Research and test of key components of the squirrel-cage bullet shell counter

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Abstract: In order to solve the problem of counting when the bullet shells is recovered, a kind of squirrel-cage bullet shells counters is designed. Through theoretical analysis and test, the angle of the bullet slot of the squirrel cage shell counter is 31.3 ° and the rotation speed of the cartridge mechanism is 10 R / min. The squirrel cage shell counter has the advantages of simple structure, few components, 3D printing technology, greatly reducing the weight and power consumption. The whole machine test results show that: The counting efficiency of the slot type bullet shell counter is 87.4 pieces / minute, and the counting accuracy is 99.8%. The counting efficiency and precision of the slot type bullet shell counter can meet the design requirements of the army. This research not only provides a practical shell counting tool for the military, but also provides a reference for the innovation, research and optimization design of other similar mechanical equipment.

1. Introduction

Bullets are of great significance to a country. In wartime, the bullet is a sharp weapon to defend the country; in non wartime, it is an important material to improve the level of military training [1-2]. The general bullet is composed of four parts: projectile, shell, propellant and cap. The projectile is used to penetrate the target by fast flying, the propellant is given a high initial velocity by combustion, the fire cap is used for firing, and the shell is used to connect the projectile and protect the propellant and closed powder gas. After the projectile is launched, the cartridge case is thrown out by the shell throwing mechanism of the gun. In daily training, all shells need to be recovered, so an efficient counting device is needed. In order to solve the problem of cartridge case counting, a squirrel cage type cartridge case counter is designed, which is jointly developed by the military and the efficient civil military integration method [3-6].

2. Overall design

2.1 working principle

The structure of the squirrel cage cartridge case counter is shown in Fig. 1. It is composed of a cage clamping mechanism, a holding mechanism, a chute, a motor and a counting device. In the process of use, the cartridge case is put into the holding mechanism, and the cage clamping mechanism is embedded in the supporting mechanism, and the relative motion occurs with the holding mechanism under the drive of the motor. The cartridge case is stuck into the cartridge case slot under the joint action of the squirrel cage cartridge mechanism and the holding mechanism, and moves upward with the cage cartridge mechanism to the position of the discharge port. Under the action of centrifugal
force and gravity, the cartridge case breaks away from the cartridge case slot and falls into the chute. A sensor is installed in the middle of the bottom of the chute, and the cartridge case passes through the sensor during sliding in the chute to realize the counting of cartridge case.

Figure 1 Schematic diagram of squirrel cage cartridge case counter

2.2 performance parameters
The performance parameters of squirrel cage cartridge case counter and the design requirements of cartridge case counter proposed by the army are shown in Table 1

| Table 1 Comparison of performance parameters |
|---------------------------------------------|
| Parameter               | Design Requirement | Squirrel cage cartridge case counter |
|-------------------------|--------------------|--------------------------------------|
| Length                  | ≤500 mm            | 330 mm                               |
| Width                   | ≤500 mm            | 300 mm                               |
| Height                  | ≤800 mm            | 300 mm                               |
| Motor power             | ≤200 W             | 25 W                                 |
| Total weight            | ≤50 kg             | 3.6 kg                               |
| Counting efficiency     | ≥70t/min           | 87.4t/min                            |
| Accuracy                | ≥99%               | 99.8%                                |

The core components of the squirrel cage cartridge case counter are the cage clamping mechanism, the holding mechanism and the chute, which are more compact in structure and 85.15% smaller in volume than the maximum design requirement. The PLA material is light and wear-resistant, and the shell is made of acrylic plate, which can reduce the overall weight by 92.8%. The high processing precision of light material with filler makes the additional loss large. The motor power is 12.5% of the maximum design requirement, which greatly improves the working endurance.

3. drive design

3.1 design of trefoil spline
The torque required to rotate the core components of the squirrel cage cartridge case counter is as follows:

\[
T_c = 0.13(k_1mg + fk_2mg)
\]

In $k_1$: The number of cartridge cases stuck into the slot;
$k_2$: The number of cartridge cases stuck into the cartridge slot is in the holding mechanism;
f: The resistance coefficient of the cartridge case to the jamming mechanism is produced by the overturning interaction of the cartridge case in the holding mechanism.

According to the calculation, $TC \leq 25nm$, 25W motor can provide power. If the output shaft of motor is directly connected with squirrel cage snap mechanism, the squirrel cage snap mechanism adopts printing shaft sleeve, as shown in Fig 2a:
Practice has proved that 3D printing shaft sleeve cannot provide enough strength. In view of this situation, a kind of three leaf spline is designed, which is made of metal material. The middle of the trefoil spline is connected with the motor output shaft to provide sufficient strength; the outer side is connected with the squirrel cage snap mechanism through three groups of extended splines to increase the contact area, reduce the pressure and provide the torque required for rotation, as shown in Fig. 2b.

3.2 Speed design of squirrel cage cartridge mechanism

When the squirrel cage type cartridge case counter is working, when the rotating speed is low, the jamming rate is high and the ejection rate is low; when the rotating speed is high, the ejection rate is high and the jamming rate is low. The results show that the counting rate is directly proportional to the jamming rate and discharging rate, and the discharging rate is directly proportional to the rotating speed and the number of jamming slots, so the rotational speed of the cage cartridge mechanism is an important factor to determine the counting rate. When the cartridge case passes through the optical counter in the form of agglomerates, the grating cannot be formed, resulting in the decrease of the count [7-10]. In order to prevent the cartridge case from entering the chute in the form of agglomerates, according to the resolution of the sensor, the falling clearance of the cartridge case shall not be less than 0.1 s. The speed and the number of slots meet the following formula:

\[
\frac{60}{K} n \geq 0.1
\]

In:
- \( n \): Rotation speed of the cage spring mechanism, \( r/min \);
- \( K \): Number of jam slots, \( t/r \).

Because of the mechanical properties of printing materials, different numbers of slots are selected for testing. On the basis of meeting the function and safety margin, the maximum number of slots set on the 270mm diameter squirrel cage cartridge mechanism is 30. According to formula (2), when the number of chutes is 30 per week, the rotating speed of the cage mechanism is \( n \leq 20 \) R / min. Five \( 5 \) R / min, \( 8 \) R / min, \( 10 \) R / min, \( 12 \) R / min, \( 15 \) R / min and six groups of rotational speeds were selected to test the sticking rate.

In the experiment, 50 groups were tested at each speed, and each group recorded the time by dropping 100 shells. The calculation formula of sticking rate is shown in formula (3):

\[
\eta_i = \frac{1.0 \times 10^6}{n \sum t_i} \times 100\%
\]

In:
- \( \eta_i \): Sticking rate, \%;
- \( t_i \): Time required to drop 100 shells i time, s;
- \( n \): Motor speed, \( r/min \).

The test results of rotating speed and jamming rate of cage clip mechanism are shown in Table 2:
Table 2: Bullet rate test results

| Motor speed (r/min) | Sticking rate (%) |
|--------------------|-------------------|
| 5                  | 41.66             |
| 8                  | 36.34             |
| 10                 | 33.72             |
| 12                 | 27.16             |
| 15                 | 21.28             |
| 20                 | 14.12             |

According to the test results, the jamming rate decreases with the increase of the rotating speed of the cage cartridge mechanism. The faster the clip mechanism rotates, the stronger the bounce of the cartridge case is, and the more difficult it is to get stuck in the slot. Without considering other factors, the theoretical ejection rate is shown in formula (4):

$$Q_p = 30\eta_k$$  \tag{4}

In: $Q_p$: Efficiency of dropped bullets, t/min;

According to the calculation, the theoretical efficiency of dropping bullets under different rotating speeds is shown in Table 3

Table 3: Theoretical efficiency of dropped bullet

| Motor speed (r/min) | Efficiency of dropped bullet (t/min) |
|--------------------|-------------------------------------|
| 5                  | 62.49                               |
| 8                  | 87.22                               |
| 10                 | 101.16                              |
| 12                 | 97.78                               |
| 15                 | 95.76                               |
| 20                 | 84.72                               |

It can be seen from table 3 that the theoretical ejection rate reaches the maximum at the rotating speed of 10 R / min, so the rotational speed is set at 10 R / min.

4. Inclination angle design of cartridge slot

The inclination angle of the cartridge groove is the angle between the pushing surface of the cartridge groove and the outer side of the surface and the column line of the cylindrical squirrel cage cartridge mechanism; the inclination angle of the holding mechanism is the angle between the upper plane at the front side of the retaining mechanism and the supporting horizontal plane; the ejection angle is the angle between the tangent direction of the shell sliding out of the slot and the supporting horizontal plane, as shown in Fig. 3.

![Fig. 3 angle of cartridge case discharged from discharge slot](image_url)

4.1 Ejection angle test

The minimum ejection angle is the minimum inclination angle required for the cartridge case to slide out of the jammed slot. At present, there is no literature report on the sliding friction angle between the 3D printing PLA material and the cartridge case. It is necessary to measure the sliding friction angle between the cartridge case and the printing material through experiments. Due to the different angles
and structures, the surface roughness of 3D printing PLA material forming plane varies greatly. The printer used in our laboratory is a low-end printer, and the printing plane with the largest roughness is the disk-shaped bottom plane. Take the plane with the largest printing roughness as the test plane to test the sliding friction angle and rolling friction angle of the cartridge case, as shown in Fig. 4:

![Fig. 4 test chart of sliding friction angle](image)

The test results show that when the axis direction of the cartridge case is perpendicular to the sliding direction, the shell moves towards the direction with low potential energy by rolling, and the rolling friction angle is 21.3° and 42.7° respectively. In the squirrel cage type cartridge case counter, the cartridge case breaks away from the cartridge slot in the form of rolling. Considering that the excessive speed of the cartridge case after sliding out will adversely affect the counting accuracy, 21.3° is selected as the ejection angle.

4.2 design of inclination angle of supporting mechanism

The inclination angle of the supporting mechanism is obtained through the test, as shown in Fig. 5. The inclination angle is changed by increasing the support cushion block to adjust the height difference.

![Fig. 5 capacitance angle test](image)

The rotating speed of the rotating motor is 10 R / min, and the falling rate of the abnormal shape is tested with six inclined angles of 3°, 5°, 8°, 10°, 12° and 15° respectively:

\[ \eta_i = \frac{\sum \lambda_i}{500} \times 100\% \]  

(5)

In: \( \eta_i \): Abnormal drop rate, %;  
\( \lambda_i \): The number of failed sensors in group i test.

According to the test results, when the inclination angle of the holding mechanism is less than 10 degrees, because the cartridge case is not stuck into the cartridge slot along the direction of the cartridge slot, it is in a special-shaped state, and its falling trajectory at the discharge port is complex, so it is easy to cause counting error. When the inclination angle of the holding mechanism is greater than 10°, the cartridge case stuck in the cartridge groove will fall into the inner part of the holding mechanism under the action of gravity, which does not affect the counter operation. Considering the
factors such as the falling of the cartridge case and the capacity of the cartridge case, the inclination angle of the supporting mechanism is selected to be greater than 10°.

4.3 design of angle of bullet groove
In order to expand the ammunition loading capacity of the holding mechanism, it is necessary to increase the wrapping angle of the cage cartridge mechanism. However, it is limited to the installation and debugging of the loading mechanism and the trefoil spline. The maximum wrapping range of the ratchet mechanism is 180 degrees, that is, the front upper plane of the loading mechanism is the diameter surface passing through the cylinder center of the cylinder cage cartridge mechanism. The angle of the slot is 31.3° by calculation.

5. whole machine experiment
After the whole machine is assembled, as shown in Figure 6, 500 groups of counting efficiency and counting accuracy are tested, and each group tests 200 shells.

The results show that the counting efficiency of the squirrel cage cartridge case counter is 87.4 pieces/min, and the counting accuracy is 99.8%.

6. Conclusion
Through theoretical calculation and a large number of experiments, it is determined that the inclination angle of the cartridge slot of the squirrel cage cartridge case counter is 31.3° and the rotation speed of the cartridge mechanism is 10 R/min. The structure of the squirrel cage cartridge case counter is simple and the number of components is small. The 3D printing technology is used to improve the efficiency of the prototype. 500 groups of test results show that the counting efficiency of cartridge case is 87.4 pieces/min, and the counting accuracy is 99.8%. On the premise of meeting the requirements of counting efficiency and counting accuracy proposed by the army, the weight and power consumption are greatly reduced.

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