Research on application of bus-bar in electromagnetic launching weapon system

R Ren¹, W Ye¹, Z Dong¹, J Liu¹, K Huang¹ and Y Zhang¹

¹ Northwest Institute of Mechanical & Electrical Engineering, Xian Yang, Shaanxi, 712099, China

E-mail: ssa2013@126.com

Abstract. At present, the electromagnetic launching weapon system is steadily turning to its engineering applications. Among them, the bus-bar, as a necessary link of the pulse power supply to transmit energy to the electromagnetic launcher, has high engineering requirements on its high power, miniaturization and lightweight. This paper analyzes and studies the high power, miniaturization, lightweight and other aspects of the bus-bar, puts forward a disk bus-bar, and compares it with other bus-bar, finally determines that the bus bar has the advantage of high power and miniaturization, and realizes the vehicle-mounted application.

1. Introduction

The bus-bar as the intermediate link of energy transmission from the pulse power source to the electromagnetic launcher, it can gather the sequential discharge waveforms from dozens of pulse capacitor modules of the pulse power supply, combined into beneficial to electromagnetic pulse current waveform of the launch, steady output to electromagnetic launcher, realization of electromagnetic launch system fast, reliable and efficient. The existing MA level bus-bar is mainly in the form of rectangular, serrated or disc-type structure, connecting dozens of input and output cables, which takes up much space and weighs a lot, making it difficult to use in vehicle.

In order to realize the on-board application of MA level bus-bar, a new type of disk-type MA level bus-bar structure is proposed in this paper. Compared with the common MA level bus-bar structure with the same performance, strong ability to pass through MA level current, improved average current performance, reduced volume by 16%, and reduced mass by 30%. The miniaturization and lightweight of the bus-bar are realized, providing a new solution for the on-board application of the MA level bus-bar.

2. Bus-bar technology

Bus-bar technology is a technology that studies how to gather dozens or even hundreds of monopulse
current waveforms from the PFN on the bus-bar through sequential discharge to combine them into pulse current waveforms conducive to electromagnetic emission, and then output them to the electromagnetic launcher smoothly and reliably [1-3]. The research focuses on such issues as the ability to pass large current, the performance of uniform current, miniaturization and lightweight.

The ability to pass current means bus-bar to pass through a large current smoothly. In order to ensure the high efficiency of electromagnetic emission, dozens of modules in the pulse power supply need to discharge in a certain sequence. Multiple monopulse currents converge to the bus-bar, forming a trapezoidal current waveform output to the transmitter. The high peak pulse current, the duration of a few milliseconds, due to the large current as MA level, electromagnetic force, huge bus-bar by instantaneous impact is big, if not effectively to offset the impact of bus-bar deformation, beating and poor contact on the electric circuit, under high voltage and high current conditions, such undesirable phenomena as ignition, arc drawing and even electric explosion occur, cannot smoothly through the large current [4].

It refers to the uniform current ability of the bus-bar with MA level current onto dozens of output cables. Dozens of output cables are connected in parallel between the confluent device and the electromagnetic launch device. Due to the limited flow capacity of each cable, and to make full use of each cable, the current must be evenly distributed to each output cable as far as possible through the confluent device. If the distribution is not uniform, the cable through the current size is different, temperature rise is different, long time working cable performance difference, affect the system performance. In the extreme case, the distributed current exceeds the carrying capacity of the cable, and the cable is directly damaged, resulting in an electrical explosion, or serious damage to components in the pulse power supply.

Miniaturization and lightening of bus-bar are also the core requirements of vehicle-mounted engineering applications. At present, the main bus-bars in use are rectangular, disc-type, comb plate structure. The rectangular confluence structure is simple and easy to operate, but the number of connecting cables per unit volume is small, large and heavy. In conventional disc-type bus structure, the current distribution is uniform, but because the input and output cables are fastened outside the disc-shaped plate, the more the number of cables increases, the faster the volume and weight increase. For MA level bus-bar, the number of connecting cables is too large and the volume is too heavy. The comb plate bus-bar can increase the cable fastening point in the limited space, which is smaller and lighter than the first two structures, but still cannot meet the requirements of the bus device. So in this paper, based on the disc confluence flow performance good, increase the number of units of its space connection cable, solve the problem of large volume and weight of disc bus-bar, proposed a new convergence of disc bus-bar structure, and comb plate bus-bar structure in the ability to pass current, the performance of uniform current, volume, weight, etc were analyzed [5-6].

3. New project on disk bus-bar

3.1. The new disc bus-bar structure

According to demand, the bus-bar through 1MA current, and has 30 input cables, 12 output cables. In this context, designed a new type of disc bus, the structure is shown in figure 1.
Figure 1. The structure of a new type disc bus-bar.

As shown in the figure 1, it mainly shows the positive and negative plate structure of the core of the disc-type bus-bar. The input cable of the pulse power supply is installed on the outer edge of the positive and negative plates. The center of the plate is no longer solid, but hollow in the regular hexagon. The output cable is installed on the six sides of the hexagon. Since there are 30 input cables and 12 output cables, the outer edge adopts octagon structure. 4 input cables can be installed on each side. The inner edge is hexagonal, and two input cables can be installed on each side. This kind of structure not only has the advantage of dish-type confluence and even flow, but also improves the space utilization and reduces the weight.

3.2. Common comb plate bus-bar

Figure 2. The structure of a normal comb plate bus-bar.

In the figure 2, the same 30 input cables and 12 output cables are installed in the comb plate bus-bar structure for comparison under the same conditions. There are 3 sets of comb teeth. Cables are installed on both sides of each set. 5 input cables are installed on the longer side and 2 output cables on the shorter side. The distance between each group is large to allow space for mounting the fastening bolts. This kind of symmetrical structure, cable arrangement is compact, space utilization is high.
4. Simulation and calculation

The same boundary conditions are set for the above two confluence devices. The input current is 1MA, and 30 input cables and 12 output cables are connected. The electromagnetic force and current distribution are simulated respectively.

4.1. Electromagnetic force simulation

Firstly, electromagnetic force simulation was carried out for the new type of disc bus feeder structure. The 1MA input current was set to be evenly distributed on 30 input cables, and the center of the disc bus structure was symmetrical. Therefore, a symmetrical region could be selected for calculation and synthesis. The force results after synthesis are shown in table 1.

|                      | Fx  | Fy  | Fz    | MagF |
|----------------------|-----|-----|-------|------|
| Positive bus bar     | 654 | 80  | 29962 | 29969|
| Negative bus bar     | -598| -77 | -28945| -28951|

Table 1. New disc bus-bar devices, electromagnetic force simulation results (unit: N).

Since the positive and negative plates are arranged in parallel, the main force on the positive and negative confluence plates is the repulsion force between them in the z direction. There is a certain difference in the force between them, which is mainly related to the mutual force on the input and output cables and the confluence. It can be seen from table 1 that the repulsive force between the positive and negative confluent plates is about 30000N, that is, the 3-ton force.

Then Electromagnetic force simulation was conducted on the comb tooth current feeding structure, and the 1MA input current was set to be evenly distributed on the 30 input cables. Since the structure has long and short sides, it needs to be divided into six parts, 1-6, as shown in figure 3. The results are shown in table 2.

![Figure 3. The structure of comb plate bus-bar in six parts.](image-url)
Table 2. Simulation results of electromagnetic force in block of comb plate bus-bar (unit: N).

|     | Fx   | Fy    | Fz    | MagF |
|-----|------|-------|-------|------|
| n1  | 5522 | -4590 | 12373 | 14306|
| n2  | -1233| -10270| 15180 | 18369|
| n3  | -4113| -8622 | 13301 | 16376|
| n4  | 4917 | 1634  | 21205 | 21829|
| n5  | -56  | 804   | 25030 | 25043|
| n6  | -4892| 1700  | 21205 | 21828|
| p1  | 140  | -3989 | -12287| 12920|
| p2  | 86   | -3943 | -14891| 15404|
| p3  | -197 | -4025 | -12573| 13203|
| p4  | 3837 | 1718  | -20438| 20866|
| p5  | -9   | 1054  | -25414| 25436|
| p6  | -3820| 1745  | -20586| 21010|

As can be seen from table 2, the electromagnetic force on the output end (n4-n6, p4-p6) in the z direction is above 20000N, while the electromagnetic force on the input end (n1-n3, p1-p3) in the z direction is below 16000N, and the repulsive force on the output end is larger. The structures on either side (n4, n6, p4, p6) are repulsed laterally in the x direction. Therefore, the force of the six parts on each bus plate of the structure is not uniform. After synthesizing the data in table 2, the overall stress of the structure can be seen, as shown in table 3.

Table 3. Simulation results of electromagnetic force synthesis of comb plate bus-bar (unit: N).

|         | Fx   | Fy    | Fz    | MagF |
|---------|------|-------|-------|------|
| Positive bus bar | 37   | -7440 | -106189| 108839|
| Negative bus bar | 145  | -19344| 108294| 117751|

As can be seen from table 3, the repulsive force between the positive and negative confluent plates is 108294N, which is about 10.8 tons.

Compared with the comb plate bus-bar, the maximum repulsion between positive and negative plates is 3 tons, only 27.8% of the latter. When the structure is designed, the same fastening mode is adopted, the overall force of the disc-type structure is small, and its flow capacity can be better guaranteed. In addition, the center of the disc-type structure is symmetrical, and all parts have uniform stress, without stress concentration point. However, the six parts of the electrode plate of the comb plate bus-bar have different forces in all directions, so it is necessary to carry out targeted structural strengthening design, and its ultimate flow capacity is worse than that of the new disc-type confluence device.
4.2. The Current distribution simulation

4.2.1. The Current Distribution simulation of disc bus-bar. The center of the new disc-type bus-bar is symmetrical, and the current distribution simulation can be conducted for half of it. The excitation surface is set as the plane where the input cable is located. Since the conductor material is the same, the current distribution after is distributed according to the impedance on the transmission path. The simulation results are shown in figure 4.

![Simulation Results of Current Distribution](image)

**Figure 4.** Disc bus-bar and Simulation results of z-current distribution.

As can be seen from figure 4, due to the uniform layout of the input and output cables, the current transmission on the positive and negative bus is relatively uniform. The screw hole on the bus plate has an impact on the current transmission, but it has little impact because it avoids the main current transmission path. In the direction shown, number the six output cables clockwise from top to bottom by 1-6. The current distribution on each output cable is shown in table 4.

| output cables No. | 1     | 2     | 3     | 4     | 5     | 6     |
|-------------------|-------|-------|-------|-------|-------|-------|
| Current Distribution (kA) | 79.95 | 96.24 | 73.81 | 80.18 | 93.77 | 76.05 |
| deviations from the mean | -4.06% | 15.49% | -11.43% | -3.78% | 12.52% | -8.74% |

It can be seen from table 4 that the average current on the output cable is 83.33kA. Since there are relatively more input cables at the positions of cable No.2 and No.4, more current is allocated to these two cables. The largest one is 96.24kA of cable No.2, with the biggest deviation from the mean value, reaching 15.4%. This deviation can be further optimized by adjusting the cable installation position.
In figure 5, it can be seen that the current is not uniformly transmitted on each electrode plate, but intensively transmitted on the two adjacent sides between the positive and negative electrode plates. In these two planes, the distribution is more uniform, will not affect the confluence device uniform flow characteristics.

![Figure 5. Current distribution simulation results.](image)

The simulation results by above knowable, on the disc confluence current transmission of even overall, because the structure of the outer octagon and inner hexagonal, distance have a little difference between the input and output cable, cause the current distribution and average of 83.33 kA deviation, maximum deviation is 15.49%, the deviation by adjusting cable installation position can be further optimized.

4.2.2. The Current Distribution simulation of comb plate bus-bar: The current distribution simulation of the comb plate bus-bar under the same conditions is carried out. The model diagram is shown in figure 6.

![Figure 6. Comb plate bus-bar simulation model.](image)
In figure 6, two rows of output cables are numbered with the z-axis forward. The first row close to the input is 1-6 from left to right, and the second row is 7-12 from left to right. The current flowing on each output cable at 1MA is listed in Table 5.

Table 5. The output cables on the cable distribution (unit: kA).

| output cables No. | 1    | 2    | 3    | 4    | 5    | 6    |
|------------------|------|------|------|------|------|------|
| Current Distribution (kA) | 110.83 | 105.39 | 97.33 | 99.88 | 101.71 | 112.54 |

| output cables No. | 7    | 8    | 9    | 10   | 11   | 12   |
|------------------|------|------|------|------|------|------|
| Current Distribution (kA) | 56.42 | 47.20 | 47.24 | 46.40 | 45.04 | 58.91 |

The current distribution on the positive and negative junction plate is shown in figure 7 and figure 8.

Figure 7. Current distribution on a positive junction plate.

Figure 8. Current distribution on a negative junction plate.
It can be seen from table 5 that the output terminal is in the form of front and rear, with a difference of nearly twice of the current. On a row of six output cables close to the input cable, the current distribution is above 97kA, with the maximum of 112.54kA. In the second row of output cable, the current distribution is all below 58.9kA, the smallest is 45.04kA, and the average current performance is poor. In engineering applications, since the impedance of the output cable is much higher than that of the junction plate, the difference in actual current distribution is not so obvious when the length of the output cable is the same and the impedance is larger. However, if the length of the output cable is short and the impedance is small, the uneven flow problem caused by the confluence structure will be more prominent. The cable with too much distribution current will either have too high temperature rise and its performance will decline rapidly, or it will be directly damaged by the current exceeding its bearing capacity.

It can be seen from the current distribution in figure 7 and figure 8 that the utilization rate of the bus plate is low, the current distribution is uneven, and the burden in some regions is large. The current flows more from the side because of skin effect, and there are many red areas with high current density. There is almost no current flowing in the middle part of the confluence structure.

Compared with the new type disc bus-bar and comb plate bus-bar, the whole cable is evenly distributed and the current distributed on the output cable is evenly distributed with the new type disc bus-bar. Regardless of the influence of cable impedance, the current distribution of comb plate bus-bar is extremely uneven. The current passing through the first row of output cables is more than one times that of the second batch of output cables, while the maximum deviation of disc bus-bar is only 15.49%.

4.3. The calculation about volume and weight of bus-bar
Because the space occupied by the bus-bar is to be compared, the volume is calculated by the size of the outer contour rather than the volume of the device itself.

The outer diameter of the disc bus-bar structure is 620mm, the thickness is 205mm, and the occupied space volume is 0.0619m³.

The confluence of comb plate bus-bar is 640mm long, 560mm wide, 205mm thick, and occupies a volume of 0.0735m³.

According to the structure shown in figure 1 and figure 2, a three-dimensional model was built on NX10. The positive and negative plates were made of copper, and the insulating parts were made of epoxy laminated plate G10. After the complete confluence device model is established, the weight measured by the analysis function of NX10 is: disc bus-bar 148kg, comb plate bus-bar 210kg.

The results showed that the disc bus-bar is smaller and lighter than the comb plate bus-bar.

5. Conclusion
In this paper, a disc bus-bar is designed to meet the requirement of vehicle application of the bus-bar technology in the field of electromagnetic emission. The comparison results with disc bus-bar and comb plate bus-bar show that at the same 1MA current, the electromagnetic force is only 27.8% of that of the latter, and the average flow capacity is improved by more than 50% compared with the latter, the contour volume is reduced by 16%, and the weight is reduced by about 30%. It provides a solution for high power, miniaturization and lightweight of bus-bar.
Since the current distribution of the disc bus-bar in this scheme is even and the electromagnetic force is low, the follow-up plan further reduces the volume and weight of the bus-bar by optimizing the distance between the bus plates and the structural parts on the premise of ensuring the flow performance, so as to provide a better solution for the on-board application of the bus device.

References
[1] Y Zhang, Z Li and Y Jin 2016 Acta Armamentarii 37 5
[2] J Wang and X Zhang 2016 Journal of Naval University of Engineering 28(S1) 70-4
[3] Z Li 2018 Acta Armamentaria 39 8
[4] Y Zhao, W Yuan and R Xu 2018 High Power Laser and Particle Beams 30(05) 134-8
[5] R Ren, Z Dong and W Guo 2014 High Voltage Engineering 40(4) 1148-52
[6] Z Dong, K Huang and Y Chen 2016 High Voltage Engineering 42(9) 2816-21