Research on Erection System of a Vehicle Missile

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Abstract. The defects of existing erection system of a vehicle missile mainly include long erection time, large volume and poor adaptability to harsh environmental condition, so a new type of gas-fired electric erection system is designed. After the structure and working principle are introduced, the similar model of a missile is established according to the similarity theory. Through the analysis of the working process of the system, the mathematical model is established and the simulation model is also established by using Matlab / Simulink. Finally, the simulation analysis is carried out. The result shows that the erection system can achieve the quick erection of a heavy vehicle missile, which lays the foundation for the subsequent engineering application.

1. Introduction

With the development of modern spying technology, a missile can be found, identified and destroyed before launching, the probability of which is greatly increased. It is very important for saving ourselves, capturing opportunity and striking the enemy effectively to decrease the erection time of a missile. The traditional method of erection is to adopt the hydraulic system of throttling speed regulation, which works reliably and has a wide range of speed regulation [1-2]. However, in the process of large load erection, the arm of erection force is short and the guide ratio of hydraulic cylinder is large, so the hydraulic cylinder needs to output large force in the initial stage of erection. Owing to the limited output of the constant pump, the speed of erection system is small. The flow rate and pressure of the system need to be greatly increased to overcome the large gravity load and inertia load in the initial state of erection, so the weight and volume of the system will be greatly increased. In addition, the hydraulic system has the defects of high maintenance cost and poor adaptability to harsh environmental condition. However, the electric cylinder has the advantages of smaller volume and better adaptability to harsh environmental condition. With the development of multi-stage electric cylinder, it is necessary that the electric cylinder replaces the hydraulic cylinder [3-4]. But because of the small power density of electric cylinder, it is not suitable for heavy vehicle missile.

In order to solve this problem, a new type of gas-fired electric erection system is designed. First, the gas-fired actuator is used to overcome the large gravity load and inertia load in the initial stage of erection and the missile is erected to a certain angle. The gas-fired actuator adopts the principle of gas damping and has good adaptability to load, but its impact is still greater than that of electric cylinder [5]. After the task of gas-fired actuator is completed, the missile is slowly erected to the final position by a electric cylinder. Owing to the limitation of the existing experimental condition, the similar model of vehicle missile is established according to the similarity theory. After the mathematical model is established, the simulation model is established by using Matlab / Simulink. Finally, the
simulation analysis is carried out and the result shows that the erection system can achieve the quick erection of a heavy vehicle missile.

2. Structure and composition of the erection system
The erection system mainly includes electric cylinder, gas-fired actuator, base, initial lock, final lock, shaft 1, shaft 2, missile bracket and missile. The diagram of initial state is shown in Figure 1. The diagram of final state is shown in Figure 2.

3. Working principle
The missile bracket is horizontal when the erection system is in the initial state. The missile bracket and base are locked by initial lock. The diagram of initial lock is shown in Figure 3. Because the load of the erection system is large in the initial state, the electric cylinder cannot rotate the missile bracket. It is necessary to overcome the large gravity load and inertia load in the initial state by gas-fired actuator. After the ignition command is given, a large amount of gas is generated in the gas-fired actuator and then it starts to work. The gas-fired actuator outputs large force to cut off the initial lock and quickly erect the missile to a certain angle. Although the gas-fired actuator has good adaptability to the load, its impact is still greater than that of electric cylinder. The electric cylinder starts to work after gas-fired actuator stops working. The electric cylinder outputs small force to erect the missile to the final position. When the pin of final lock is coaxial with the hole on the missile bracket, the spring starts to work. It pushes the pin into the hole for locking. The diagram of final lock is shown in Figure 4. The impact surface between missile bracket and base is inclined surface. Because the area of the inclined surface is larger than that of the horizontal surface, the impact on the surface can be reduced when the missile is erected to the final position. The diagram of the impact surface is shown in Figure 5.

4. Establishment of the similar model
Considering the experiment equipment and economic condition, the size of missile is usually reduced according to the similarity theory. The research is carried out by the ground experiment of similar model [6-7]. The parameters of missile can be expressed by formula (1). The parameters of similar model can be expressed by formula (2).

\[ m_p = \rho_p L_p \pi D_p^2 / 4 \]  

(1)
In the formula:

\( m_p \) — the weight of the missile, kg; \( \rho_p \) — the density of the missile, kg/m³; \( L_p \) — the length of the missile, mm; \( D_p \) — the diameter of the missile, mm.

\[
m_p = \rho_p L_p \pi D_p^2 / 4
\]

In the formula:

\( m_m \) — the weight of the similar model, kg; \( \rho_m \) — the density of the similar model, kg/m³; \( L_m \) — the length of the similar model, mm; \( D_m \) — the diameter of the similar model, mm.

\[
m_m = \rho_m L_m \pi D_m^2 / 4
\]

The similarity constants are the ratio of the parameters of the similar model to the parameters of the missile. They mainly include \( \lambda_L \), \( \lambda_\rho \), \( \lambda_m \) and can be calculated according to formula (3).

\[
\begin{align*}
\lambda_L &= \frac{L_m}{L_p} \\
\lambda_\rho &= \frac{D_m}{D_p} \\
\lambda_\rho &= \frac{\rho_m}{\rho_p} \\
\lambda_m &= \frac{m_m}{m_p}
\end{align*}
\]

Formula (4) can be obtained according to formula (2) and formula (3).

\[
\lambda_m m_p = \lambda_L^3 \lambda_\rho m_p L_p \pi D_p^2 / 4
\]

If similar model is similar to missile, formula (5) can be obtained.

\[
\frac{\lambda_m^3 \lambda_\rho}{\lambda_L^3 \lambda_\rho} = 1
\]

The parameters of the similar model that are obtained according to the similarity theory are shown in Table 1.
Table 1. The parameters of the similar model.

| m_m  | \( \rho_m \) | L_m | D_m | \( \lambda_m \) | \( \lambda_p \) | \( \lambda_l \) |
|------|---------------|-----|-----|---------------|---------------|--------------|
| (kg) | (kg/m³)       | (mm)| (mm)|              |               |              |
| 200  | 7.90E+03      | 1024| 177 | 4.76E-3       | 9.72          | 0.079        |

5. Simulation and analysis

5.1. Establishment of mathematical model and simulation model

The working process of the erection system is shown in Figure 6 [8]. Its mathematical model can be expressed by formula (6). The simulation model of erection system established by Matlab / Simulink is shown in Figure 7 [9-10].

\[
J \frac{d^2 \phi(t)}{dt^2} = \frac{F l_1 sin(\phi_0 + \delta_0 + \phi(t))}{\sqrt{l_1^2 + l_2^2 - 2l_1l_3 cos(\phi_0 + \delta_0 + \phi(t))}} - G l_2 cos(\beta + \phi(t))
\]  

In the formula:

- \( J \) — the rotary inertia of the system, kg.m²;
- \( \phi(t) \) — the angle of erection, °;
- \( F \) — the driving force of erection, N;
- \( G \) — the gravity of missile and missile bracket, N;
- \( \phi_0 \) — the included angle between point O₂ and horizontal line, °;
- \( \delta_0 \) — the included angle between point O₃ and horizontal line, °;
- \( \beta \) — the included angle between point O₄ and horizontal line, °;
- \( l_1 \) — the distance between point O₂ and point O₁, m;
- \( l_2 \) — the distance between point O₂ and point O₃, m;
- \( l_3 \) — the distance between point O₃ and point O₁, m;
- \( l_4 \) — the distance between point O₄ and point O₁, m.

5.2. Setting of input parameters

The input parameters are as follows:

- the driving force of gas-fired actuator \( F_0 \) is 8717 N, the driving force of electric cylinder \( F_1 \) is 2535 N, the rotary inertia of the system \( J \) is 17.917 kg.m², the gravity of missile and missile bracket \( G \) is 1960 N, the included angle between point O₂ and horizontal line \( \phi_0 \) is 5.4 °, the included angle between point O₃ and horizontal line \( \delta_0 \) is 29.7 °, the included angle between point O₄ and horizontal line \( \beta \) is 9.8 °, the distance between point O₂ and point O₃ \( l_1 \) is 0.554 m, the distance between point O₂ and point O₃ \( l_2 \) is 0.421 m, the distance between point O₂ and point O₃ \( l₃ \) is 0.179 m, the distance between point O₄ and point O₁ \( l₄ \) is 0.52 m.
5.3. Analysis of the result
The angle-time curve of erection system is shown in Figure 8. The velocity-time curve of erection system is shown in Figure 9. According to the simulation curve, we can know that the working time of gas-fired actuator is 0 ms ~ 250 ms and the maximum velocity is 470 °/s, the working time of electric cylinder is 250 ms ~ 20000 ms and the velocity is very small. The erection system can achieve the quick erection.

![Figure 8. The diagram of angle-time curve.](image1)

![Figure 9. The diagram of velocity-time curve.](image2)

6. Conclusion
According to the erection requirement of a heavy vehicle missile, a new type of gas-fired electric erection system is designed. This paper introduces its structure and working principle. After similar model, mathematical model and simulation model are established, the simulation is carried out by using the MATLAB/Simulink. The result of simulation shows that the system can meet the erection requirement of a heavy vehicle missile.

References
[1] Zhang J H, Liu D F, Xu B and Zhang C F 2018 Transactions of Beijing Institute of Technology. 38 44–48
[2] Feng J T, Gao Q H, Shao Y J and Qian W X 2018 Acta Armamentarii. 38 209-216
[3] Liu Y X, Gao Q H, Niu H L and Cheng X R 2017 Journal of Vibration and Shock. 36 212-217
[4] Zhang S, Wang H and Gao J G 2018 Manufacturing Automation. 40 144-146
[5] Wu J G, Huang M and Shang Y L 2016 Journal of Ordnance Equipment Engineering. 37 34-44
[6] Wei K J, Wu Q, Zhang Y and Li X 2019 Journal of XIAN Aeronautical University. 37 28-32
[7] Zhao L J, Fan S M and Liu X D 2017 Journal of Machine Design. 34 94-98
[8] Wang X, Wang S C, Duan J Y and Guan Q Z 2019 Machine Building & Automation. 1 190-192
[9] Sun Y D, Guo S and Zhou P 2018 Machinery Design & Manufacture. 1 16-22
[10] Li A M 2018 Machine Tool & Hydraulics. 46 50-53