The summary of missile electromagnetic catapult technology

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Abstract. Missile electromagnetic catapult technology is the important application of electromagnetic launch technology in the field of missile and a great breakthrough compared with tradition catapult technology. Inducing main components and technological advantages of missile electromagnetic catapult system. Sketching technical characteristics of three missile electromagnetic launcher including coil launch, DC motor and rail launch. Introducing current development situation of missile electromagnetic catapult technology in home and abroad. Carding key technologies which restrict practicability of missile electromagnetic catapult technology. Expecting prospects for development of missile electromagnetic catapult technology.

1. Introduction
Electromagnetic launch technology accelerate substance with armature by electromagnetic force, so as to achieve the effect of launching. Electromagnetic catapult technology is an important application of electromagnetic launch technology in high mass and low speed objects, and a scientific breakthrough in tradition launch technology. Electromagnetic launch can catapult many things effectively which small to a few thousand grams models, large to missiles or carrier based aircraft. It has widely used in military, civil and industrial fields [1].

For missile electromagnetic catapult, the general requirements of mass are from 100kg to tens of tons, the general requirements of ejection catapult are from 10m/s to 100m/s. Missile electromagnetic catapult technology is the specific application of electromagnetic catapult technology in missile catapult field. It can not only improve the hit accuracy, combat radius and battlefield concealment of the missile, solve the sinter problem of the launch system, but also meet the mission of multiple types of missiles with one catapult, showing broad prospects [4].

2. The basic composition and working process of missile electromagnetic catapult system

2.1. Basic composition
The generalized missile electromagnetic catapult system consists of target detection, tracking and positioning system; weapon control system; missile launch control system; power system and electromagnetic launcher [6], as shown in figure 1. The missile electromagnetic launch system of narrow sense only includes three parts: missile launch control system, power supply system and electromagnetic launcher, as shown in the dotted line in figure 1.
1) Target detection, tracking and positioning system. Detect, track, locate and provide target information to weapon control system.
2) Weapon control system. Receive operational target information and send instructions to missile launch control system.
3) Missile launch control system. Control the discharge of pulse power system to make the missile reach the given catapult speed.
4) Power system. Providing pulse current waveform for missile electromagnetic launcher.
5) Electromagnetic launcher. Convert the input electric energy into kinetic energy, push the projectile to move in a straight line, and make the missile reach the required catapult speed within a certain distance.

Figure 1. Composition diagram of missile electromagnetic catapult system

2.2. Working process
Generally, the working process of missile electromagnetic catapult system is: according to the relevant information and parameters input by the target detection, tracking and positioning system, the weapon control system sends the corresponding control signals to the missile launch control system after information processing. The missile launch control system settles and forms the control signals according to the missile launch speed and travel requirements of the weapon control system, and the control power system sends the pulse power waveform according to the requirements, the electromagnetic catapult transforms electric energy into kinetic energy, drives the projectile to move in a straight line, and makes the missile reach the required ejection speed within a certain distance.

3. The advantages of missile electromagnetic catapult technology
Compared with the thrust launch by the recoil thrust or auxiliary thermal ejection mechanism of the missile's own engine combustion, missile electromagnetic catapult technology has the following advantages [6]:
1) The control accuracy of electromagnetic launch thrust is high, which can improve the hit accuracy of missile.
   Compared with the cold launch mode, it overcomes the uncontrollable ballistic overload. The electromagnetic force of the missile in the electromagnetic catapult can be adjusted by the pulse current waveform to make the missile evenly stressed in the whole ejection process and the missile body has good stability, so as to improve the hit accuracy of the missile.
2) The electromagnetic catapult can adjust the magnitude of electromagnetic thrust, and can launch many kinds of missiles.

Compared with the cold launch mode, the missile electromagnetic ejection system can quickly adjust the size of electromagnetic force according to the nature and range of the target missile, so as to meet the requirements of ejection quality and initial velocity launch energy of multiple target missiles. It is a multi-purpose missile ejection system to launch multiple types of missiles.

3) Improving missile operational radius.

Without increasing the weight of the missile itself, the operational radius of the missile can be improved. With the continuous development of high-power pulse power technology, the improvement will play an increasingly important role in the electromagnetic launch system of the missile.

4) Solving the sinter problem of launch system thoroughly.

After adopting the electromagnetic launch technology, the initial kinetic energy of the missile is given by the electromagnetic thrust of the launch system, so that the missile leaves the launch system for a certain distance, and the engine ignites and flies autonomously. Because there is no burning and sticking problem of high temperature gas and super high speed melting residue in the firing system of high energy composite propellant, the ablation problem of the engine to the firing system is completely solved, so as to avoid the equipment performance degradation caused by the ablation problem and significantly shorten the service life.

5) Improving the concealment and security of the battlefield.

In the process of missile electromagnetic catapult, there is no fire, smoke and shock wave, so it is relatively hidden in the operation and not easy to be found by the enemy, which is conducive to the safety of the launch platform and meets the requirements of the concealed operation in the modern battlefield.

4. Classification of missile electromagnetic catapult technology

At present, there are three kinds of missile electromagnetic catapult technologies: electromagnetic coil missile catapult, linear motor missile electromagnetic catapult and electromagnetic orbit missile catapult, a brief account is as follows.

4.1. Electromagnetic coil missile catapult technology

The electromagnetic coil launching technology has the characteristics of relatively small driving current, large projectile thrust, no mechanical contact between the launching component and the driving coil, avoiding friction and guide rail ablation, high utilization efficiency and long service life [2]. It can also improve the kinetic energy of projectile by increasing the number of driving coils, which is very suitable for launching high-quality low-speed load. It is the current mainstream missile electromagnetic catapult technology.

In view of the heavy mass of missile, the structure of multistage coil gun is usually adopted in the ejection system of electromagnetic coil missile, as shown in figure 2. The multistage induction coil gun uses multiple pulse power sources to discharge the coils synchronously and the flux alternating induction in the armature at the bottom of the missile to accelerate the missile movement. When the missile is installed in the initial position, the first stage drive coil is discharged, its magnetic field changes in the armature, the armature induction generates current, the magnetic field interacts with the induced current, and pushes the armature to drive the missile forward; then through the 2nd, 3rd, 4th...... the last stage coil accelerates the missile step by step until it reaches the rated muzzle velocity.
4.2. Linear motor missile electromagnetic catapult technology

Linear motor missile catapult technology is another commonly used missile electromagnetic catapult technology, which has the characteristics of high efficiency and high thrust volume ratio. Linear motor missile electromagnetic catapult system mainly consists of three parts: energy storage system, control system and linear motor.

Linear motor is the core of electromagnetic ejection system, which includes permanent magnet linear motor (PMLM), linear induction motor (LIM) and linear reluctance motor (LRM). For the linear induction motor with injection current excitation, the winding can load a large current, so the output thrust of LIM is usually larger than that of the permanent magnet linear motor, which is very suitable for the electromagnetic launch of large load missile. The permanent magnet linear motor with higher energy conversion efficiency is more suitable for electromagnetic ejection of missiles with smaller mass. The moving magnet linear motor is the most suitable for electromagnetic ejection applications with high thrust and high speed.

4.3. Electromagnetic orbit missile catapult technology

The Electromagnetic Orbit Missile Catapult Technology is the missile electromagnetic ejection technology which uses the electromagnetic orbit gun as the catapult body. According to the action law of the rail gun, the force on the armature is proportional to the square of the current, and proportional to the inductance gradient of the system. At the same time, considering the actual demand of the Missile Ejection quality and low initial speed, the electromagnetic rail gun as an electromagnetic catapult, needs to improve the inductance gradient as much as possible and reduce the peak value of the pulse current. This makes the electromagnetic rail gun for catapult only use layered electromagnetic rail gun.

By dividing the rail into N layers and connecting them in series, the inductance gradient of the layered rail gun is $N^2$ times of that of the single-layer rail, so the smaller current peak ($1/N$ of the same volume rail) can produce the same thrust to drive the armature. The $N=3$ layered rail gun is shown in

![Diagram of layered electromagnetic rail gun]
figure 3. However, due to the voltage difference between the layered rails, the rails must be insulated, and the armature design is a technical difficulty.

![Diagram of layered rail gun](image)

**Figure 3.** The diagrammatic sketch of $N=3$ layered rail gun.

5. **Research status of missile electromagnetic catapult technology**

5.1. *Research status of electromagnetic coil missile catapult technology*

Through cooperative research and development agreement, Sandia National Laboratories and Lockheed Martin Space Systems Company have developed an electromagnetic coil missile catapult system (EMML) based on the existing BGM-109 cruise missile and its launch [5], as shown in figure 4. EMML is a high efficiency electromagnetic booster system based on the synchronous induction coil launching technology. It uses the electromagnetic coil launching technology to boost the missile combined with the armature to a certain height, and then the missile and the armature are separated and launched to complete the launch. At the end of 2004, Sandia National Laboratories and Lockheed Martin Space Systems Company jointly carried out the launch demonstration experiment of electromagnetic missile catapult. They accelerated the launch load of 650kg to 12m/s through the five-stage synchronous induction coil gun, and the system efficiency reached 17.4%, which laid the foundation for the later engineering application.

![Electromagnetic missile booster](image)

**Figure 4.** Electromagnetic missile booster.
Experiments show that EMML can boost low-speed and high-quality missiles. After years of research, EMML can also eliminate the risk of propulsion, improve deck safety, improve speed and range, provide high-precision and controllable launch speed, and reduce the launch signal.

5.2. Research status of Linear motor missile electromagnetic catapult technology
At present, there are few researches on linear motor missile catapult technology, but considering that missile catapult, UAV and aircraft ejection have basically the same requirements on catapult technology, and have little relationship with specific catapult carrier, the development of linear motor Missile catapult Technology represents the development of linear motor missile electromagnetic catapult technology [3].

In the world, the United States is mainly engaged in the research of carrier based aircraft electromagnetic catapult technology, while the United Kingdom is engaged in the research of UAV electromagnetic catapult technology.

5.2.1 Research on the catapult technology of electromagnetic aircraft in American. The catapult system of electromagnetic aircraft (EMALS) in American mainly consists of three parts: linear motor, disc alternator and high power frequency charger, the composition is shown in figure 5. Its electromagnetic catapults all adopt four linear motors with single power over 30MW, and the total power can reach 100MW [2].

The U.S. military spent 28 years and 3.2 billion dollars. It was not until December 18, 2010 that General Atomics successfully launched an F/A-18 fighter with an electromagnetic ejection device, that it marked the success of the EMALS system test. The success of EMALS test indicates that linear motor electromagnetic ejection system tends to be practical, which is of great significance to the development and application of missile electromagnetic ejection technology.

![Figure 5. Composition of the catapult system of the electromagnetic aircraft in U.S.](image-url)
5.2.2 Research on electromagnetic catapult technology of UAV in British. The UK Ministry of Defense signed a contract with Ford Electric Co., Ltd. for electromagnetic force integration technology (EMKIT) research for UAV electromagnetic ejection technology research. EMKIT system consists of two energy storage systems, two frequency charger, a set of advanced linear induction motor (ALIM) with bilateral configuration, plus a vertical moving disk, motion control system, mechanical launching track and braking system, the system composition is shown in figure 6.

The advanced linear induction motor used in the ejection body of EMKIT system is composed of a series of separate identical stator units, which is convenient for installation and production; and each stator unit is equipped with a thyristor switch. When the motor passes through a certain sub unit, the thyristor switch is closed, which pushes the motor forward and reduces the inverter current; the advanced linear induction motor has a small slip rate, it has the advantages of low loss and high power factor. It can control speed without sensor, which overcomes the disadvantages of ordinary linear induction motor, such as high slip, low power factor and high loss.

EMKIT system can adapt to the change of mass and load of UAV, launch UAV with different mass. At present, more than 2500 tests have been carried out, which can accelerate the weight of 524kg to 51m/s in 15m orbit, the maximum peak power is 3MW, and the maximum acceleration is 8.7g.

![Figure 6. Composition diagram of EMKIT system.](image)

5.3. Research status of electromagnetic orbit missile catapult technology

Few published layered orbit electromagnetic launch technologies, only Zhengzhou Institute of Mechanical and Electrical Engineering has published that its use of 30 layer layered rail gun has an inductance gradient of 592 ηH/m [9], which can accelerate 5-300kg armature to 35m/s. Seeing table 1 for specific performance indexes. However, it can be seen from table 1 that the layered orbit gun as the catapult body can also be used for missile catapult.

| Table 1. Performance parameter index of layered rail gun. |
|---------------------------------------------------------|
| Device1 | Device2 |
| Caliber/mm | 140*120 | 400*370 |
| Track length/m | 4.5 | 7.0 |
| Quality/kg | 5 | 300 |
| Speed/ m*s\(^{-1}\) | 35 | 35 |
| Peak current/A | 2500 | 9000 |
6. Key technology of missile electromagnetic catapult

Although missile electromagnetic catapult technology has many advantages and wide application prospect, as a new missile catapult technology, the following key technologies need to be solved in the real application [7, 8].

6.1. Miniaturization, lightweight and low cost pulse power supply technology

Ordinary power supply cannot meet the needs of 100 megawatt pulse power of missile electromagnetic launch system, only pulse power supply can be used. At present, the common capacitance energy storage pulse power supply has the problems of low energy storage density and high cost; the inductive energy storage pulse power supply has the problems of lack of high-power batteries and small high current switches for charging, which makes it difficult to be practical; the pulse power supply of the pulse alternator has the problems of complex structure and high safety requirements. Therefore, miniaturization, lightweight, low-cost and high-power pulse power supply technology is one of the key technologies to realize the practical application of missile electromagnetic launch technology.

6.2. Design and manufacturing technology of high efficiency and stable electromagnetic catapult

Electromagnetic catapult is the core component of missile electromagnetic launch system. Its performance determines the performance of missile electromagnetic launch system to a large extent. A large amount of joule heat and friction heat will be accumulated in the process of electromagnetic launch of missile with strong magnetic field, high current and heavy load, which will cause the temperature rise of the catapult and armature to be too large. Meanwhile, the key parts of the electromagnetic catapult will also be subjected to strong pulse electromagnetic force, which may damage the launch system and affect the launch efficiency, structural strength and stability of the catapult. Therefore, the design and manufacture technology of high efficiency and high stability missile electromagnetic catapult is one of the key technologies in the practical application of missile electromagnetic catapult technology.

6.3. Precise control technology of missile overload

There is a certain range of launch overload that the missile can adapt to, and there is a upper limit. Exceeding the upper limit may cause damage to the missile and affect its combat performance. Therefore, the overload range of high-quality missile is required to be strictly limited. For the electromagnetic ejection system, it can achieve a variety of overload requirements in the catapult process, but to maximize the operational performance of the missile through electromagnetic catapult, it is bound to overload the missile electromagnetic catapult system very close to its upper limit. Therefore, the precise control technology of missile overload is one of the key technologies to give full play to the performance of missile electromagnetic catapult system.

6.4. Suppression technology of strong electromagnetic interference in the process of electromagnetic catapult

The strong magnetic field produced in the process of missile electromagnetic launch will have a certain impact on the control system, launch control system and electronic components of the missile. It will cause serious damage to the components and even the system, and affect the use of the missile in combat. At the same time, the strong electromagnetic signal may also expose the launch position and bring security risks. Therefore, the suppression technology of strong electromagnetic interference is one of the key technologies in the practical application of missile electromagnetic launch technology. It is considered that the electromagnetic shielding and protection measures can be taken to reduce the interference intensity and improve the anti-electromagnetic interference ability of the missile itself.
6.5. Test and verification technology of missile electromagnetic catapult system

With the development of missile electromagnetic launch technology to a certain stage, the test and verification has become a very important key technology in the development of missile electromagnetic launch system. Only sufficient test and verification can reflect whether the overall and subsystem functions, technical approaches and implementation plans of the missile electromagnetic launch system are reasonable; whether the pulse power subsystem works reliably, whether the electromagnetic catapult can work efficiently and stably; whether the overload control of the missile is accurate and effective, whether the electromagnetic interference suppression measures are effective and whether they are compatible with the combat platform, then find the countermeasures, push the missile electromagnetic launch technology to become practical.

7. Concluding remarks

Although there are still a series of technical problems to be solved in the electromagnetic missile launching system, such as the volume, weight and cost of the pulse power supply, the low efficiency and stability of the catapult, the strong electromagnetic interference in the launching process, and the insufficient test, etc., the control accuracy of the electromagnetic catapult technology is high, which can improve the hitting accuracy of the missile, launch multiple types of missiles, improve the operational radius and penetration of the missile. To solve the sinter problem of the launch system and improve the concealment of the battlefield, the electromagnetic missile launch technology has a bright future in the military field. With the further development of related technologies, electromagnetic ejection technology will be applied to missile ejection, and extended to UAV, carrier based aircraft, torpedo and other high-quality, low-speed load catapult fields.

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