Research on Erecting Joint and Dynamic Characteristics of Four-Hinge-Point Dual-Drive Missile

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Abstract. In order to improve the quick reaction ability and stability of the missile launching erecting system, the driving mode of the erecting joint is optimized. A four-hinge-point double-driving erecting joint is proposed and the mechanical model is established, the force and time of erecting cylinder are calculated by Matlab, and compared with two kinds of three-hinge-point joint. The results show that the response speed of the four-hinged double-drive erecting joint is fast, the erecting process is fast in the early stage and stable in the later stage, and the elongation and the erecting cylinder force are between two kinds of three-hinged joints, the four-hinge erecter can not only combine the advantages of the three-hinge front-mounted and rear-mounted structure, but also realize the aim of compatibility design and improve the rapidity and stability of the missile erector, it can provide an important basis for the structural design of missile launcher.

Keywords. Erecting joint, dynamic analysis, numerical simulation, compatible design.

1. Instruction

With the rapid development of detection and precision strike technology in modern war, the survival of weapon system will be faced with more and more threat [1]. Therefore, the reduction of Combat Readiness Time and the enhancement of its rapid reaction capability are effective means to deal with this threat. For missile launching equipment, erecting to combat status is a long link in combat preparation. Generally speaking, two requirements need to be met [2, 3]: First, the erecting process should be stable without violent vibration, to avoid a large impact on the instrument on the missile, to ensure that the accuracy of the Entry Vertical Angle meets the requirements [4]. Therefore, when designing the erection system, how to shorten the erection preparation time of the launching under the premise of satisfying the accuracy requirement of the launching angle control is the key point of the research [5, 6].

In order to improve the erecting speed, the current research focuses on two aspects, one is to optimize the driving mode, such as mechanical, hydraulic, electric drive, etc., factors such as viscosity and external interference [7, 8]. The other is to optimize the structural design, which usually adopts the three-hinge-point erecting joint composed of the erecting arm or the launching cylinder, the frame and the erecting oil cylinder of the launching vehicle. According to the position of erecting cylinder, it can be divided into two kinds of structure: Front direct push type and rear direct push type. The rapid response is realized by controlling the erecting speed, but the launching precision is affected by the vibration of the system caused by the larger impact load.

In this paper, a four-hinged double-drive quick erecting joint is presented, which has two degrees of freedom by the combination of the erecter and the booster cylinder, and its dynamic model is
established, the dynamic characteristics of the joint are analyzed by theoretical method and compared with those of the three-hinge-point joint. The erecting velocity, the elongation of erecting cylinder and the force during erecting process of three kinds of erecting joints are studied by using Matlab numerical calculation method to verify the rapidity and stability of erecting motion.

2. Dynamic Modeling
As shown in figure 1, a simplified mechanical model of the four-hinge-point double-drive quick erecting joint consists of a missile, a launching arm, a erecting cylinder, a booster cylinder and a fixed member of a launching vehicle.

State 1 is the Horizontal Transport State of the missile, and State 2 is a certain state during the erection of the missile. \( O \) is the center of rotation for the lower fulcrum of the launching arm, \( O_1 \) is the fixed point at one end of the booster cylinder, \( O_2 \) is the center of rotation for the upper fulcrum of the erecter cylinder, \( O_3 \) is the hinge center of rotation for the erecter cylinder and the booster cylinder. And the position of the center of mass for the launcher arm. \( O_b, O_d, G_b, G_d \) are the missile and the gravity for the launcher arm and the missile, respectively. \( J_b \) is the rotational inertia of the launcher arm, \( J_d \) is relative to the missile relative to the rotational inertia of the missile. Let the Horizontal Transport State be set at \( \angle O_2 O_1 = \gamma_1, \angle O O_1 O_3 = \gamma_2 \) are all constant.

![Figure 1. Mechanical model of four hinge point erecting joint.](image)

3. Dynamic Characteristic Analysis
According to the simplified model of the four-hinged erecting structure shown in figure 1, the theoretical analysis of its dynamic characteristics is as follows:

(1) When it is transported, the initial State 1, there are:

\[
L_{03} = \sqrt{L_1^2 + L_2^2 - 2L_1L_2 \cos \gamma_2}
\]

\[
\beta = \arcsin\left(\frac{L_1 \sin(\pi - \gamma_2)}{L_{03}}\right), L_{23} = \sqrt{L_2^2 + L_{03}^2 - 2L_2L_{03} \cos(\gamma_1 - \beta)}
\]

(2) In the erecting process of the erecting joint, at State 2, there are:
\[ L_3' = L_3 + x_5(t), L_{03'}(t) = \sqrt{L_1^2 + L_3^2 - 2L_4L_5 \cos \gamma_2'}, \beta' = \arcsin \left( \frac{L_5 \sin (\pi - \gamma_2')}{L_{03'}} \right) \] (3)

\[ L_{23'}(t) = L_{23} + x_1(t) = \sqrt{L_2^2 + L_{03'}^2 - 2L_2L_{03'} \cos (\theta + \gamma_1 - \beta')} \] (4)

The elongation of the erector is obtained as follows:

\[ x_1(t) = L_{23'}(t) - L_{23} = \sqrt{L_2^2 + L_{03'}^2 - 2L_2L_{03'} \cos (\theta + \gamma_1 - \beta')} - \sqrt{L_2^2 + L_{03'}^2 - 2L_2L_{03'} \cos (\gamma_1 - \beta')} \] (5)

The equation (5) is derived to obtain the cylinder extension velocity:

\[ V_e(t) = \frac{-L_2L_{03'} \sin (\beta' - \theta - \gamma_1)}{\sqrt{L_2^2 + L_{03'}^2 - 2L_2L_{03'} \cos (\beta' - \theta - \gamma_1)}} \dot{\theta} \] (6)

According to the D’Alembert principle, the launching arm and the missile are selected as the research objects, and the Torque Balance Equations are established at the point. The main torque acting on the research objects is the gravity moment of the launching arm, the missile and the thrust moment of the erecting cylinder and the booster cylinder, if the constraint reaction moment is zero and the corresponding inertia moment is added to the object, the following results can be obtained:

\[ F_sL_2 \sin \alpha + F_sL_1 \sin (\pi - \gamma_2') - G_bL_b \cos (\theta + C_b) - G_dL_d \cos (\theta + C_d) - J_b\ddot{\theta} - J_d\ddot{\theta} = 0 \] (7)

The force acting on the erector cylinder is obtained as follows:

\[ F_s = \frac{\left( G_bL_b \cos (\theta + C_b) + G_dL_d \cos (\theta + C_d) \right)}{L_2 \sin \alpha} + \frac{\left( J_b\ddot{\theta} + J_d\ddot{\theta} \right)}{L_2 \sin \alpha} + \frac{F_sL_1 \sin (\pi - \gamma_2')}{L_2 \sin \alpha} \] (8)

Among them: \[ \alpha = \arcsin \left( \frac{L_{03'} \sin (\theta + \gamma_1 - \beta')}{L_{23'}} \right) \]

Since the four-hinged vertical structure can be simplified to a three-hinged joint when the booster cylinder remains stationary.

### 4. Comparative Analysis of Dynamic Response of Erecting System

Taking a certain type of missile-frame system as an example, the relevant parameters are listed in table 1, the elongation velocity of the erector is 0.03 m/s, and the horizontal assist cylinder is loaded by sine curve motion to realize the extension and contraction of the erector and the post-erector, using Matlab to carry out numerical calculation, the dynamic model and dynamic characteristics of three kinds of erecting structures are compared and analyzed as follows.

| Table 1. Structure parameter table of erecting joint |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| \( L_4 \) | \( L_2 \) | \( L_3 \) | \( L_b \) | \( L_d \) | \( G_b \) | \( G_d \) | \( J_b \) | \( J_d \) | \( \gamma_1 \) | \( \gamma_2 \) |
| (m) | (m) | (m) | (m) | (N) | (N) | (kg.m²) | (kg.m²) | (°) | (°) |
| 1 | 3 | 1.1 | 3.6 | 3 | 800 | 1000 | 2400 | 4320 | 20° | 160° |

### 4.1. Erecting Velocity Analysis

On the premise of satisfying the precision requirement of launch angle control, it is very important to shorten the time of launching stand-up preparation for preserving its own strength and catching the fighter quickly. Figures 2 and 3 show the variation of erecting angle and erecting angle acceleration with time for three erecting joints respectively.
It is known that under the action of the horizontal cylinder, the vertical angle of the launching arm of the four-hinge joint is larger than that of the front and back mounted of three-hinge joint, that is, the erecting response speed is faster, and the acceleration of the erecting vertical angle first decreases, then increases and finally tends to the transverse value, when the vertical angle of velocity changes from 0 to 35 degree, the acceleration of vertical angle rises. After 35 degree, the vertical structure overlaps with the three-hinge-point back mounted structure and tends to be linear. This is mainly due to the lengthening of the horizontal cylinder which accelerates the erection of the launching arm, after that, the horizontal cylinder shrinks and the three-hinge back mounted structure approaches, so the vertical angle changes slowly in the later period. In a word, the four-hinge joint has the characteristics of fast response, fast early stage and stable later stage. At the same time, it can be found that the erecting speed of the back-mounted of three-hinged joint is faster than that of the front-mounted.

### 4.2. Analysis of Elongation of Erecting Cylinder

The extension of erecting cylinder directly determines the dimension of erecting structure of launcher. Figure 4 shows the extension and angle of erecting cylinder of three kinds of erecting joint.
It can be concluded that the four-hinged joint structure combines the advantages of the front-mounted and the back-mounted type of the three-hinged joint. The elongation of the four-hinged joint is the smallest when the angle changes from 0 to 35 degree, and the elongation of the front-mounted joint is smaller than that of the back-mounted joint when the angle changes, in the middle position, the overall advantage is obvious.

5. Conclusion
Through the research of this paper, the main conclusions are as follows:
(1) A four-hinge-point double-drive fast erecting joint is put forward, and its dynamic model is established, the joint is compared with three-hinge-point forward joint and three-hinge-point backward joint.
(2) By using Matlab numerical calculation, the dynamic characteristics of three kinds of erecting joints are compared and analyzed. It is found that the four-hinge-point double-drive erecting joint has the characteristics of fast response, fast erecting and stable erecting.
(3) Through the comparative analysis of the dynamic characteristics of the three kinds of erecting joints, it can be concluded that the four-hinge erecting joints can not only combine the advantages of the three-hinge front-type and the three-hinge rear-type structures, but also overcome their disadvantages, the aim of compatibility design is realized.

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