Comparative study on longitudinal momentum characteristics of L-type and I-type breech in railgun

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1. INTRODUCTION

When the railgun is launched, the armature is subjected to a forward electromagnetic force. According to the momentum conservation law, there must be a corresponding reverse axial force. However, the magnitude and position of the reverse force have been controversial. Actually, the reverse force acts on the current pool at the breech of railgun. Generally, the breech is mainly composed of a coaxial cable connector, a current injection plate and insulating support. However, the influence of different types of breech current injection structure on the reversed momentum has not been studied.

In this paper, based on the Maxwell equations, the momentum conservation equation of the electromagnetic railgun was derived. And, two types of breeches finite element models were established. Then, the electromagnetic field distribution of the breech during the launch process was simulated with The finite element method. Some results, such as, the electromagnetic field distribution and the momentum density distribution of different breeches were obtained. According to the simulation results, the momentum characteristics of different components in different breeches were compared and analyzed.

2. EQUATIONS

The force density of the charge is:

$$f = \rho E + J \times B \qquad (1)$$

In Maxwell's equations:

$$\nabla \cdot B = 0 \qquad (2)$$

$$\nabla \times E = -\frac{\partial B}{\partial t} \qquad (3)$$

$$J = \frac{1}{\mu_0}\nabla \times B - \varepsilon_0 \frac{\partial E}{\partial t} \qquad (4)$$

the equation (1) can be rewritten as:

$$f = \varepsilon_0(\nabla \cdot E)E + \varepsilon_0[\nabla \times E + \frac{\partial B}{\partial t}] \times E + \frac{1}{\mu_0}(\nabla \cdot B)B + (\frac{1}{\mu_0}\nabla \times B) \times B - \varepsilon_0 \frac{\partial E}{\partial t} \times B \qquad (5)$$

Here define:

$$g = \varepsilon_0 \left(E \times B\right) \qquad (6)$$

$$\bar{\bar{T}} = -\varepsilon_0 \bar{E}\bar{E} - \frac{1}{\mu_0}\bar{B}\bar{B} + \frac{1}{2}\bar{\bar{I}}(\varepsilon_0 E^2 + \frac{1}{\mu_0}B^2) \qquad (7)$$

Where, g is the field momentum, T is the Maxwell tensor. For a space V , integrate both sides of the equation (5), according to equation (6, 7), equation (5) could be rewritten as:

$$-\oint_s \bar{\bar{T}} \cdot dS = \int_V f dV + \frac{\partial}{\partial t}\int_V g dV \qquad (8)$$

Where, equation (8) is the momentum conservation equation of the whole system including electromagnetic field [23]. For a brief expression, we define:

$$F_S = F_m + F_e = \frac{\partial}{\partial t}(G_m + G_e) \qquad (9)$$

$$F_S = -\oint_s \bar{\bar{T}} \cdot dS \qquad (10)$$

$$F_m = \frac{\partial G_m}{\partial t} = \int_V f dV \qquad (11)$$

$$F_e = \frac{\partial G_e}{\partial t} = \frac{\partial}{\partial t}\int_V g dV \qquad (12)$$

Where, Gm + Ge is the total momentum of railgun system, which includes mechanical momentum and electromagnetic field momentum. Fs is the surface force subjected to external electromagnetic fields, which could characterize the transfer of momentum. For the longitudinal momentum, it only needs to take the axial component of Fs.

3. MODELS AND SIMULATION PARAMETERS

According to the electromagnetic momentum conservation equation, the characteristics of the electromagnetic momentum in the breech are related to the direction of the source current. Based on whether the direction of the source current is the same as the current direction in the rails, the breech can be divided into two types, L-type and I-type structures. The source current direction of the L-type breech is perpendicular to the current direction of the rails. Fig.2 and Fig.3 is the structural diagram of an L-type and I-type breech respectively.

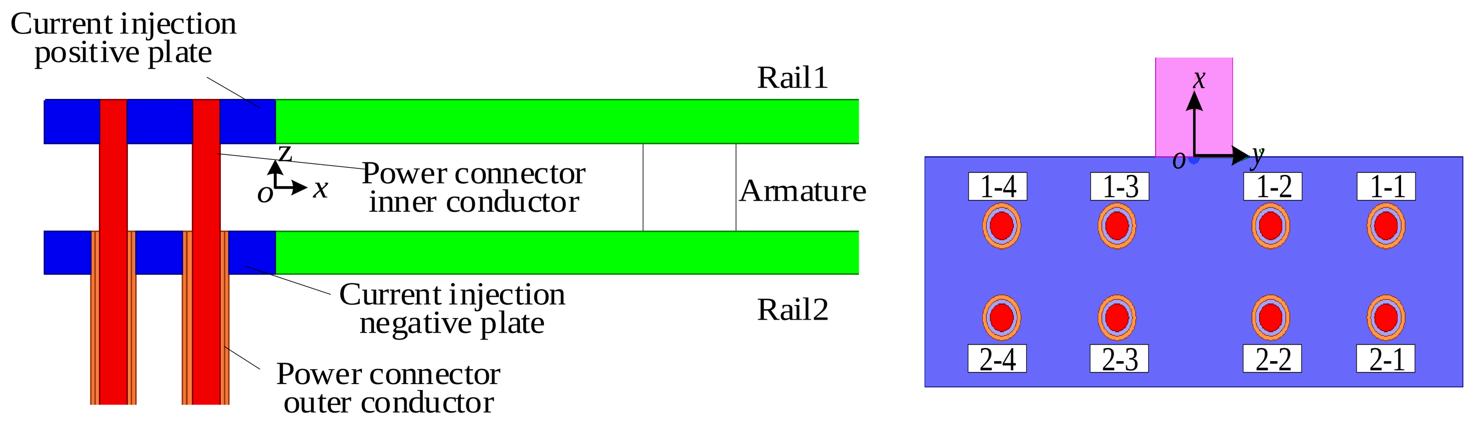

Fig. 1 Configuration of L-type breech.

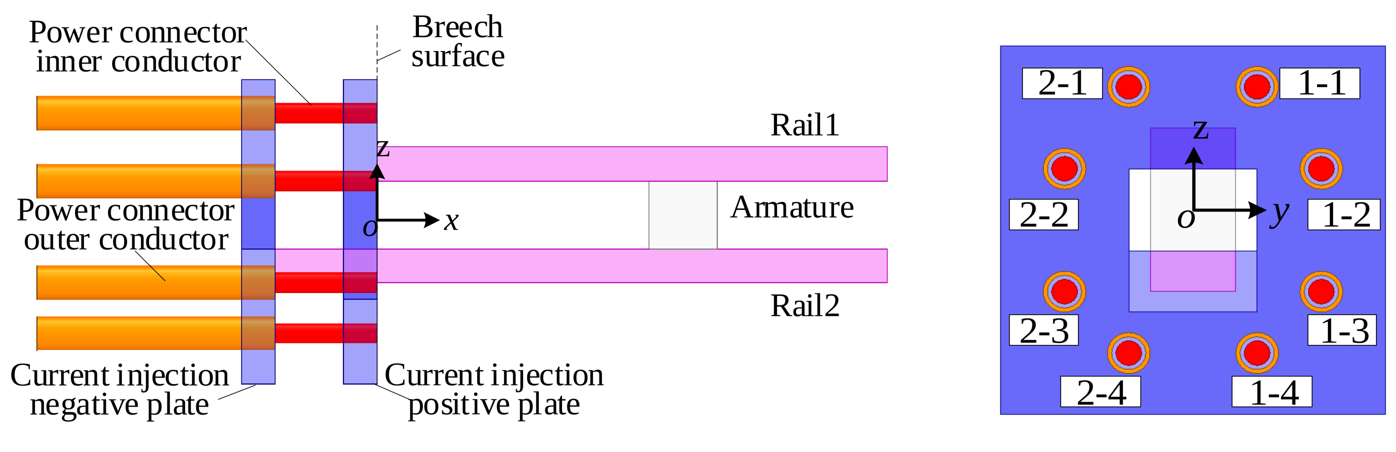

Fig. 2 Configuration of I-type breech.

Table 1. Structure parameters of the L-type breech and I-type breech.

Component	L-type berech x∗y∗z(mm)	I-type breech x∗y∗z(mm)
Rail1	150∗20∗10	150∗20∗10
Armature	10∗10∗10	10∗10∗10
Rail2	150∗20∗10	150∗20∗10
Plate-P	50∗140∗10	10∗90∗90
Plate-N	50∗140∗10	10∗90∗90
Connector-P	φ6∗100	φ6∗100
Connector-N	(φ10−φ8) ∗70	(φ10−φ8) ∗70

4. RESULTS AND DISCUSSIONS

4.1 magnetic force results

Table 2 listed the results of the longitudinal magnetic forces on components of the two railgun with L-type breech and I-type breech. The forces on the armatures are 2333N and 2331N, respectively. It indicates that the different structure of the breech will not affect the launch performance on the armature. This phenomenon can be explained by the four-caliber rule. 99.6% propellant force on the armature is generated by the rails at four times the caliber behind the armature. In Fig 3, the reverse force on the L-type breech is most distributed on the two current injector plates and the power connectors. And that on the I-type breech is mainly concentrated on two current injector plates.

Table 2. Results of longitudinal magnetic force on the railgun.

Component	Fmx(N) (L-type)	Fmx(N) (I-type)
Rail1	236	208
Armature	2333	2331
Rail2	236	195
Plate-P	-1006	-1269
Plate-N	-900	-1356
Connector	-908	-102

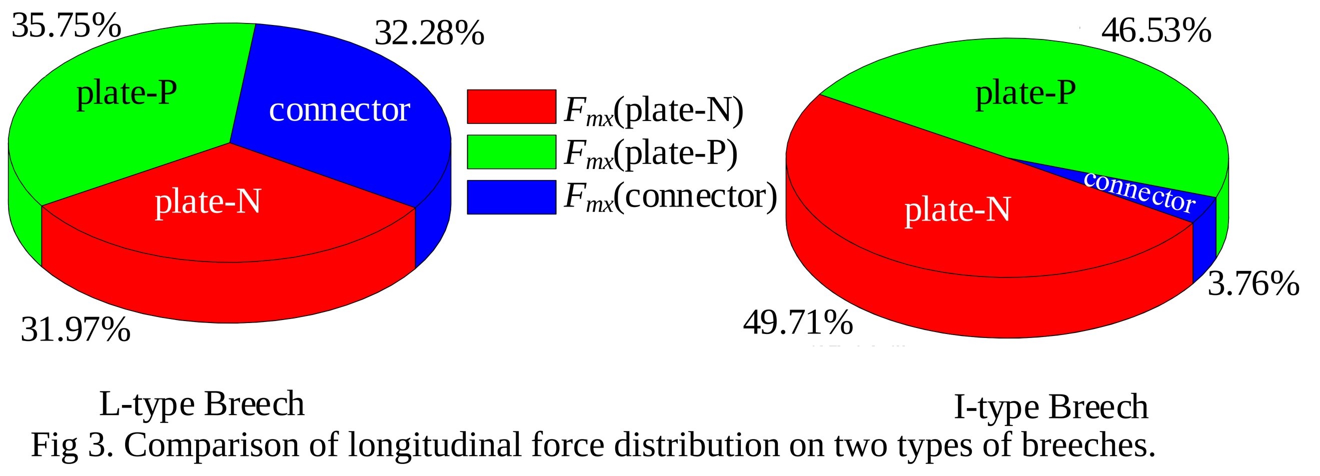

Fig 3. Comparison of longitudinal force distribution on two types of breeches.

4.2. Surface force results

According to equation (12), the surface force could present the momentum distribution of the whole railgun including the field momentum and the mechanical momentum. In order to study the features of longitudinal momentum, take the x direction component of the surface force named Fsx.

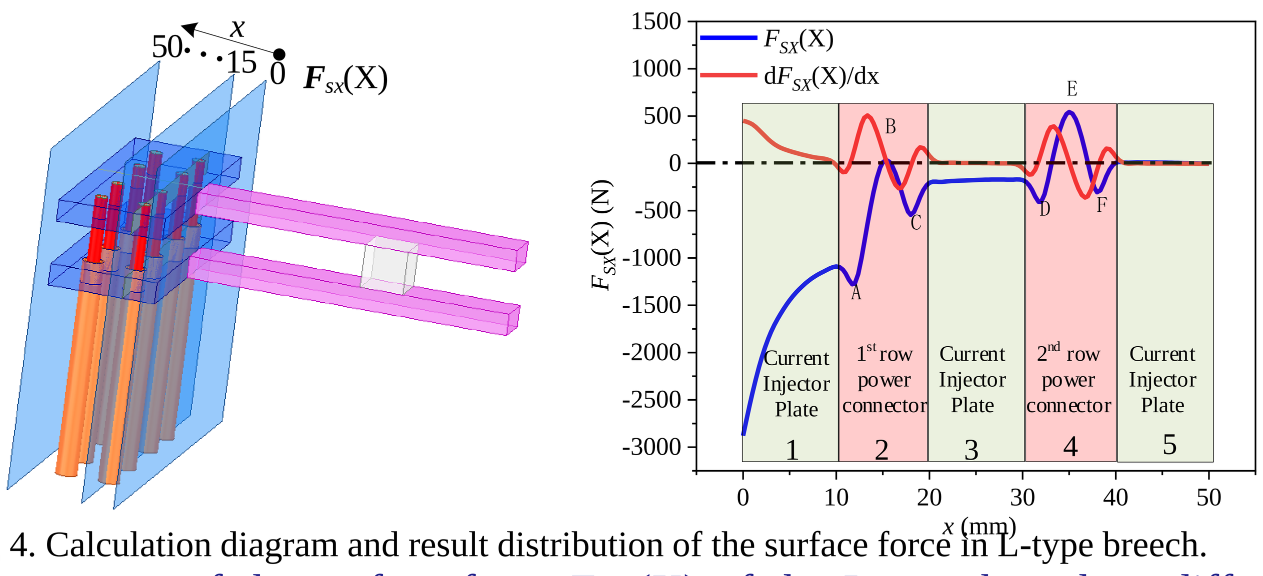

Fig 4. Calculation diagram and result distribution of the surface force in L-type breech.

Figure 4 is the curves of the surface force Fsx(X) of the L-type breech at different x position. The blue curve represents the surface force Fsx(X), and the red curve represents the gradient of Fsx(X) in the x direction. According to different corresponding conductors at x, the breech could be divided into 5 regions in the x direction. According to equation (8), the gradient of Fsx(X) represents the electromagnetic force experienced by the conductor, which also shows the momentum distribution on the breech. In region 1, the electromagnetic momentum decreases extremely fast. And correspondingly, current injector plates suffer strong force. The electromagnetic force on the end face of the gun in region 1 is close to 500N at the maximum, however, the electromagnetic forces on region 3 and 5, located at the current injector plates are almost zero. Regions 2 and 4 are where the power connectors connect to the plates. In these two regions, the surface force Fsx(X) is alternating, which indicated that the electrical connectors are under internal stress. It showed that the net electromagnetic force experienced by the electrical connector is less than the peak electromagnetic force that on the inside of the connector

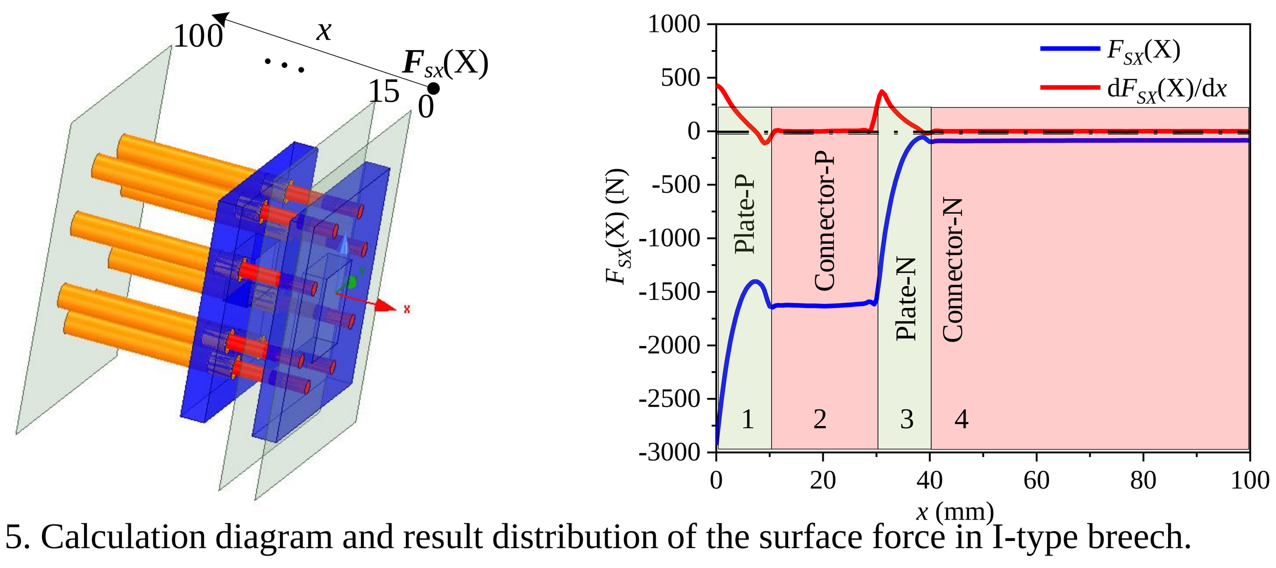

Fig 5. Calculation diagram and result distribution of the surface force in I-type breech.

The curves of the surface force Fsx(X) of the I-type breech at different x position is shown in figure 5. Similarly, the breech could be divided into 4 different regions in the x direction. Overall, compared with the L-type, the surface force distribution on the I-type breech is much smoother. The surface force changes are mainly concentrated in region 1 and region 3, which indicates that the two current injector plates have received the most electromagnetic force. On the other hand, it represents that the force on the connector is very small.

5. CONCLUSIONS

In this paper, railguns are divided into two types based on the direction of the source current in the breech. According to the momentum conservation equations, two types breeches were modeled and simulated with the finite element method. By analyzing and discussing the simulation results, the conclusions are as follows.

1) The momentum of the railgun system is conserved, and the reversed force is transmitted to the breech by the electromagnetic field in the forms of the surface force. Besides, different structures of the breech will not affect the launch performance of the railgun.

2)The reverse force is mainly concentrated on the current injector plates and the power connectors. Moreover, the force on the I-type breech is more uniform than that of L-type breech.

3)The longitudinal force on the power connectors of L-type breech is much bigger than that of the I-type breech, up to nine times.

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