Optimization of A Novel Retractable Suspension Structure

Kun Yin, Zhongkai Chen, Ye Sun, Xiaodong Liang and Erkang Li
The Northwest Institute of Nuclear Technology, Xi'an Shaanxi 710024, China

Corresponding author: yinkun5991@foxmail.com

Abstract. This paper designs a novel retractable suspension structure for amphibious equipment, combined with the principle and characteristics of the retractable suspension mechanism, and uses ADAMS/Insight to develop a set of optimization strategies that meet the characteristics of its dual-function process. Then based on this optimization strategy, the retractable index and the wheel alignment parameters of the retractable suspension are optimized respectively, and significant results are obtained, which verifies the feasibility of the optimization strategy.

1. Introduction
Amphibious platforms are important for water transport, marine development and military activities in a country. [1] The walking system of amphibious platform is one of the most critical factors to realize the high speed in water and high adaptability in land. Based on this, we propose a walking system with "deformable track + retractable suspension". When the platform is traveling on land, it can adjust the touchdown area of the track according to the road features automatically. When the platform is running in water, the retractable suspension can pull up the deformable track and reduce the water resistance. The amphibious platform using this new type of walking system has the function of high mobility and high efficiency, and the speed is fast in water. The structure of the walking system is shown in Figure 1.

Figure 1. The structure of the retractable suspension.
The kinematics and dynamics models of the proposed retractable suspension can be established by using the predicted parameters. However, in order to obtain the maximum retraction of the walking mechanism and make the suspension have reasonable kinematics characteristics when traveling on land, it is necessary to optimize the predicted parameters. [2, 4]

2. Optimization Strategy

The designed mechanism realizes two motion processes, and the two processes are coupled to each other. And it is impossible to obtain a clear objective function and constraint function, this paper proposes a new optimization method for two mutually coupled motion processes, whose specific process is shown in Figure 2.

![Figure 2. Optimal flowchart of retractable suspension system.](image)

Considering that the absolute value of the wheel alignment parameters is small and sensitive to the change of system parameters, sensitivity analysis of the two motion processes is carried out first. Then the parameters with high sensitivity to one motion process and low sensitivity to another are selected as the optimization variables. Finally, Adams/insight was used for experimental design and repeated optimization to determine the final system parameters.

3. Optimization

3.1. Sensitivity Analysis

According to the structure of retractable suspension, the mechanism can be simplified into a plane figure, as shown in Figure 3. And then we use D as the origin of the frame. At the same time, it is assumed that the lower arm remains horizontal at the design position, so the coordinate parameters of C₁ and C₂ only need to take the x coordinates as variables. In addition, as the connecting arm remained relatively fixed with the walking mechanism during the whole process, the lifting, turning and
positioning parameters of the walking mechanism were all dependent on point E and C₂, rather than the connection point C₃.

Figure 3. Schematic diagram of retractable suspension system.

Therefore, the factors actually used for sensitivity analysis are shown in Table 1.

Table 1. Factors of Sensitivity analysis.

| Factor | Meaning         | Original value | Variation range |
|--------|-----------------|----------------|-----------------|
| DV_1   | coorX of C₂     | 300            | -5.0, 5.0       |
| DV_2   | coorX of C₁     | 225            | -4.5, 4.5       |
| DV_3   | coorX of B      | -50            | -2.0, 2.0       |
| DV_4   | coorY of B      | 275            | -4.5, 4.5       |
| DV_5   | coorX of A      | -150           | -2.5, 2.5       |
| DV_6   | coorY of A      | 300            | -5.0, 5.0       |
| DV_7   | coorX of F      | -25            | -1.0, 1.0       |
| DV_8   | coorY of F      | 275            | -4.5, 4.5       |
| DV_9   | coorX of E      | 175            | -2.5, 2.5       |
| DV_10  | coorY of E      | 325            | -5.0, 5.0       |

Screening studies (Screening) of linear Fractional Factorial types were used in the design of experiments. A total of 16 simulation experiments were conducted on the lifting height of the walking mechanism during the retracting and releasing process. The analysis results are shown in Figure 4.

Figure 4. The results of sensitivity analysis of lifting height.
Then, by using the same experimental design method, 16 simulation experiments were conducted on the turning angle of the walking mechanism during the retracting and releasing process. The result is shown in Figure 5.

![Figure 5. The result of sensitivity analysis of turning angle.](image)

The results of sensitivity analysis showed that the design variables with high sensitivity for both targets are DV_4, DV_6, DV_5, DV_1, DV_10, and DV_9. DV_3, DV_2 and DV_7 are less sensitive to both targets. Therefore, DV_4, DV_6, DV_10, DV_5 and DV_1 are selected as the optimization variables of the retracting process after comprehensive consideration. DV_3, DV_2 and DV_7 were selected as the optimization variables of the wheel alignment parameters.

### 3.2. Optimization of Retractable Index

According to the Fig. 3, it is easy to know that retractable suspension can correctly realize the retraction of the walking mechanism, under the following conditions:

\[ AB + AD < BC_1 + DC_1 \]  \hspace{1cm} (1)  
\[ |BC_1 - DC_1| < AD - AB \]  \hspace{1cm} (2)  
\[ AB < AD ; AB < BC_1 ; AB < DC_1 \]  \hspace{1cm} (3)

At the same time, when the retracting process reaches the extreme position of the four-bar mechanism ABC1D, the mechanism needs to satisfy:

\[ C_2F \leq EF + EC_2 \]  \hspace{1cm} (4)

and:

\[ x_{C1} < x_{C2} \]  \hspace{1cm} (5)

Formulas (1) to (5) are connected as the constraint conditions for the optimization of the retracting process, and the maximum value of the coorY of G is used as the optimization target. The values of the optimized design variables after multiple iterations are shown in Table 2.

| Factor | Before optimization | After optimization | Change  |
|--------|---------------------|--------------------|---------|
| DV_4   | 275.00 mm           | 262.63 mm          | -0.045% |
| DV_6   | 300.00 mm           | 315.00 mm          | 0.05%   |
| DV_10  | 325.00 mm           | 341.25 mm          | 0.05%   |
| DV_5   | -150.00 mm          | -153.75 mm         | 0.025%  |
| DV_1   | 300.00 mm           | 315.00 mm          | 0.05%   |
The lifting height and the turning angle before and after optimization are compared respectively, as shown in Figures 6 and 7.

![Figure 6. Optimization results of lifting height.](image)

![Figure 7. Optimization results of turning angle.](image)

According to Fig. 6 and Fig. 7, the maximum lifting height and maximum turning Angle of the walking mechanism were significantly increased, with 64.8% and 112.2% respectively. At the same time, the optimized lifting speed has been increased. On the other hand, in the process of lowering the walking mechanism before lifting, its lowering maximum value was reduced by 12.9% after optimization.

3.3. Optimization of Wheel Alignment Parameters
The novel amphibious platform is driven by four identical tracks independently and differential steering. Considering the different concepts and uses of wheel alignment parameters, the kinematics characteristics of retractable suspension described in this paper need to study the wheel camber angle, kingpin inclination angle and wheel-base of the walking mechanism, as shown in Figure 8. [3] In particular, if the amphibious platform adopts wheeled walking mechanism and steering knuckle, the
optimization strategy described in this paper can also be applied to other wheel alignment parameters optimization.

![Figure 8. Schematic diagram of wheel alignment parameters.](image)

According to Figure 8, the formulas for calculating the wheel camber angle $\gamma$, the kingpin inclination angle $\alpha$ and wheel-base $L$ are as follows:

$$\gamma = \arctan \left( \frac{(x_{C3} - x_{C2})}{(y_{C3} - y_{C2})} \right)$$  \hspace{1cm} (6)

$$\alpha = \arctan \left( \frac{(x_{C2} - x_{E})}{(y_{E} - y_{C2})} \right)$$  \hspace{1cm} (7)

$$L = 2x_K$$  \hspace{1cm} (8)

Based on the ADAMS model, we add a wheel-jump experiment table, as shown in Figure 9. At the same time, three measurements in Eq. (6), (7) and (8) are established, and then DV_2, DV_3, DV_7 and DV_9 are selected as optimization variables of suspension kinematics characteristics.

With the objective of minimizing the maximum kingpin inclination angle, the optimized variables are obtained by many iterations in the [-50,50] mm wheel-jump experiment as shown in Table 3.

![Figure 9. Retractable suspension wheel-jump test table.](image)
Table 3. Variables before and after the second optimization.

| Factor | Before optimization | After optimization | Change |
|--------|---------------------|-------------------|--------|
| DV_2   | 225.00 mm           | 225.00 mm         | 0.00%  |
| DV_3   | -50.00 mm           | -50.00 mm         | 0.00%  |
| DV_7   | -25.00 mm           | -25.25 mm         | -0.01% |
| DV_9   | 175.00 mm           | 179.38 mm         | 0.25%  |

The comparison of the kingpin inclination angle, wheel camber angle and wheel-base before and after optimization is made. The result is shown in Figure 10–12.

![Figure 10. Optimization results of kingpin inclination angle.](image)

According to the optimization results, the maximum and minimum pin inclination angles of [-50,50] mm wheel-jump test are reduced by 0.75 degrees, and the corresponding wheel inclination angle is increased by about 1 degree. At the same time, the balance position inclination angle is increased from the original approximate 0 degree to 1 degree, which reduces the wheel inclination angle to zero when the platform is fully loaded. It is beneficial to reduce the abnormal wear of the walking mechanism. And the wheelbase basically did not change.

![Figure 11. Optimization results of wheel camber angle.](image)
4. Conclusion

Through the analysis above, we can draw a conclusion: the optimization strategy described in this paper has obvious effect on retractable index of the retractable suspension for greatly improving the retractable height and the turning angle; at the same time, the kinematics characteristics of the suspension are improved by optimizing the alignment parameters of the walking mechanism.

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