

Effective Analysis on Metal-Metal Contact on C-Shaped Armature-Rail Interface

Saravana Kumar .M .N¹, Murugan .R²Research Scholar, Department of Electrical and Electronics Engineering, St. Peters University, Chennai, TN, India¹Associate Professor, Department of Electrical and Electronics Engineering, Easwari Engineering College, TN, India²

ABSTRACT: Railgun is an electromagnetic launcher works under the very basic laws of electromagnetic theory to propel an object. It consists of two parallel conducting plates between which the projectile sits so as to complete the electrical circuit between them. It is a device in which a magnetic force can accelerate the projectile to a high speed in short time. Railgun model is one of the major problems in launch process. In that, contact is generally provided by the deformation of the trailing arm, from which it can keep a good metal-metal contact at the armature-rail interface, by providing sufficient contact force to ensure the launch without transition. In order to get more uniform contact pressure and current distribution, a novel modified C-shaped armature for round-like bore railgun are proposed. Based on the literature survey, concave and convex ASCA are simulated with finite element method. From that one split-leg concave ASCA shows the best result on electromagnetic launch process.

KEYWORDS: Deformation, C-shaped armature, contact force, finite element method, metal-metal contact.

I. INTRODUCTION

Railgun is an electromagnetic launcher contains two parallel conducting plates called rails and a projectile sits so as to complete the electrical circuit between them. Generally Railgun works under the basic principle of Lorentz force. A large current is used to generate magnetic field, which will accelerate the projectile at high speed in a short time. There is no need for any other components although some designs do have additional rails that seek to augment the flux generated by the rails and some are further complicated by the addition of circuits that recover the energy stored in the rails as the projectiles leaves the gun. When rails were energized by applying a large current and it will starts to flow by creating a current loop together. In order to get higher velocity of armature, railgun needs huge amount of current. The performance characteristics parameters of the rail gun such as force and velocity acting on the armature, induced voltage, power loss and B field plots over rail and armature are greatly affected by its current distribution. These parameters depend on rail and armature dimension, shape, and the magnitude of current as well as the shape of current supplied to rails. In this paper the different models of railgun is compared and analysed by the use of literature survey and also discussed about which model will be more efficient of electromagnetic launch. It is seen that analytic method shows the relationship between inductance gradient and various parameters, but it is only suited for regular rail. But for measuring inductance gradient by experimental method is direct and efficient and can verify the result obtained by analytic method and numerical method.

II. LITERATURE SURVEY

Glen C. Long et al., (1989) have analysed the limits to the velocity of a solid armature in a railgun based on the temperature and the internal force which suppress to yield the strength of the material. They had done two dimensional finite element analyse over several rail and armature designs. Geometry of the rails, material properties versus temperature, current input profile versus time, mass of the armature, coefficient of friction data versus speed over the rail/armature interface, and the iteration time step are the inputs parameters which were taken into consideration during finite element analysis. They compared the result with different designs of rail and armature and

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016

concluded that copper rail and molybdenum chevron armature are the good design combination for the solid armature railgun.

Asghar Keshtkar et al., (2008) had done some calculation over the inductance gradient of the railgun by Intelligent Estimation Method. Many researchers used analytical as well as numerical methods to calculate L' . Here analytical method is suitable for solving simple problems and numerical method includes sufficient coding time and programme performance time. To overcome all these factors they introduced a new method to calculate L' by using structural design of the railgun. They derived an equation with unknown multiplication of L' formula based on the behaviour of the railgun magnetism and geometrical structure. They used Rectangular railgun to derive the formula for inductance gradient.

Y. Zhou et al., (2009) have analysed the distribution of current and inductance gradients for the different rail geometry. They investigated over the thickness, width and other rail geometric parameters, together with spacing which were affecting the current density distribution, magnetic flux density and L' . They used two dimensional Finite Element Analysis techniques to calculate all these parameters. They analysed over several rectangular shaped rails like T-Shape, Annular Shape and waxing moon shaped rails. They have done a two dimensional simulation model of railgun with the rectangular 10mm width, 40mm height and spacing of 30mm in length between the rails. They assumed the rail is to be brass and 1 MA current and 60Hz frequency. They used Eddy Current Solver to do all these analysis and they compared all the result with various geometry of rail.

Asghar Keshtkar et al., (2009) have optimized the rail dimensions to improve the current distribution and the inductance gradient over the railgun. They used analytical formulas and Lagrange's optimization equation [$P = G + \sum_{i=1}^m \lambda_i g_i$] to determine the tolerable current and optimum rail dimensions. From the result of finite element method they obtained the analytical formula which is bonded with Lagrange's equation and found the optimum dimension of rail which is compared with simulation result.

Yudong YANG et al., (2010) have modelled a three dimensional railgun and by the use of three dimensional finite element method of electromagnetic field they analysed the model parameters like inductance gradient, resistance gradient, electromagnetic force, back electromotive force, etc.,. First, they constructed a 3D railgun model by using eddy current analysis method to analyse the inductance gradient and resistance gradient. Since the actual railgun driven by the use of pulse current which cause the change in frequency. So they concentrated on below 500Hz frequency and done the time-frequency analysis. Finally they calculated the Electromagnetic parameters of the rail and armature and the simulation results were shown using Matlab Simulation Software.

Asghar Keshtkar et al., (2011) have modelled a railgun with tapering rails to increase the projectile final velocity and uniform current distribution in the railgun. To maintain constant current they used narrow rails, so that the current density will be higher in the cross section of the rail. They concluded that narrowing the length of the rail until in the output gate it amount reaches to zero by making the height of the rail constant, the gradient inductance increased with increase in the final projectile velocity.

Zhanzhong Pang et al., (2012) have designed a rail launcher and made a 2-D analysis by Peaceman-Rachford format which is employed to the finite difference method (FDM) to calculate the current and flux density distribution over the railgun. They used copper made square rail and aluminium armature. They used massive input of 180mF capacitor bank to charge up to 4 kV. When discharge is over they used flywheel diode to prevent the reverse current. They derived magnetic diffusion equations which were solved by employing Finite Difference Method. As soon as the magnetic field distribution is attained the current distribution can easily solved.

M Sajjad Bayati et al., (2012) have designed the electromagnetic launcher with the combination of IEM-TD and FEM. They found that inductance gradient in the railgun is the function rail dimensions, thickness and ohmic losses. Considering these parameters they introduces calculation algorithm using IEM-TD and modelled a railgun. By using this model and its analytical solutions they derived for Inductance Gradient. Using this L' formula they calculated the applied force to the projectile. For different size of rail, output velocities of the projectile were analysed.

Peng Zuo et al., (2013) have made a current distribution analysis over the different types of rail and armature. They changed the interior surface shape of the rail to plane-rail, convex-rail, and concave-rail from this they have made the current distribution analysis over different rail structure and compared their efficiency during rising, dropping and the flat part of the exciting current source. On comparison, they have suggested that the current distribution in convex rail is more even. The evenness can be obtained by adjusting the height of the convex part. They made the ratio of

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016

thickness and height of the convex part as 0.35. During the rising part, the current mainly flows through the convex part which will decrease the current density at the edges and there won't be any reverse current.

Tao Huang et al., (2013) have described that the armature geometry in railgun plays an vital role in the Electromagnetic launcher. During launching process the geometry of armature directly affect the process and it get easily destroyed due to enormous force. They analysed that four geometrical parameters are used to characterize the maximum deformation of the armature. (Armature's shoulder thickness, Arm thickness, Contact length and Inner curve radius). They mainly concentrated on C - Shaped Aluminium armature with four different versions. They are Armature I (standard C-shaped armature), Armature II (curved C-shaped), Armature III (C-shaped with leading legs), and Armature IV (curved with leading legs). They concluded that the armature's curved rear version can reduce the deformation of the armature. Comparison is made with different versions C-Shaped Armature.

Deng Feng et al., (2013) made a simulation on arch surface C-shaped armature for round like bore railgun. In this they acquired more uniform contact pressure and current density distribution at rail-armature interface. In the proposed railgun model they removed two piece of circular arch from the conventional C-shaped armature trailing arms. Based on this, they constructed two types of arc surfaced C-shaped armature called as concave ASCA and convex ASCA and simulated with finite element method. In addition split-leg ASCA also simulated and discussed.

Deng Feng et al., (2015) had done some simulation analyses on non-uniform contact pressure distribution on the armature and rail. They simulated a 3-D model and the contact pressure distribution had been carried out using FEM. The electromagnetic force was perpendicular to the armature trailing arm which was equivalent to the uniform load on the inner surface of the trailing arm. They have done a series of simulation for different magnitudes of magnetic pressure and with different armature structure parameters.

Liangliang Tang et al (2015) have compared the current concentration with different caliber railguns. Compared to small- and medium-caliber railgun, the current concentration on large-caliber railgun is more due to high energy density and large current. Here they compared the current distribution and concentration on LCA and SCA and shown that current density in large armature is more concentrated than small armature.

III. ARMATURE MODEL IN A RAILGUN

During the electromagnetic launch process, there is a contact surface between the trailing arm of C-shaped armature and the rail. This contact is generally provided by the deformation of the trailing arm, from which it can keep a good metal-metal contact at the armature-rail interface, while providing sufficient contact force to ensure the launch without transition. Nowadays C-shaped armatures with curved-surface trailing arms have been also used in rectangular bore railguns. The outer surface curve and the inner surface curve of the trailing arm, as shown in Fig.1, can have different curve shapes in the armature design.

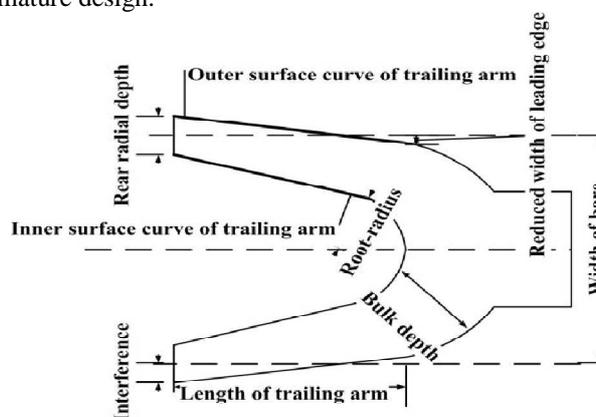


Fig.1. Schematic representation of conventional C-shaped armature.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016

A large current is used to generate magnetic field, which will accelerate the projectile at high speed in a short time. Here Fig.2, shows the current pulse for electromagnetic launch that the maximum value of current (I) is I_{peak} which lasts from t_1 to t_2 .

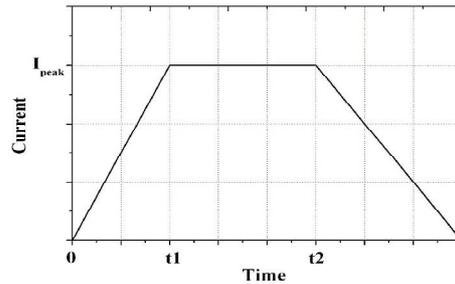


Fig.2. Current pulse for electromagnetic launch

The electromagnetic propelling force,

$$F_p = \frac{1}{2} L' I^2, (1)$$

$$F_p = B X I, (2)$$

Where, L' is the inductance gradient for the railgun bore.

Electromagnetic force perpendicular to the armature trailing arm

$$F = BI \frac{ds}{\cos \theta} = \frac{1}{2} \frac{L' I^2}{X} \frac{ds}{\cos \theta}, (3)$$

Magnetic pressure at the armature–rail interface

$$F_{EM} = F \cos \theta, (4)$$

By means of the equivalent method, the electromagnetic force perpendicular to the armature trailing arm can be equivalent to the uniform load on the inner surface of the trailing arm.

Then, the uniform load on the inner surface of the trailing arm is

$$F_{LOAD} = P_{EU} A_o = F, (5)$$

Where, P_{EU} is the equivalent uniform load, and A_o is the whole area of the inner surface of the trailing arm.

A novel modified C-shaped armatures shown in fig.3 and fig.4 called concave arc surfaced C-shaped armature (ASCA) and convex arc surfaced C-shaped armature (ASCA) for round-like bore railguns are proposed and analyzed.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016

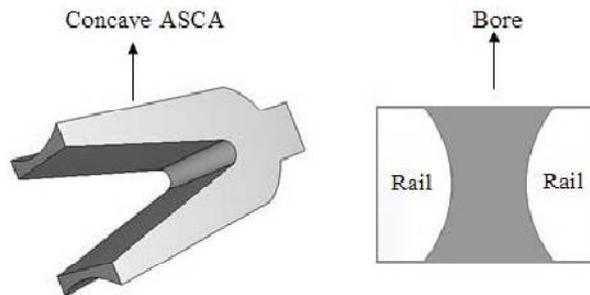


Fig.3. Concave ASCA and its corresponding round-like bore

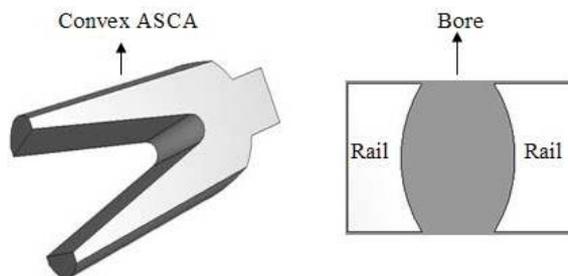


Fig.4. Convex ASCA and its corresponding round-like bore

Contact pressure and current density distributions for the proposed armature model were calculated by finite element method. By removing and adding two pieces of circular arch from the conventional C-shaped armature trailing arms, we can construct two types of ASCA for corresponding round-like bore railguns. They are called concave ASCA and convex ASCA, as illustrated in Figs. 3 and 4, respectively. The conventional C-shaped armatures were used for a 30-mm-square caliber railgun. In Fig. 3, the trailing arm length of the armature is 39 mm, the rear radial depth is 5 mm, the leading edge adduction depth is 0.5 mm, and the contact interference is 1 mm. In Fig.4, the trailing arm length of the armature is also 39 mm, the rear radial depth is 2 mm, the reduced width of the leading edge is also 0.5 mm, and the contact interference is 1 mm, too. The constructions for both the concave and convex ASCA's for round-like bore railguns were proposed and exhaustively demonstrated. In addition fig.5 depicts the split-leg ASCAs. By using finite element method, some elastic contact calculations of Al-6063 ASCAs were conducted. Furthermore, current density simulations of ASCAs were modelled according to the results of contact calculations. Simulation results showed that the performances of one split-leg concave ASCA were the best. The concave ASCA can effectively weaken the contact pressure concentrations and the current density concentrations. The concave ASCA can also obviously increase the contact area at the armature-rail interface. Moreover, split-leg can improve performances for the convex ASCA. And the electromagnetic launch experiments of concave ASCAs are in good agreement with the simulation results. Some simulation and experiments about the split width and length of the split-leg ASCA will be further studied to optimize the structure of ASCA.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016

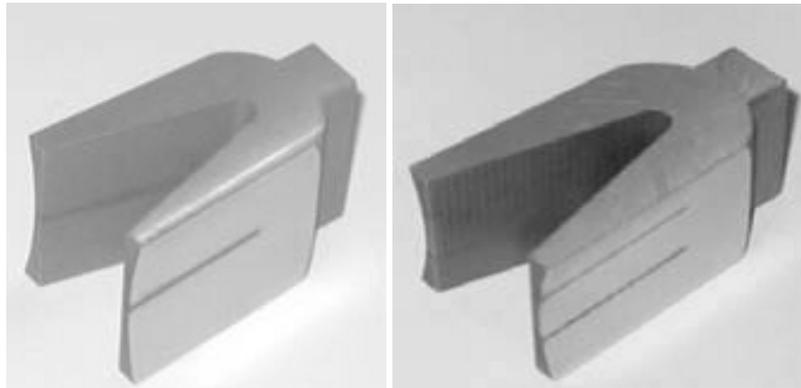


Fig.5. One split-leg and two split-leg concave ASCA

IV. CONCLUSION

In this paper, the concave and convex ASCA's for round-like bore railguns were exhaustively demonstrated. In addition, split-leg ASCA's were also presented. The current density distribution was simulated and analysed using finite element method. The concave ASCA obviously increases the contact area at the armature-rail interface. However, the convex ASCA does not perform well. Concentrations of the contact pressure and the current density are all increased in the convex ASCA. Meanwhile, the contact area is decreased. Moreover, split-leg can improve performances for the convex ASCA. Further studies has to be performed on the split width and length of the split-leg ASCA to optimize the structure of ASCA.

REFERENCES

- [1] G. C. Long, W. F. Weldon, "Limits to the velocity of solid armature in railguns", *IEEE Transactions on Magnetic*, vol. 25, no. 1, pp.347-352, 1989.
- [2] Asghar Keshtkar, Sadjad Bayati, Ahmad Keshtkar. "Derivation of a formula for Inductance Gradient using Intelligent Estimation Method", *IEEE Transactions on Magnetics*, vol.35, no. 1, pp. 978-982, 2008.
- [3] Y Zhou, P Yan, W Q Yuan, J Wang, M T Li, "Current Distribution And Inductance Gradient Calculation At Different Rail Geometric Parameters", *IEEE Pulsed power Conference*, pp. 1290-1293, 2009.
- [4] Asghar Keshtkar, Toraj Maleki, Ali kalantarnia, Ahmad Keshtkar, *IEEE Transactions on Magnetics*, vol.45, no.1, pp. 594-597, 2009.
- [5] Yudong Yang, Kui jin, "Dynamic Analysis for Inductance gradient of railgun", *Information and Computing (ICIC), Third International Conference*, vol.2, pp.46-49, 2010.
- [6] Asghar Keshtkat, Shahab Mozaffari, Ahmad Keshtkar, "Effect of Rail Tapering on the Inductance Gradient versus Armature position by 3D-FEM", *IEEE Transactions on Plasma Science*, vol.39, no.1, pp. 71-74, 2011.
- [7] Zhanzhong Pang, Housheng Wang, Hui wang, Li Zhang, "Analysis of current and magnetic field distributions in rail launcher with Peaceman-Rachford finite difference method", *IEEE transactions on Plasma Science*, vol.40, no.10, pp.2717-2722, 2012.
- [8] M Sajjad Bayati, Asghar Keshtkar, Farshad Khosravi, Ahmad Keshtkar, "Analyzing the Electromagnetic Launcher with combination both FEM-3D and IEM methods in time domain", *IEEE Electromagnetic Launch Technology, 16th International Symposium*", pp.1-7, 2012.
- [9] Peng zuo, jun li, Xiangqian Song, Jiansheng Yuan, "Characteristics of current distribution in rails and armature with different section shape rails", *IEEE Transactions on Plasma Science*, vol.41, no.5, pp.1488-1492, 2013.
- [10] Tao Huang, Jiangjun Ruan, Yujiao Zhang, Yadong zhang, Junpeng Liao, Yuanchao hu, "Effect of Geometry change on the Deformation in C-Shaped Armatures through 3-D magnetic-structural coupling FE analysis", *IEEE Transactions on Plasma Science*, vol.41, no.5, pp.1436-1441, 2013.
- [11] Deng Feng, Junjia He, Lixue chen, Shengguo Xia, Zheng Xiao, Jun Li and Ping Yan, "Study on the curve shape of C-Shaped armature's trailing arms in rectangular bore railgun", *IEEE Trans. Plasma Science*, Vol.41, No. 5, pp. 1460-1466, 2013.
- [12] Deng Feng, Junjia He, Shengguo Xia, Lixue chen, Liangliang Tang, Jun Li and Ping Yan, "Investigations of the Armature – Rail contact pressure distribution in a Railgun", *IEEE Trans. Plasma Science*, Vol.43, No. 5, pp. 1657-1662, 2015.
- [13] Liangliang Tang, Junjia He, Lixue che, Shengguo Xia, Deng Feng, Jun Li, Ping Yan, "Current concentration of Large – Caliber C-Shaped armature in square railgun", *IEEE Trans. Plasma Science*, Vol.43, No. 5, pp. 1125-1130, 2015.