

# The Concept of Liquid Metal Armature

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Abstract—Now, we are demonstrating and researching the concept of liquid metal armature for rail gun. The paper introduced the concept, the principles, the characteristics, feasible realization methods of liquid metal armature and etc.

## I. INTRODUCTION

The armature is one of the key components of electromagnetic gun. The function of the armature is the conversion of electromagnetic energy into kinetic energy of the projectile, and the performance of electromagnetic gun depends on the design of the armature to a great extent<sup>[1]</sup>.

At present, the armatures used mostly are solid armature, plasma armature and hybrid armature. They have both advantages and disadvantages. Their performances are contrasted in Table.1. To sum up, there are the following four aspects needing consideration in the design of armature. The first is whether it can obtain anticipated velocity; the second is whether it has high efficiency; the third is whether it can reduce the ablation to the gun chamber to minimum; the fourth is whether it can suit well with the launch system and with the projectile.

The authors of the paper firstly put forward the concept of liquid metal armature according to the above-mentioned design requirements, and analyzed the problem of its structure, advantages, material choice and etc. in detail.

## II. THE ADVANTAGES OF LIQUID METAL ARMATURE

Liquid metal armature adopts liquid metal as the material of rail gun armature. Before launching, heat the armature material to over its melting point and make it be liquid. The projectile, which is enclosed in insulation material, is placed between the rails of rail gun. After the charging of high power pulsed capacitor, liquid metal is sprayed on the bottom of the projectile through the nozzle. At the moment, this switches on both rails, and stored energy capacitors discharge through both two rails and liquid metal armature. This produces electromagnetic force driving the projectile forward.

Compared with solid armature, liquid metal armature can easily realize electric contact between the armature and rails well and can effectively reduce the friction

between the armature and rails because the contact is between the solid and the liquid. This can avoid the phenomena of bad contact, the ablation and plane-pin of rails, and improve the launch efficiency.

Table I. The performance contrast of the armatures

Type of armature	Advantages	Disadvantages
Solid armature	Small resistance, low voltage drop of armature; Simple design; No ablation resistance.	Contact between solid and solid, velocity limitation to 3km/s; Efficiency decreases because of parasitical mass; Its structure may limit the acceleration.
Plasma armature	Small parasitical masses; Electric contact well in high velocity; No consideration of the reliability of the armature's structure.	Big resistance, high voltage drop of armature; Easily produce ablation resistance; The un-stability of plasma armature may affect its performance; Easily produce the secondary arc and leakage.
Hybrid armature	Extend the working range of solid armature to 10 km/s.	No clear the characteristics of plasma interface and its effectiveness for performance; Big parasitical masses; Its structure may limit the acceleration.

When the projectile flies away from the muzzle, liquid metal armature scatters under the action of air drag, which induces the parasitical masses.

Compared with plasma armature, liquid metal armature has better performance, such as better conductive performance, small voltage drop of the armature, and without the secondary arc and so on.

What's important is that liquid metal armature can switch on discharge circuit automatically so that high-power switch can be saved. The method can make the system of electromagnetic gun simpler, and can obtain the maximum launch efficiency by accurately controlling the mass of liquid metal armature according to the different discharge currents.

### III. THE STRUCTURE OF RAIL GUN USING LIQUID METAL ARMATURE

Fig.1 illustrates the structure of rail gun using liquid metal armature. Charge circuit is composed of charge power supply G, switch K and high-power pulsed capacitor bank. The rail gun using liquid metal armature constitutes charge circuit, rails, projectile P and the spray device

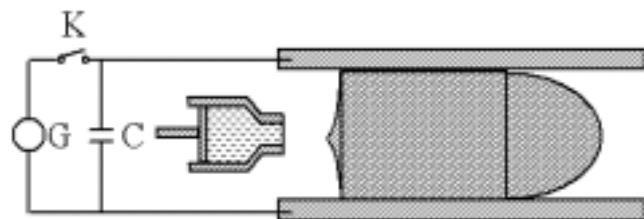


Fig. 1. The structure of liquid metal armature

of liquid metal armature. The spray device is made up of the plenum, spray nozzle and piston. The liquid metal armature material is filled in the plenum, and is heated into liquid by heater. The bottom of the projectile is processed in cone form so that liquid metal armature can shunt easily here and easily form a layer of liquid metal armature.

#### IV. MATERIAL CHOICE OF LIQUID METAL ARMATURE

Single metal is the simplest liquid metal armature. From the angle of convenience, the Hg metal that is liquid in house temperature is the most suitable for liquid metal armature, but Hg metal is intensely poisonous and cannot be utilized by arms.

From the angle of engineering application, the metal whose melting point is lower than 500 °C suits for liquid metal armature. Table.2 shows the physic characteristics and electrical characteristics of some common metals.

Table. The comparison of electrical characteristics of some single metals

	Resistivity (20 °C) $\mu\Omega\cdot\text{cm}$	High temp resistivity $\mu\Omega\cdot\text{cm}/$	Density(20 °C) $\text{g}/\text{cm}^3$	Melting point ( °C)	Boiling point( °C)
Li		24.0/180		180	1329
Na		9.57/100		97.8	882
K		12.9/65		63.5	779
Ga		25.8/30		29.8	2250
Rb		22.0/60		39	680
Cd	7.40	33.7/300	8.64	320.9	765
In		33.1		157	2075
Sn	12.8	48.0/250	7.30	231.9	2450
Cs		36.0/30		29.8	700
Pb	20.6	95/350	11.34	327.4	1740
Zn	5.92	37.4/430	7.14	419.5	907
Al	2.69	24.2/700	2.70	660.1	2480
Ag	1.60	17.2/1000	10.5	960.8	2210
Au		31.2/1100		1063	2950

From the angle of price, we should exclude the expensive metals, such as Ga, Rb, Cd, In, Cs. Among these metal materials whose melting point lower than 500 °C, Sn and Zn are better material. When melting point higher than 500 °C, Al is the best alternative.

The alternative room of single metal is limited after all, but the alternative range of alloy material is much larger. Table.3 gives physical characteristics of some common alloys. We are determining their electrical characteristics through experiments. Therefore, we cannot present their electrical parameters perfectly here<sup>[2]</sup>.

From the above parameters, it is clear that the difference of different metal materials in both electrical characteristics and physical characteristics is very distinct.

Therefore, when choosing the material for liquid metal armature, we mainly take into account the following:

Table. The comparison of physical characteristics of metal alloy materials

Chemical component %						Melting point( )
Bi	Pb	Sn	Cd	Hg	Sb	
20	20			60		20
50	27	13	10			72
52	40		8			92
53	32	15				96
54	26		20			103
29	43	28				132
	32	50	18			160
15	41	44				164
33		67				166
20		80				200
	90	18			2	277
	68	30			2	256
	58	40			2	235
	49.2	50			0.8	210
	39.5	60			0.8	185
	9.85	90			0.15	222

#### <1> High temperature resistivity

Firstly, take into account the resistivity of liquid metal armature because it works in liquid state. The lower its resistivity, the smaller the voltage drop of armature is.

#### <2> Melting point

The reason of taking into account melting point is the requirement that the heated temperature of metal material should be up to its melting point before it is sprayed into the electromagnetic gun. The lower the melting point of metal material is, the shorter of heated time is, and the simpler the heater device is and the smaller the affection of spray device for liquid metal armature is.

#### <3> Density

The smaller the density of liquid metal armature is, the smaller the parasitical masses are, and the higher the efficiency of electromagnetic gun is.

#### <4> the compatibility with rails

The better the compatibility between liquid metal material and rails is, the better the contact between liquid-solid is, and the lower the voltage drop of armature is. In addition, some armature material is attached to the rails during the launch, and these can protect the rails from ablation and can make contact between them easier. The

compatibility between liquid metal material and rail material can only be determined by the results of experiments.

## V. CONCLUSIONS

Liquid metal armature is a promising armature according to our preliminary researches and experiments. At least it no longer needs high-power switch in experiment, and the effective mass of projectile is higher. But it faces many challenges because it involves in many disciplines, such as electromagnetics, material, hydrodynamics and magnetic fluid hydrodynamics. The key technologies are the choice of armature material, the control of spray press and spray mass of liquid metal armature. The forming of jet flow and the cumulation of armature material on the bottom of projectile need further study and experiments.

### *References*

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