficulties in designing a multi-bar linkage mechanism that satisfies the hydraulic lifting dam [3].

Many scholars have carried out related work on the research of connecting rod mechanism design, and have also achieved gratifying results. Yu et al. proposed a new computer method to approximate the trajectory of the four-bar mechanism by using the link angle function curve, and the satisfactory four-bar mechanism can be obtained by this method [4]. Mehar et al. studied the function synthesis of the four-bar mechanism, using the Freudenstein equation to establish the four-bar linkage equation with 5 precise points, and using the least square method to minimize the structural error [5].

Chu et al. conducted on the connecting rod curve, introduced the fast Fourier transform theory, expressed the connecting rod curve in the form of Fourier series, and provided an effective method for the track synthesis [6]. Huang used digital modeling, finite element method, mechanism simulation and dynamic optimization in the synthesis of planar linkage mechanisms, improving the vibration resistance of the mechanism [7]. Shen et al. studied the gap between the connecting rods of the planar four-bar mechanism. The particle swarm optimization was used to optimize the parameters of the connecting rods and pins and the smoothness of motion was improved [8].
In this paper, the optimization design theory is used to establish the optimization model of the six-link lifting mechanism of the hydraulic lifting dam. The optimization toolbox in MATLAB is used to optimize the connecting rod parameters.

2. Simplified model of lifting mechanism of hydraulic lifting dam
The multi-link lifting mechanism in the hydraulic lifting dam studied in this paper is shown in Figure 1. The hydraulic cylinder drives the connecting rod 1 and 2 to rotate, driving the door leaf to rotate around the O point to realize the raising and falling. In the figure, O and E are the bottom hinge and thrust hinge on the door leaf, and their parameters are related to the structure of the door leaf. In this article, the total height of the door leaf is 3000mm, $L_{11}=2164$ mm, $\alpha_1=84^\circ$.

3. Establishment of optimization model
In the lifting mechanism, the stroke and force of the hydraulic cylinder are important parameters. When the stroke is smaller, the opening and closing of the gate can be completed faster. Since the size and cross-section of the connecting rod are unknown, the establishment of the mechanical model is too complicated, so the maximum stroke is selected as the optimization target.

3.1. Objective function
When the gate is in the water-blocking state, the stroke of the hydraulic cylinder in the lifting mechanism is the largest, so the objective function is determined in this state. As shown in Figure 2.

According to Figure 2, the following objective function can be obtained:
In $\triangle BCD$, the value of $\angle BCD$ can be represented by formula 1:
\[ \angle BCD = \pi - \angle ECD - \angle BCA \quad (1) \]

Where the value of \( \angle ECD \) can be obtained from \( \Delta ECD \), and the value of \( \angle BCA \) can be obtained. According to the law of cosines, the length of \( BD \) is expressed by the following formula:

\[ BD = \sqrt{CD^2 + CB^2 - 2CD \cdot CB \cos \angle BCD} \quad (2) \]

In \( \Delta GBF \), the value of \( \angle GBF \) can be represented by formula 3:

\[ \angle BCD = \pi - \angle ECD - \angle BCA \quad (3) \]

In \( \Delta DBC \), the value of \( \angle DBC \) can be represented by formula 4:

\[ \angle DBC = \arccos \left( \frac{BC^2 + BD^2 - CD^2}{2BC \cdot BD} \right) \quad (4) \]

The value of \( \angle FBD \) can be represented by formula 5:

\[ \angle FBD = \arccos \left( \frac{FB^2 + BD^2 - FD^2}{2BC \cdot BD} \right) \quad (5) \]

The value of \( \angle FBC \) can be represented by formula 6:

\[ \angle FBC = \angle FBD - \angle DBC \quad (6) \]

The value of \( \angle ABG \) can be represented by formula 7:

\[ \angle ABG = \angle ABC - \angle FBC - \angle GBF \quad (7) \]

In \( \Delta HGB \), the maximum stroke \( s \) can be expressed by the following formula 8:

\[ s = \sqrt{BG^2 + BH^2 - 2BG \cdot BH \cos \angle ABG} \quad (8) \]

Therefore, the optimized objective function is shown in equation 9:

\[ \min f(x) = \sqrt{L_6^2 + L_3^2 - 2L_6 \cdot L_3 \cos \angle ABG} \quad (9) \]

3.2. design variable

In the lifting mechanism, design variables are the length of each link and the distance between the hinge points \( O \) and \( A \).

\[ X = [x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}]^T \]

\[ = [L_1, L_2, L_3, L_4, L_5, L_6, L_7, L_8, L_9, L_{10}, x_4, y_4]^T \]

The lower limit vector of the design variables selected according to the same type of organization is: [1350 144 1477 243 126 369 288 169 1343 1488 1904 589]. The upper limit vector is [1650 176 1806 298 154 452 353 207 1642 1819 2328 -482].

3.3. restrictions

3.3.1. If the hydraulic cylinder fails when the gate is in the state of draining water, only the hinge shaft at point G needs to be removed, and the door leaf can be separated from the lifting mechanism. Therefore, the hinge point G cannot be blocked by the door leaf, as shown in Figure 3. There, the constrains is:
3.3.2. When the gate is in the lying position, the linkage mechanism should meet the horizontal position requirements, as shown in Figure 4. Projected to the two coordinate axes:

\[ L_9 + L_{11} > 3164 \]  \hspace{1cm} (10)

3.3.3. The triangle cosine formula is used, so it needs to satisfy the triangle constraint condition.

\[
\begin{align*}
L_{11} \cos \alpha_1 + L_{10} \cos \beta_{EC} &= L_{12} \cos \beta_{OM} + L_5 \cos \alpha_5 \\
L_{11} \sin \alpha_1 + L_{10} \sin \beta_{EC} &= L_{12} \sin \beta_{OM} + L_5 \sin \alpha_5 
\end{align*}
\]  \hspace{1cm} (11)

4. Optimal calculation and analysis

4.1. Introduction to optimization algorithms

Genetic algorithm is an algorithm for global optimization search by simulating biological evolution mechanism. Generally divided into: initial population; Calculate the fitness of each individual; Use the crossover operator and the mutation operator to update the population [9]. As shown in Figure 5.
Genetic algorithm has universality, global search, and strong robustness. However, it also has many shortcomings, such as poor local search ability [10]. In view of the poor local search ability of genetic algorithm, the nonlinear programming function fmincon is used. This article first uses genetic algorithm to solve the problem. Using the optimized value as the initial value, the optimal solution is obtained in the fmincon function.

4.2. Optimization Results

Use the GA function in MATLAB to solve, set “PopInitSize” 300, “TolFun” 1e-12, “TolCon” 1e-12, mutation probability 0.4, and the rest to keep the default settings. The iterative process curve is shown in Figure 6 and Figure 7. The optimized parameters are shown in Table 1.

| Design variable | GA optimization results (mm) | Fmincon optimization results (mm) |
|-----------------|-------------------------------|----------------------------------|
| $L_1$           | 1475.7                        | 1487.4                           |
| $L_2$           | 176.0                         | 173.8                            |
| $L_3$           | 1636.7                        | 1648.5                           |
| $L_4$           | 297.8                         | 298.0                            |
| $L_5$           | 126.5                         | 126.1                            |
| $L_6$           | 391.1                         | 386.0                            |
| $L_7$           | 288.2                         | 288.0                            |
| $L_8$           | 169.0                         | 169.0                            |
| $L_9$           | 1497.5                        | 1533.2                           |
| $L_{10}$        | 1612.3                        | 1648.0                           |
| $x_A$           | 2118.5                        | 2135.5                           |
| $y_A$           | -488.9                        | -535.2                           |
| $s$             | 1686.1                        | 1675.7                           |

It can be seen from Figure 6 that the genetic algorithm obtains the optimal solution around the 6th generation. Then the optimized value is taken as the initial value of fmincon to solve. It can be seen from Figure 7 that the optimal solution is obtained around 50 generations. It can be seen from Table 1 that the objective function is smaller than that calculated by the genetic algorithm.
5. Conclusion
This article takes the connecting rod lifting mechanism in the hydraulic lifting dam as the research object. An optimization model with hydraulic cylinder stroke as the objective function is established. It is solved by genetic algorithm and fmincon function in MATLAB. The results show that the genetic algorithm can obtain the optimal value in a small number of iterations. When the initial value of the fmincon function is appropriate, the optimal value can be obtained in less time, but the number of iterations is more. The optimized results provide a reference for the design of the multi-link lifting mechanism, which can reduce the experimental cost and design time.

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