Research on Anti-seated Device of Certain Electromagnetic Weapon

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Abstract. The electromagnetic railgun is a new concept weapon that uses Loren magnetic to accelerate the projectile to super high-sonic speed instantaneously. The initial velocity of the projectile muzzle can reach 2km/s or more in an instant. The projectile launched by the electromagnetic railgun has a high speed and thus has a strong kinetic energy to impact the target. According to the principle of force, when the weapon system pushes the armature, the recoil part will be subjected to a force in the opposite direction, that is, the combined force of the gun. If there is no anti-rear device, the force will generate strong vibration excitation to the launching frame, affecting the shooting intensity of the projectile. In order to reduce the influence of the squat resistance of the electromagnetic weapon on the accuracy of the weapon system, the model of the anti-rear device of the electromagnetic weapon is established. The simulation analysis and experimental verification are carried out. The simulation structure and experimental data are in good agreement.

1. Introduction
The electromagnetic orbital gun [1] is a new concept weapon that uses Loren magnetic force to instantly accelerate the projectile to be supersonic. The initial velocity of an electromagnetic orbital gun announced by the US Navy has reached more than 2km/s. The projectile fired by the electromagnetic orbital gun has a high speed, and thus has a strong kinetic energy impact to the target. According to the principle of Newton's third law, it is known that when the weapon system pushes the armature, the recoiled part will be pushed backward by the combined force of the gun bore, which affects the firing intensity of the projectile and may decrease the damage probability of the electromagnetic railgun.

In order to reduce the influence of the recoil resistance of the electromagnetic weapon on the accuracy of the weapon system, the anti-recoil device needs to be properly designed [2-6]. According to D'Alembert's principle, the recoil device can reduce the effect of the gun's combined force on the frame. In addition, the reverse recoil device can also push the recoil part to the original position. In order to ensure that the recoil device has a small recoil resistance within the range of the recoil, and has a small collision limit speed when it's in the receding position, the spring grooved recoil device is optimized and tested in this paper. The research results provide important theoretical support for the design of anti-seated devices for electromagnetic weapons.
2. The model and motion model of anti-recoil device

2.1. The layout of anti recoil device
The layout of the anti recoil device in the electromagnetic weapon system is shown in figure 1. The front of the anti recoil device is fixedly connected to the cradle and is in a stationary state during launch. The end of the anti recoil device is fixedly connected to the transmitter. When launching the projectile, the transmitter drives the anti recoil device to move backward; when the recoil is in place, the anti recoil device drives the transmitter to perform re-entry motion.

![Figure 1. the layout of anti recoil device.](image1)

2.2. The model of anti recoil device
The two-dimensional model of the anti recoil device is shown in figure 2 and is mainly composed of a piston rod, a spring, a cylinder, some grooves, some seal rings, and a liquid drainage system. It adopts the principle of the rod recoil, the cylinder is mounted on the cradle, the piston rod is connected to the transmitter, and the piston rod, the transmitter, and the cables (referred to as the recoil part) are used for reclining and receding movement.

![Figure 2. the model of anti recoil device.](image2)

2.3. The motion model of anti recoil device
When the electromagnetic orbital gun fires a projectile, the body tube drives the piston rod and cables to move backward. The spring is compressed and in a state of energy storage, while the spring hinders the backward movement of the seated portion. The retentive fluid in the right cavity is compressed into the left cavity through the groove. According to Bernoulli's equation, the pressure in the right cavity which can hinder the backward movement of the recoiled part is greater than that in the left
cavity.
When the recoil part is seated in place (speed equal to 0m/s), recuperating movement is started. Because the spring is compressed, the stored energy is released, and the recoil part is forced to move in the opposite direction. The liquid from the left cavity is compressed into the right cavity through the groove, and the recuperating movement process is prevented. Throughout the movement, friction acts as an obstacle to movement. In the case of the high angle shooting of recoil part, due to the existence of gravity, the anti recoil device will move downward along the guide groove of the cradle, affecting the use of the device. The spring is preloaded to ensure that it cannot be moved.

It is considered in this paper that after the armature exits the muzzle, although there is residual energy release from the muzzle, the forward Lorentz force cannot be generated because the guide rail is disconnected and no conductive circuit is formed. The instantaneous ionized gas may be able to conduct the circuit, but the momentum of the recoil part does not change much due to the small mass of the ionized gas relative to the recoil. Therefore, the effect of the blasting force on the muzzle of the projectile can be neglected. The motion model of the anti-recoil device of the electromagnetic weapon [7]:

\[
\begin{align*}
\frac{dv}{dt} &= \frac{P_t - kx(1 + \phi) - \mu m_h g \cos(\phi) - f_x + m_g g \sin(\phi) - kx_0}{m_h} \quad t < t_g \\
\frac{dv}{dt} &= \frac{-kx(1 + \phi) - \mu m_h g \cos(\phi) - f_x + m_g g \sin(\phi) - kx_0}{m_h} \quad t \geq t_g \\
dx &= v \\
x_0 &= 0 \\
v_0 &= 0
\end{align*}
\]

The differential equation of the complex motion is shown in equation 2:

\[
\begin{align*}
\frac{dv}{dt} &= \frac{kx(1 + \phi) - \mu m_h g \cos(\phi) - f_x + kx_0 - m_g g \sin(\phi)}{m_h} \\
dx &= v \\
x_0 &= L \\
v_0 &= 0
\end{align*}
\]

In Eq. 1~2, \(v\) is the speed of the recoiled part, \(P_t\) is the combined force of the gun bore, \(\phi_2\) is the spring damping coefficient, \(k\) is the spring stiffness coefficient, \(\mu\) is the friction coefficient, \(f_\phi\) is the cushioning resistance generated by the retracting machine, \(t_g\) is the movement time in the projectile bore, \(m_b\) is the mass of the recoiled part, \(x_0\) is the initial preload of the spring.

The combined force of the bore is calculated by combining the current output curve which is shown in figure 3 and the internal ballistic formula of the electromagnetic gun. The detailed formula is referred to reference 8.
Calculation of buffering resistance generated by the machine is as follow:

\[ f_b = \frac{K \rho}{2} A_0 \left( \frac{A_0 - a_x}{a_x} \right)^2 V^2 \]  

(3)

Combining Equation 3 with the differential equations, the synchronous integral is used to calculate the cushioning resistance generated by the machine. In Eq. 3, \( K \) is the hydraulic resistance coefficient of the brake, \( \rho \) is the density of the recoil liquid, \( A_0 \) is the pressure bearing area of the brake piston, \( a_x \) is the through hole area of the groove, and \( V \) is the speed of the recoil part.

3. Simulation Analysis of Anti-recoil Device

The optimal analysis and calculation model of anti-recoil device of electromagnetic weapon is simulated by visual basic software, and the optimal design parameters of anti-recoil device are shown in table1.

| Bore diameter /mm | Release rod diameter /mm | Groove depth /mm | Groove width /mm | Number of grooves | Spring stiffness N/m |
|-------------------|--------------------------|------------------|------------------|-------------------|---------------------|
| 110               | 36                       | 2.2              | 20               | 4                 | 70000               |

The simulation of the elements of the recoil device at the shooting angles of 0° and 87° are carried out.

The change curve of the recoil velocity, displacement, drag resistance and recoil force over time at 0° and 87° shooting angles are shown in figures 4, 5, 6, and 7.

Figure 3. current change diagram of an electromagnetic weapon.

Figure 4. curve of velocity time at 0° and 87° shooting angles.
Figure 5. curve of displacement-time at 0° and 87° shooting Angles.

Figure 6. curve of hydraulic retarding force-time at 0° and 87° shooting Angles.

Figure 7. curve of recoil-time at 0° and 87° shooting Angles.
When the shooting angle is 87°, the recoil force reaches the peak value of 17.4KN. When the shooting angle is 0°, the recoil force reaches the minimum value of 16.7KN.

When the shooting angle is 87 °, the peak of the recoil displacement is 40.0mm. The minimum recoil displacement at angle of 0 ° is 16.4mm.

The anti-recoil device model takes the form of a relatively large hydraulic pressure-making force, which is conducive to the rapid attenuation of the speed of the recoil part and has the advantage of a smaller collision limit speed during recuperating movement.

4. **Test Verification of Anti-Recoil Device**

The design of an anti-recoil device was tested and verified by experiment. Test conditions are as follows:

1) The velocity of the projectile with fixed mass and current output are consistent, and the barrel force of the gun is consistent with that of simulation;

2) The quality of the recoil part was consistent with the analysis;

3) The processing of the anti-recoil device is consistent with the results of optimization analysis, such as the same groove width and depth.

According to the test, the displacement time data of the recoil part is obtained, and the comparison diagram with the simulation displacement time curve is shown in figure 8.

**Figure 8.** comparison of displacement-time curves under experimental and simulation.

It can be seen from figure 8 that in the 0 ° shooting angle test, the recoil length is 13.1 mm and the time is 100ms. The simulated recoil length is 16.4mm, and the recoil time length is 102ms. The simulation data is basically consistent with the test data and has high accuracy.

5. **Conclusion**

When the electromagnetic gun fires, there is a big barrel force. After installing the anti-recoil device, the recoil force on the frame can be significantly reduced, and the shooting accuracy can be improved. Through the simulations of 0° and 87° firing angle, it is concluded that the recoil force is 17.4kn when the firing angle is 87° and is 16.7KN when the shooting angle is 0°. The speed of the recoil part can be rapidly attenuated by the method of hydraulic resistance, and the collision limit speed can be smaller when the recoil angle is 0°. Experiments are carried to verificate the models. The recoil displacement of the simulation model was 16.4mm, and the length of the recoil time was 102ms; the length of the test recoil was 13.1mm, and the time was 100ms. The simulation model has high accuracy which can
provide theoretical support for the optimal design of anti-recoil device of electromagnetic weapon.

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