Design of Armature Interference Structure of New Quadrupole Track Electromagnetic Launcher

Qingrong Chen¹, Tao Shu², Gang Feng², Shaowei Liu², and Mengyang Cui¹

¹ Graduate School, Air Force Engineering University, Xi’an, Shan xi, 710051, China
² Air Defense and Missile Defense College, Air Force Engineering University, Xi’an, Shan xi, 710051, China

*Corresponding author’s e-mail: 1034021926@qq.com

Abstract. How to provide pre-tightening force for armature and how to achieve interference fit between armature and track are the basic and key difficult problems in the research process of electromagnetic track launcher, which directly affect the contact characteristics between armature and track, and have important research significance. Firstly, according to the armature arm structure of C-type armature of railgun, the interference structure of armature of new quadrupole track electromagnetic launcher is designed. Then, in the simulation process, two kinds of interference structures are simulated and analyzed by the loading assembly method. Finally, the final structure of armature interference is determined based on the four performance indicators of stress, pressure contact efficiency, stress and pressure distribution uniformity to quantify the contact characteristics. The results show that scheme 2 is more suitable for armature of new quadrupole track electromagnetic launcher, and has the best performance index when the interference is 0.6 mm.

1. Introduction
The structure of electromagnetic launcher plays a fundamental and decisive role in its performance. Researchers have found that the electromagnetic launcher with multi-pole track structure can greatly improve the comprehensive performance of simple rail gun [1-3]. In reference [4], a new quadrupole track electromagnetic launcher model is proposed on the basis of the existing main types of rail guns, and a full theoretical and simulation analysis of the model is carried out. Because of its unique structure and current-passing mode, the model has excellent electromagnetic and current effects, and can generate larger and more stable electromagnetic thrust, which has strong research significance.

In the electromagnetic track launcher, the armature needs interference fit with the track to ensure effective electrical contact, so that the contact area becomes larger and the contact pressure distribution becomes more uniform. The design of armature interference structure directly affects the contact characteristics of armature rail contact surface [5-6]. Therefore, this paper mainly designs the interference structure of the armature of the new quadrupole track electromagnetic launcher, in order to fully tap the performance of the model and promote its practical engineering research.

2. Model structural analysis
The model of the new quadrupole track electromagnetic launcher is shown in figure 1 below. The structure of the model is symmetrical. The armature moves rapidly towards the exit direction under the combined action of magnetic fields generated by four tracks with identical size and material. Current
flows from the two tracks marked blue on the left, through the armature clamped in the upper and lower tracks, and then from the two tracks marked red on the right to form a closed loop. By adding insulation material, support material and cladding around the track to form the launcher barrel, the left and right armature displacement can be prevented, and the overall stability of the model can be enhanced [4].

Figure 1. Integral model of a new quadrupole track electromagnetic launcher.

Figure 2. Schematic diagram of armature structure size.

As one of the core components of electromagnetic track launcher, armature plays the role of forming closed circuit and carrying launch load. Reasonable armature structure can improve the current distribution in armature, reduce the generation of Joule heat and friction heat, maintain the stable force of armature in the process of high-speed movement, and restrain the problems of transition, ablation and melting to a great extent [7-9]. The armature model of the new quadrupole track electromagnetic launcher is shown in figure 2. In order to provide pretension force for the model and ensure the good contact between armature and track during the whole launching process, two kinds of interference armature arm structures are designed according to the C armature pretension mode of rail gun and the characteristics of the model. The armature model of scheme 1 is shown in figure 3(a) below, and the armature model of scheme 2 is shown in figure 3(b) below. These two kinds of armature with interference structure are developed on the basis of armature shown in figure 2.

(a) scheme 1  
(b) scheme 2

Figure 3. Armature integral model with interference structure.

Because of the symmetrical structure of the new quadrupole track electromagnetic launcher, in order to reduce the computational load and simulation time, a quarter armature and the corresponding track are taken to form the simulation model in the simulation process, as shown in figure 4.
The left view of the armature quarter model of the two interference structures is the same. Its size is shown in figure 5. Among them, $q$ is the interference size and $P$ is the armature tail thickness. In this paper, let $P=11$mm. The two kinds of armature have the same size as the armature model in figure 2, except for the different structure of interference.

Figure 5. Dimensional schematic diagram of armature model quarter.

3. Two common armature assembly methods
Generally, armature loading has two kinds of assembling modes: fastening and loading. Among them, the fastening method is to install the armature in the track first, and then fix the track from the external force, as shown in figure 6(a); the loading method is to fix the track, and then insert the armature directly into the gun bore from the end of the track, as shown in figure 6(b).

In practical engineering applications or tests, armature is usually fed from the end of the track, and the interference of the tail fin is flattened in the process of pressing, thus generating pre-tightening force to provide contact stress and pressure. Therefore, in order to be more in line with engineering practice, this paper adopts the loading assembly method as shown in figure 6(b) when analyzing the contact characteristics between armature and track.
4. Pre-test simulation analysis

After establishing the armature simulation models of two schemes and determining the assembly mode, the finite element analysis software ANSYS Workbench is used to simulate the pre-test and analysis of armature assembly, and the metal-metal contact in the process of armature-track assembly is simulated. The basic type is the surface-to-surface contact between rigid body and flexible body. The simulation focuses on armature analysis, so the track is regarded as a rigid body that can not be deformed and the armature as an elastic body. The armature material is aluminium alloy and the track material is copper alloy. The rail is fixed and the armature guide rail moves in the direction until it enters the guide rail completely. In the pre-test process, the interference magnitude of the two models is the same, 0.6mm, and the armature tail thickness $p=11$mm. The results are shown in the following figure.

In order to facilitate the quantitative analysis of the distribution of contact stress and pressure between armature and track, the results shown in figure 7 and figure 8 are replaced by three-level scale simulation cloud map as follows:
In the process of armature-rail contact, Marshall's "1g/1A" criterion is generally used to judge whether the effective electrical contact is achieved, and von-Mises criterion is used to calculate the effective equivalent stress in the contact surface [10-11]. In the simulation model shown above, when 100kA current is applied, the effective contact is found when the stress is greater than 9.85MPa and the pressure is greater than 0.5MPa. Therefore, the green and red areas in figure 9 are the effective stress areas and the green and red areas in figure 10 are the effective pressure areas.

The main performance indicators of contact characteristics between armature and rail are contact efficiency and uniformity of contact distribution. Now let $A_1$ represent the area of red area, $A_2$ represent the area of green area and $A_3$ represent the area of blue area. So there is $S_1 = \frac{A_1 + A_2}{A_1 + A_2 + A_3}$ for the contact efficiency of armature-rail interface and $S_2 = \frac{A_1}{A_1 + A_2}$ for the uniformity of contact distribution of armature-rail interface. Among them, the values of $S_1$ and $S_2$ are between 0 and 1, and the greater the value, the more sufficient the contact, the better the situation [11-12]. The results show that when the interference is 0.6mm, the performance indicators are as follows:

| Category | Stress | Pressure |
|----------|--------|----------|
|          | Contact Efficiency | Distribution Efficiency |
|          | Contact Uniformity | Distribution Uniformity |

Table 1. Performance indicators of contact characteristics for interference of 0.6mm.
5. The influence of interference on the performance index of contact characteristics

The control variable method is used to change the magnitude of armature interference $q$, keep other structural parameters of armature unchanged and various settings unchanged in the simulation process. The simulation results of two kinds of armature interference structures are obtained by calculation as follows:

| Scheme | Contact Efficiency | Distribution Uniformity |
|--------|--------------------|-------------------------|
| Scheme 1 | 0.56 0.24 0.19 0.11 | |
| Scheme 2 | 0.64 0.28 0.27 0.17 | |

Figure 11. The relationship between the magnitude of interference and contact characteristics.

From figure 11, it can be seen that the variation law of the relationship curve between the interference magnitude and the contact characteristics of the two schemes is basically the same, and both of them increase first and then decrease. With the increase of the interference $q$ value, the contact efficiency and distribution uniformity decrease gradually, and even tend to be stable. This is because when the interference $q$ is too large, serious stress concentration occurs, resulting in smaller and smaller effective contact area and tends to be fixed. Obviously, from the point of view of stress and pressure contact characteristics, the performance index of scheme 2 is better than that of scheme 1, and when $q=0.6mm$, scheme 2 has the maximum stress, pressure contact efficiency and the maximum uniformity of stress and pressure distribution.

6. Conclusion

For the rail electromagnetic launcher, the contact characteristics between armature and track are directly related to the whole process of armature and track assembly and movement, and directly affect the launching efficiency and accuracy of the whole launching system. Therefore, the design of armature interference structure is an indispensable and important link. Based on the original armature
structure of the new quadrupole track electromagnetic launcher, two interference structures are
designed in this paper. The simulation results show that the contact performance index of scheme 2 is
better than that of scheme 1. When \( q = 0.6 \text{mm} \), scheme 2 has the maximum stress, pressure contact
efficiency and the maximum uniformity of stress and pressure distribution. Therefore, scheme 2 is
applied to the armature model of a new quadrupole track electromagnetic launcher with \( q = 0.6 \text{mm} \).

References

[1] Marshall R A, Wang Ying. Science and Technology of Electromagnetic Rail Gun[M].
Beijing: Weapon Industry Press, 2006, 23-25.

[2] Bai Xiangzhong, Zhao Jianbo, Tian Zhengu. Mechanical analysis of electromagnetic track
launching components[M]. Beijing: National Defense Industry Press, 2015, 1-12.

[3] Xue Xinpeng, Shu Tao. Design of multipole electromagnetic emitter for surface-to-air
Missile[J]. Journal of Projectiles, Rockets, Missiles and Guidance. 2017, 37 (02): 27-31.

[4] Chen Qingrong, Shu Tao, Ding Rixian, et al. [J/OL]. Journal of Missile and Guidance: 1-8
[2018-11-05]. http://kns.cnki.net/kcms/detail/61.1234.TJ.20181102.1004.002.html.

[5] Feng Deng, Xia Shengguo, Chen Lixue, et al. Characteristic analysis of the initial contact
between C-shaped armature and rail based on interference fit[J]. High Voltage
Engineering. 2014, 40 (4): 1077-1083.

[6] Liu Feng, Dang Shenggang, Zhao liman, et al. Shape design and contact stress analysis of
H-shape solid armature[J]. Journal of Gun Launch & Control, 2015, 36 (1): 1-4.

[7] Cao Zhaojun, Xiao Zheng. Current density distribution characteristics and mechanism
analysis of C-type solid armature in electromagnetic launching system[J]. New Electrical
and Electrical Technology, 2012, 31(2): 23-26.

[8] Liu Ming, Shu Tao, Miao Haiyu, et al. Distribution characteristic of armature current in
different orbit structures[J]. High Power Laser and Particle Beams, 2018,30(5):055005-
2-7.

[9] Li Gang. Optimal design of C-shaped solid armatures in electromagnetic railgun[D]. Qin
Huangdao: Yanshan University, 2013.

[10] Marshall R A, Wang Y. Railguns: their science and technology[M]. Beijing: China
Machine Press, 2004: 3-24.

[11] Tong Siyuan, Feng Gang, Yang Zhiyong, Miao Haiyu, Liu Yuqian. Optimizing the orbit
interference fit parameters of the armature of the missile's four-stage magnetic field[J].
Strong laser and particle beam, 2019, 31 (01): 38-44.

[12] Shu Tao, Liu Ming, Chen Qingrong, Ding Rixian, Zhao Jie. Study on non-uniform contact
pressure after armature assembly [J/OL]. Journal of Missile and Guidance: 1-5 [2019-
08-16]. http://kns.cnki.net/kcms/detail/61.1234.TJ.20181101.1604.006.html.