Research on Electrical Contact Characteristics of Interference Fit Armature Based on Simulation

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Abstract The electrical contact characteristics between the armature and the rail directly affect the current distribution on the armature and the rail during the launch process, which in turn affects key characteristics such as the thrust of the launcher and the distribution of Joule heat. In this paper, based on the Cooper-Mikic-Yovanovich contact theory, the electrical contact characteristics of the quadrupole electromagnetic orbit launcher under the interference fit condition are simulated, and the simulation results closer to the real current distribution are obtained. Based on the results, the electromagnetic characteristics of the launcher are analyzed. An analysis is carried out and it is pointed out that compared with ideal contact conditions, factors such as contact surface roughness will affect the electrical contact efficiency, which in turn affects the electromagnetic thrust and Joule heating of the launcher.

1. Introduction
The armature is a moving part in the launching process of the electromagnetic railgun, and its contact characteristics with the launcher track greatly affect the performance of the electromagnetic railgun. In order to obtain good pivot-rail contact characteristics, an interference fit is often used in the industry. The interference fit is not only an inevitable requirement for the projectile loading of the launcher, but also through the interference fit, it can also increase the contact pressure of the pivot rail and alleviate the unfavorable factors such as the planing phenomenon. Therefore, the interference fit of the pivot rail of the launcher becomes current research hotspots.

At present, the research on the interference fit between the pivot and the rail mainly focuses on the physical contact characteristics between the pivot and the rail. For example, Wei-qun Yuan and Ying-dong Che of the Institute of Electrical Engineering of the Chinese Academy of Sciences used the finite element simulation method to analyze the influence of the initial contact state of the pivot rail and the pre-tightening force on the starting characteristics of the electromagnetic rail launcher, and proved that optimizing the contact state of the armature in the starting process can improve current distribution and alleviation of ablation are of great significance; Jun-jia He, Sheng-guo Xia and others used the interference fit method to carry out simulation studies on the initial contact characteristics of the pivot-rail and conducted experimental verification. The results show that a reasonable interference design will indeed improve the track. The firing performance of the gun; Shao-wei Liu and Hai-yu Miao proposed a reverse loading method for designing the armature interference, and designed the shape of the armature arm according to the expected contact pressure.
The above-mentioned research has been very in-depth research on the physical contact characteristics of the armature and the track, but when studying the impact of the armature-rail contact on the current distribution of the launcher, it is assumed that the armature and the track are in complete contact, that is, as long as the armature-rail is physically. If contact is made, it is considered that current can be conducted between the pivot rails. This assumption is obviously different from the actual electrical contact between the pivot rails and may cause large errors.

Therefore, this paper designs an interference armature structure applied to a four-pole electromagnetic rail launcher, and simulates and analyzes its electrical contact characteristics with the track based on the Cooper-Mikic-Yovanovich contact theory. The results of full contact are compared, the influence of electrical contact on the electromagnetic thrust and current distribution of the electromagnetic rail launcher is analyzed, and a method to improve the electrical contact characteristics of the pivot rail is proposed.

2. Armature model

This article uses a four-pole electromagnetic orbit launch device for analysis, and the launch device model is shown in Figure 1. The structure mainly includes four parallel guide rails with the same structure and an interference armature adapted to the guide rail. Among them, two opposite rails pass currents in the same direction with equal magnitudes, and two adjacent rails pass reverse currents with equal magnitudes. According to Ampere's law, the vicinity of the rail will be excited by the current to form a circular magnetic field, and in the middle of the four tracks, the direction of the magnetic field is the same. According to Biot-Saffar's law, the current flowing through the armature interacts with the magnetic field excited by the current on the track. The thrust generated by the track at any point on the armature is:

\[ B = \int_{-\frac{h}{2}}^{\frac{h}{2}} \int_{0}^{\frac{b}{2}} \frac{\mu_0 I}{4\pi hw} (\cos \alpha_1 - \cos \alpha_2) dy dz \]

(1)

Therefore, the electromagnetic thrust received by the armature with current density \( J \) is:

\[ F = \int J \times B dV \]

(2)

The track used in this paper is 1000mm in length, 20mm in width, and 10mm in height, and the material is copper; the armature model and its size is shown in Figure 2. Among them, the armature head has a circular through hole with a radius of 7mm, and the overall material of the armature is aluminum.

Figure 1 Launcher model
3. Analysis of physical contact characteristics of interference armature

The armature and the rail are assembled by the fastening assembly method. After the assembly is completed, the contact pressure distribution of the contact interface between the pivot and the rail is shown in Figure 3. It can be seen from the figure that the contact pressure between the armature and the track is concentrated on the tail of the armature arm, and there is an obvious layering phenomenon. Considering the distribution of the circumferential electromagnetic force during the launch process and its compensation effect, it is considered that the armature structure design is more reasonable.

4. Analysis of electrical contact characteristics

The traditional contact theory assumes that the contact interface between the pivot and the rail is smooth. Therefore, as long as the rail and the armature are geometrically adjacent, it can be considered that the two are in contact with each other and can conduct current. In fact, due to factors such as machining errors, the pivot-rail contact interface cannot be completely smooth. According to the A-spot contact theory, the contact between the armature and the track is actually a point contact as shown in Figure 4.
The distribution of contact points on a non-smooth contact surface is random, so it is difficult to calculate directly. Yovanovich, Mikic and others respectively proposed the current conduction mode based on the non-smooth contact surface of the point contact, that is, the Cooper-Mikic-Yovanovich correlation theory, which believes that the current on the contact interface is completely conductive, but according to the different contact conditions, it needs to pass The contraction conductivity calculates the conduction efficiency of the current. Among them, the shrinkage conductivity is related to the contact pressure on the interface, the hardness and roughness of the contact material. The formula for calculating shrinkage conductivity is as follows:

$$h_c = 1.25 \sigma_{\text{contact}} \frac{m_{\text{asp}}}{\sigma_{\text{asp}}} \left( \frac{p}{H_c} \right)^{0.95}$$

$$\frac{2}{\sigma_{\text{contact}}} = \frac{1}{(\sigma_{n_d}) \cdot n_d} + \frac{1}{(\sigma_{2n_d}) \cdot n_d}$$

Among them, $\sigma_{\text{asp}}$ is the average height of the surface roughness of the contact surface, $m_{\text{asp}}$ is the average surface roughness slope, $p$ is the contact pressure, and $H_c$ is the microhardness of the material.

This theory analyzes the electrical contact situation of the contact interface by defining the contact efficiency. According to the model, the current distribution of the launching device and the armature current distribution can be obtained, as shown in Figure 5 and Figure 6.
It can be seen that the current calculated according to the Cooper-Mikic-Yovanovich contact theory is lower than that of the traditional full contact theory. Compared with the current distribution of the non-interference-fitted armature, the current distribution of the interference-fitted armature is more evenly.

According to previous experimental results, after the launch, the ablation of the armature is mainly concentrated in the armature throat. The throat ablation is obviously caused by Joule heat, and its distribution should be similar to the current distribution. Therefore, it can be seen that the current distribution obtained by Cooper-Mikic-Yovanovich simulation is more accurate.

It can be seen that the current distribution calculated by the Cooper-Mikic-Yovanovich correlation theory is more accurate and more consistent with the experimental conclusions.

5. Conclusion

Based on the Cooper-Mikic-Yovanovich correlation theory, this paper simulates the electromagnetic characteristics of the launcher under the interference fit condition, and obtains the following conclusions:

1) The interference fit can improve the contact characteristics between the pivot and the rail and prevent the contact separation due to high temperature during the launch process, so it can reduce the occurrence of gouging;

2) According to the Cooper-Mikic-Yovanovich correlation theory to analyze the electrical contact characteristics of the pivot rail interface, it can be seen that the contact pressure will have a great impact on the electrical contact efficiency, so a reasonable armature interference design can effectively improve the electrical contact efficiency and reduce the occurrence of ablation;

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