Design and Simulation of Cam Curve for Automata

Li Rong¹*, Wei Lixin¹, Yang Hongliang¹

¹Zhengzhou Electromechanical Engineering Research Institute, Zhengzhou, Henan, China

*Corresponding author’s email: 1758885661@csic713.com.cn

Abstract: Aiming at the problems of long movement stroke and complicated driving of the automatic machine breech block during the launching process of ammunition with large fineness ratio, it is proposed to use a crossed cam to drive the automata to complete the shooting progress. The three-dimensional model of the cam drive mechanism was established, and the maximum pressure angle of modified-sine curve and SMS-3 curve were compared according to the motion characteristics of the mechanism; the multi-rigid body dynamics and dynamics simulation software were used to obtain simulated displacement, speed and driving torque, and compared with the theoretical value. The simulation results show that under the same input conditions, the input torque required to complete the automata transport process using modified-sine curve is relatively small. This result provides a certain technical support for the research of automata on ammunition with large fineness ratio.

1. Introduction

Artillery automata is the general name of various agencies that use gunpowder gas or external energy to automatically and continuously fire when automatic artillery fires [1]. In order to enhance the current real-time defense capabilities from air and surface threats, combining the long range of ammunition with large fineness ratio and the advantage of the high initial velocity of artillery, rapid launch ability and large amount of ammunition, it is proposed to use artillery automata as the large fineness ratio ammunition launcher. The external energy cam automata has attracted wide attention due to its simple structure and high reliability [2].

Stroke movement law of cam automata follower in the process of transportation the bomb affects the stability of ramming and breechblock opening and closing. Lv Ning [3] takes the disc cam with offset linear push rod follower as the design object, and compares the kinematics of the modified front cam mechanism with the establishment of the modified constant velocity motion law to eliminate the rigid impact and flexible impact in the push rod motion. The motion characteristics of the revised constant velocity motion law have been significantly improved. According to establishment of two-mass dynamic model, Kou Pan [4] describes the measurement index of the error of the cam mechanism follower, and discusses the influence of the stiffness and damping of the follower on the cam movement error. Wan Fang [5] programs the theoretical curve to generate plane contour data points, and import them into 3D modeling software to generate a three-dimensional model to judge the prostate and constant of the cam contour curve performance. Li Li [6] uses a sinusoidal curve to optimize the dynamic characteristics of the transition section of the cam curve of the original automation, and establishes the dynamic performance of the virtual prototype curve groove of the automaton before and after optimization. This paper based on ammunition with large fineness ratio, and the space crossed cam is
used as the active part to research the stroke of the breech block follower of the ammunition, and to compare the influence of different curve laws on the movement characteristics of the ammunition.

2. Follower position curve

2.1. Automata position law

The cam type involved in this paper is a spatial cylindrical crossed cam, and the maximum pressure angle is set to $\alpha^\circ$.

In the fig. 1:
- 0-zero position, 1-start of bombing, 2-in palace of recoil, 3-end of bombing, 4-end of re-entry acceleration, 5-start to re-entry deceleration, 6-start to block, 7-start to firing, 8-in palace of re-entry, 9-start to recoil, 10-start to unlock, 11-end of unlock, 12-return to zero position.

Under the premise of satisfying the working cycle process of the automata, the angle of the automaton curve groove is allocated. In order to ensure locking and unlocking of the breech, set:
1) The time required for the movement stroke 7 to 10 is 20ms;
2) The time required for the movement stroke 0 to 3 is 20ms;
3) The rate of fire is 60 rounds per minute.

Therefore, the time required for the cam in the lift motion segment is 480ms. Taking the number of cam engagements and the cam diameter as input variation, the parameters are determined as follows: cam diameter of base circle is 300mm; follower stroke is 910mm; motion angle for actuating travel ($\varphi_1$) and motion angle for return travel ($\varphi_2$) is:

$$\varphi_1 = \varphi_2 = 0.48 \times n \times 2\pi$$ (1)

In the formula: $n$-the follower moves for one cycle when the cam rotates $n$ times.

For different curve motions, the speed and acceleration generated by the follower during high-speed motion will cause shock and vibration. It is necessary to choose excellent dynamic characteristics. There are various motion equations suitable for the cam mechanism. In this paper, modified sine curve and SMS-3 curve are used as the motion law of the follower, and the input output characteristics curve under the same input condition is compared.

2.2. Modified-sine curve

Modified-sine curve is the most common standard curve, which can make the load changes of the motor special smooth. The maximum dimensionless velocity ($V_m$) and maximum dimensionless acceleration ($A_m$) are lower than the modified trapezoidal curve, and the overall performance is better. The curve is mostly suitable for high-speed and medium-load occasions, such as indexing workbenches[7].

When the cam thrust and return are both modified-sine curve, the displacement equation of the cam thrust is discussed as:
\[
S = \begin{cases} 
\frac{2T}{\pi} A_s (T - \frac{2T}{\pi} \sin \frac{\pi T}{2T}) & 0 \leq T \leq T_1 \\
\frac{(T_2 - T_1)^2}{\pi^2} A_s \left[ 1 - \cos \frac{\pi (T - T_1)}{T_2 - T_1} \right] + V_1 (T - T_1) + S_1 & T_1 \leq T \leq T_2 \\
4(1 - T_2)^2 \pi A_s \left[ -1 + \cos \frac{\pi (T - T_1)}{2(T_1 - T_2)} \right] + V_1 (T - T_2) + S_2 & T_2 \leq T \leq T_1 
\end{cases}
\]

In the formula: \( T_1 = \frac{1}{8}, T_2 = 1 - T_1, A_m = \frac{4\pi^2}{\pi + 4}, V_1 = V_2 = \frac{2T_1}{\pi} A_m, S_1 = \frac{2T_1}{\pi} A_m \left( T_1 - \frac{2T_1}{\pi} \right), S_2 = 1 - S_1. \)

### 2.3. SMS-3 curve

The SMS-3 curve is similar to the modified-sine curve. It is an algebraic polynomial universal cam curve with parameters that can be input in the interval. Compared with the modified trapezoidal curve, \( V_m \) and \( A_m \) are smaller, and it is suitable for high-speed occasions \([7]\).

When the cam thrust and return are both SMS-3 curve, the displacement equation of the cam thrust is discussed as:

\[
S = \begin{cases} 
A_s \left[ \left( T - \frac{T_1}{2} \right)^3 + \frac{1}{2} \left( T - \frac{T_1}{2} \right)^2 + \frac{3T_1}{4} \left( T - \frac{T_1}{2} \right) + \frac{T_1^2}{10} \right] & 0 \leq T \leq T_1 \\
A_s \left[ \frac{1}{2} \left( T - \frac{T_1}{2} \right)^3 - \frac{3(T_2 - T_1)}{20(\frac{T_1}{2} - T_1)} \right] + V_1 \left( T - \frac{T_1}{2} \right) + S_1 & T_1 \leq T \leq T_2 \\
A_s \left[ \frac{3(T_2 - T_1)}{20(\frac{T_1}{2} - T_1)} - \frac{3(T_2 - T_1)}{4} \left( T - \frac{T_1}{2} \right) - \frac{3(T_1 - T_2)}{10} \right] + V_1 \left( T - \frac{T_1}{2} \right) + S_2 & T_2 \leq T \leq T_1 \\
A_s \left[ \frac{(T - T_2)^3}{20(\frac{T_1}{2} - T_2)} - \frac{(T - T_2)^2}{4} \right] + V_1 \left( T - \frac{T_1}{2} \right) + S_2 & T_2 \leq T \leq T_1 
\end{cases}
\]

In the formula: \( T_1 = \frac{1}{8}, 1 - T_1, A_m = \frac{4\pi^2}{\pi + 4}, V_1 = V_2 = \frac{2T_1}{\pi} A_m, S_1 = \frac{2T_1}{\pi} A_m \left( T_1 - \frac{2T_1}{\pi} \right), S_2 = 1 - S_1. \)

### 2.4. Maximum pressure angle

The pressure angle is the angle between the common normal of the cam driver and the direction of movement of the follower. In order to ensure that the follower travels on a predetermined trajectory at the intersection and increase reliability, after determining the maximum radius and minimum pressure angle of the cylindrical cam, the cam should minimize the number of intersections and compare the maximum pressure angle of the modified-sine curve and the SMS-3 curve.

According to calculations, when the number of rotations is 4, the maximum pressure angle of the modified-sine curve is 41.5°, and the maximum pressure angle of the SMS-3 curve is 42.44°.

### 3. Curve simulation

The modified-sine curve and the SMS-3 curve which is established by using program are imported into 3D modeling software. And use hybrid scan command to build the cam curve groove models, as shown in Fig 2. Import the model into Adams and set the input speed \( n = 1440°/s \), and coefficient of friction between the cam diver and the follower is 0.3.
4. Simulation and result analysis

4.1. Simulation

On the premise of a rate of fire of 60 rounds per minute, compare the dynamic characteristics of the two curves to obtain the displacement and speed of the actual curve, and compare with the theoretical displacement and speed, as show in Fig 3-4.
Measure the torque changes of the cam driver of the two curves during the entire firing process, as shown in Fig 5-6.

![Fig 5 Modified-sine torque](image1)

![Fig 6 SMS-3 torque](image2)

Table 1 Two curves performance parameter

|                  | Theoretical and simulated displacement deviation(m) | Theoretical and simulated velocity deviation(m/s) | Maximum driving torque(N·m) | Maximum driving torque without cross point(N·m) |
|------------------|-----------------------------------------------------|--------------------------------------------------|----------------------------|-----------------------------------------------|
| Modified-sine curve | 0.0065                                              | 0.6707                                           | 3393.5                     | 230.8                                        |
| SMS-3 curve      | 0.0165                                              | 0.6659                                           | 4056.8                     | 246.7                                        |

4.2. Result analysis

Under the same base circle radius, numbers of intersections and driving speed, the results are analyzed
as follows:
1) Compared with the maximum pressure angles of two curves, it is be seen that the pressure angle using modified-sine curve is smaller;
2) In figure 2 and 3, compare the theoretical and simulated values of the two curves respectively: the displacement deviation of the modified-sine curve is 0.0065m, the maximum speed deviation is 0.6707m/s, and the time of occurrence is 0.781s and 0.621s respectively; the displacement deviation of the SMS-3 curve is 0.00165m, the maximum speed deviation is 0.6659m/s, and the time of occurrence is 0.778s and 0.621s respectively;
3) In figure 4 and 5, compare the theoretical and simulated values of the two curves respectively: the maximum driving torque of the modified-sine curve is 3393.5N·m, and the time occurs at 0.620s; the maximum driving torque of the SMS-3 curve is 4056.8N·m, and the time occurs at 0.619s;
4) According to the data, the maximum displacement deviation, velocity deviation and driving torque of two are all produced at the intersection of the cams;
5) Excluding to intersection point, the maximum driving torque of the modified-sine curve is 230.8N·m, which is slightly smaller than SMS-3 curve.

5. Conclusion
The modified-sine curve and SMS-3 curve equations are established under known constraint conditions. The simulation results of the two curves are obtained by using multi-rigid body dynamics and dynamics simulation software, and compare with the theoretical model. For automata that fire ammunition with a large fineness ratio, selecting modified-sine curve as the movement law of the follower under the same conditions can make the power of the motor driving the automata smaller.

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