Letter

Two stage travelling charge accelerator for high velocity

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Abstract

This short note proposes a concept of two stage accelerator which can attain more than 4 km/s with fairly high acceleration level under the condition of tolerable heat damage of accelerator tube. Here the electro-magnetically pre-accelerated projectile with a charge by a composite armature is further accelerated by the pressure and the jet thrust of the ignited charge. The ignition of travelling charge is performed by the ohmical explosion of a metallic filament in the composite armature at a pre-determined moment. A possiblity of this ignition is discussed briefly with a result from a basic experiment.

1. Introduction

Two decade is already passed since Rashleigh and Marshall have attained velocities of 5.9 km/s by the ANU rail gun[1]. After them many reserchers have tried to attain higher velocity with rail guns. The maximum velocity attained was, at best, around 8 km/s with a projectile having the mass of 1 gram. In the case of using the heavier projectile of order 1 kg or more, the original velocity was never again realized at present.

The rail gun consists of two parallel rails connected to a source of direct current, and the projectile consisting of a short circuit slide is propelled between the rails by the Lorentz force, F, usually expressed as $F=L'I^2/2$, where L' is the inductance per unit length of the rails and I is the current through the slide in amperes. This short circuit slide is called armature since a rail gun is actually a linear dc motor consisting of a pair of rigid, field-producing conductors and a movable conducting armature. And though the material of the armature is made of a metal in the case of low velocity rail gun, dense plasma is used for the high velocity case like ANU rail gun[1].

One serious problem of the rail gun is a single shot operation since the rails are hard to withstand the thermal load on them especially in the case of high velocity operation. The gun is dismantled at best after several shots. Fortunately, however, in the case of low velocity operation of 2 km/s or less, the rail damage by the electro-thermal load is tolerably low so that the rep-rate operation is possible. This gives us a hope of obtaining more than 3 km/s repetitively with tolerably low damage of accelerator's rail, if the armature of rail gun is divisible into two parts at a desirable moment immediately after attaining 2 km/s. For example, if an armature with velocity 2 km/s is divided by an explosive into two parts with equal weight in a barrel, the front part of armature can attain 4 km/s at the time when the rear one ceases to travel along the barrel.

More realistic example is that a projectile with an in situ rocket engine or travelling charge is accelerated by a rail gun with laminated containment[2] which is stiff enough to minimize elastic displacement of the rails during operation. Since this travelling charge is contained in such a stiff tube, an operational gas pressure of the engine can be more than one order of magnitude higher than the rocket in space. This means that a high acceleration level can be tolerated. Thus, this projectile can get velocity more than 4 km/s with relatively short accelerator length. We will therefore call this launcher as "Two Stage Travelling Charge Accelerator (TSTCA)" hereafter in this study.

The purposes of this study are 1) to determine the potential of TSTCA, 2) to select a configuration of in-bore travelling charge that appears promising, and 3) to examine a basic experiment of igniting a candidate charge for TSTCA.

2. Motion of armature and projectile along accelerator tube

In order to determine the potential of TSTCA we will firstly consider the motion of an armature and a projectile with a travelling charge theoretically. The armature and the projectile are assumed to be stuck together and they are accelerated by a rail gun along a tube. And the instant the velocity of armature attains about 2 km/s, the current along the rails is supposed to be terminated for simplicity. At the same time, the travelling charge loaded on the projectile is ignited by a certain way which will be discussed later. This means that the railgun acts as a pre-accelerator of projectile with travelling charge. Then, the gas pressure, P, generated from the rear of the charge begins to separate the armature from the travelling charge with the projectile.

By these simplification a set of equations of motion for the armature and the projectile may be

$$M_1 du/dt = - PS \quad (1)$$

$$M_2 dv/dt = PS - c\,dM_2/dt \quad (2)$$

Here, S is the crosssection of the accelerator tube and u represents the velocity of the armature. The notations v corresponds to the velocity of the projectile with travelling charge and c does the exhaust velocity of gas from the charge. The suffix 2 corresponds to the projectile and that of 1 does to the armature.

For the initial condition $u = v = U$ and $M_2 = M$ at t=0, we have a solution for u and v as follows.

$$u = U - S/M_1 \int_0^t P dt \quad (3)$$

$$v = U + c \ln(M/M_2) + S \int_0^t P/M_2 dt \quad (4)$$

The behavior of the armature strongly depends on the explosive used. Usually, it is thought to be quite hard to attain more than 2 km/s for a projectile with a gun by a chemical explosive except ANA[4)] and ANSA[5)] because of large molecular number (usually 21~25) of the reaction products. This means that u>0 suggesting that the armature can pass through the accelerator tube with velocity around 1 km/s, provided that a viscous interaction between the tube and the armature were negligible small. In these exceptional cases[4,5)] the averaged molecular number can be lower than 18 which is that of water. If ANA or ANSA is employed for this travelling charge, the velocity of the armature at the muzzle can be made quite slow. That is, the armature will fall within reach. In this case R.H.S. of the 3rd term in Eq. (4) will be close to U so that the mass ratio M/M_2 need not be a large number in order for v to be more than 4 km/s. This situation facilitates the design of projectile with a travelling charge.

3. Configuration of armature and projectile with travelling charge

Because of the high acceleration levels at which TSTCA could operate, the associated structure of armature with a travelling charge and a projectile must be considered in a package. Especially, since the burning pressure of the charge in TSTCA is more than 10 times higher than the rocket engine in space, the pressure container of the charge must be the accelerator tube as shown in Fig.1.Also, the propellant has to be ignited as soon as the velocity of the armature attains 2 km/s. This function will be realized if we employ a composite armature. An example of the composite armature is described in Fig.2, where the armature is composed of three parts. The main part of this armature is the current-carring 1st layer which is slowly ablated by ohmical heating, but it survives until its speed attains 2 km/s. This can be done by selecting the thickness of the layer for the operation condition. After the 1st layer is fully ablated at about 2 km/s, the 2nd layer made of thin aluminum filament works as an exploding wire in the travelling charge since the central part of the 2nd layer is inserted into a short tunnel of the plastic block, in which AN or ANSA is contained. The instant the high current flows along this layer, it explodes. And the hot aluminum plasma is generated in AN. This hot aluminum plasma reacts upon AN to explode and a strong shock wave is generated.

Since the tunnel through the plastic block works as a guide of the shock wave toward the travelling charge,this charge is ignited by the shock wave without delay, although experimental verification is inevitably neccesary. And by the help of separable sabot of the projectile, this axisymmetric projectile together with launch tube works as an annular nozzle of the reacted gas from the charge to give a forward thrust to the sabot which draws the projectile. On the other hand, the plastic block is decelerated by the pressure from the reacting charge. The projectile can thus attain maximum speed at the muzzle. And the sabot is automatically taken off just outside of the muzzle by the aero-dynamic pressure from the atmosphere.

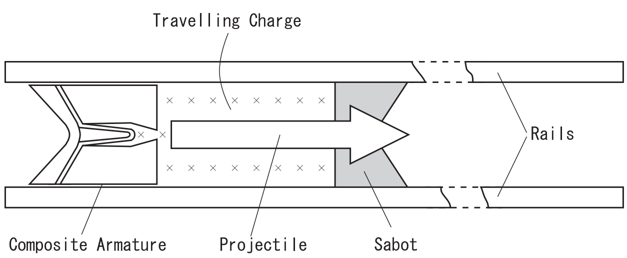

Fig.1 A structure of two stage travelling charge accel erator composed ofrail gun with composite armature and projectile.

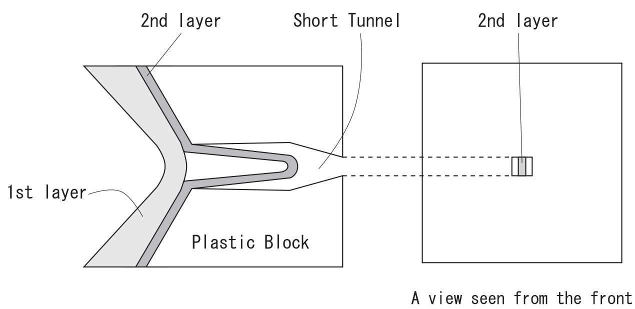

Fig.2 A detailed description of composite armature.

4. Interaction of aluminum plasma with ammonium nitrate (AN)

Ignition of AN by aluminum plasma is the most important phenomenon for TSTCA to work. In order to observe the explosion of ammonium nitrate by the aluminum plasma, a thin aluminum filament with a cross-section 1 mm^2 is inserted in AN inside a small explosion chamber made of glass fiber. The aluminum filament (AlF) is connected to a capacitor of 40000 μF through a switch. For safety reason AN used for this experiment is just 0.6 gram. For a charging voltage of the capacitor less than 150 volt, nothing happened between AN and AlF. However, once the voltage was over 160 volt, we could hear a great noise with good reproducibility. The noises became louder as the charging voltage was higher.

To understand this phenomenon qualitatively, the chemical reaction of AN with aluminum plasma can be represented by the equation:

$$2Al+3NH_4NO_3 \rightarrow Al_2O_3+3N_2+6H_2O. \qquad (5)$$

This equation suggests that large amount of hot gas is easily generated by this reaction. The big noise may be produced by the expansion of these hot gases into the atmosphere. By this experiment we confirmed that aluminum plasma interacted with AN, although the experiment with a large amount of AN was still left as a future study.

5. Discussions and conclusion

In order to simulate the reaction (5) with voluminous AN in stead of igniting small amount of AN inside a slender tunnel, a mixed Al-AN powder of about 100 gram was heated in a hole bored in a lime stone of about 2 m^3 by a thermitic reaction with aluminum and calcium peroxide, i.e.

$$2Al+CaO_2 \rightarrow Al_2O_3+CaO. \qquad (6)$$

As soon as this thermitic reaction is ignited to heat Al-AN package, the lime stone was exploded with a great noise. One of a broken lime stone of about 1 cm^3 reached roughly 100 meters away from the original position. This result suggests a strong shock wave generation by Al-AN reaction represented by Eq. (5) because of the long distance flight of the pebble. This experiment is also telling us that hot aluminum can easily reacts with AN, provided that the temperature of aluminum is over a certain critical value.

Once the shock wave generated by Al-AN reaction were able to ignite ANA or ANSA, the travelling charge made of ANA or ANSA should really work.

We may therefore conclude that TSTCA has potential to attain more than 4 km/s, provided that ANA or ANSA is employed as a travelling charge propelled through astiff rail gun.

References

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