ACCELERATION OF SOLIDS BODIES IN RAIL PLASMA ACCELERATORS[1])

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The acceleration of solid bodies in rail plasma accelerators under atmospheric pressure is discussed in the paper. The influence of the electrodynamic force and the force of pressure of the wire explosion initiation of the discharge is treated. Theoretical results were compared with experimental ones.

1. INTRODUCTION

In the past decade plasma accelerators are applied in diverse branches of plasma physics, astrophysics, physics of thin layers, plasma chemistry, etc. [1]. Especially coaxial and rail accelerators are developed in various laboratories. The coaxial accelerators are advantageous for their simple geometry without boundary effects. On the other hand, the plasma clusters in the rail accelerators can be simply influenced by an external magnetic field and the plasma diagnostics can be better realized. It has been pointed out in the last years that the plasma clusters in the rail plasma accelerators can pull various solid bodies along and accelerate them to considerable velocities. The force of acceleration arises due to the electrodynamical force F_l and the pressure force F_P caused by wire explosion initiation of the discharge, i.e.

$$\frac{d}{dt}(mv) = F_l + F_P. \qquad (1)$$

The basic principle of the acceleration of solid bodies in the rail plasma accelerator and the influence of both electrodynamical and pressure forces on the acceleration process will be discussed in the paper presented.

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2. ACCELERATING PROCESS WITHOUT PRESSURE TERM

For a simple solution of the equation of motion (1) of the accelerating process without pressure term the following assumption will be used [2]:

A) The mass dependence is supposed to be

$$m(x) = m_0 + m_1 x, \qquad (2)$$

where m_0 is a constant part of the accelerated mass (accelerated body and plasma cluster), $m_1 = S\varrho$ is the mass of the air snowploughed ahead of the solid body per unit length, S is the cross section area of the accelerator and ϱ the density of the air.

B) The electrodynamic force is given by:

$$F_l = \frac{lI^2}{2}, \qquad (3)$$

where l is the inductance of the electrodes per unit length and I is the discharge current.

C) Time dependence of the discharge current is supposed to be

$$I = A\,e^{-\delta t} \sin \omega t, \qquad (4)$$

where $A = U_0/(L_0\omega)$, $\omega^2 = \omega_0^2 - \delta^2$, $\omega_0^2 = 1/(L_0C_0)$, $\delta = (R_0 + R_p)/(2L_0)$, U_0, C_0 are the initial voltage value and the capacitance of the condenser battery, respectively, L_0, R_0 are parameters of the external circuit, R_P is the constant plasma resistance.

After the integration of the equation of motion (1) we obtain

$$(m_0 + m_1 x)v = p(t), \qquad (5)$$

where

$$p(t) = \int_0^t \frac{lI^2}{2}\,dt = \frac{lA^2}{8}\left[e^{-2\delta t}\omega_0^{-2}(\delta\cos 2\omega t - \omega\sin 2\omega t) - \frac{\delta}{\omega_0^2} + \frac{1 - e^{-2\delta t}}{\delta}\right]. \qquad (6)$$

Performing the integration of eq. (5) we get a quadratic equation for the space coordinate x, wherefrom the $x(t)$ dependence is obtained:

$$x(t) = \frac{-m_0 + \sqrt{m_0^2 + 2m_1\pi(t)}}{m_1}, \qquad (7)$$

$$v(t) = \frac{p(t)}{\sqrt{m_0^2 + 2m_1\pi(t)}}, \qquad (8)$$

Table 1

Parameters of the accelerator

Initial voltage value	U_0	1×10^4 V
Capacitance	C_0	1.77×10^{-4} F
Inductance of the outer circuit	L_0	7.8×10^{-6} H
Inductance of the electrodes per unit length	l	1×10^{-6} Hm^{-1}
Plasma and outer circuit resistance	$R_0 + R_P$	7×10^{-2} Ω
Mass of the solid body	m_0	4.95×10^{-3} kg
Mass of the snowploughed air per unit length	m_1	3.24×10^{-4} kgm^{-1}
Cross section area	S	3.24×10^{-4} m^2
Initial pressure	P_0	1×10^7 Pa
Initial volume	V_0	5.09×10^{-6} m^3
Accelerator length	b	0.5 m

where

$$\pi(t) = \int_0^t p(t)\,\mathrm{d}t = \frac{lA^2}{8}\left[\frac{1}{\omega_0^4}\left\{\omega\delta \mathrm{e}^{-2\delta t}\sin 2\omega t + \frac{\omega^2-\delta^2}{2}(\mathrm{e}^{-2\delta t}\cos 2\omega t - 1)\right\} + \right.$$
$$\left. + \frac{-1 + 2\delta t + \mathrm{e}^{-2\delta t}}{2\delta^2} - \frac{\delta t}{\omega_0^2}\right]. \qquad (9)$$

The time dependences $v(t)$ for the parameters from table 1. and various values of initial voltages are indicated in fig. 1.

3. ACCELERATING PROCESS WITH ELECTRODYNAMICAL AND PRESSURE TERMS

The wire explosion process would be a fairly long problem [3] except that the system permits some simplifications. It is supposed here that the wire explosion begins at the time of the discharge initiation. Next, the explosion is supposed to be isothermal (this assumption arises from the unknown temperature dependence in the accelerator [4]). The pressure force can then be expressed in the form

$$F_P = P(x)S = \frac{P_0 V_0}{V(x)} S = \frac{P_0 S}{1 + \dfrac{Sx}{V_0}}, \qquad (10)$$

where $V(x) = V_0 + Sx$ is the volume of the accelerator behind the accelerated body, V_0 is the initial volume and P_0 the initial pressure of the wire explosion which is about 10^7 Pa. Having assumed that both the electrodynamical and the pressure forces are present we solved the eq. (1) numerically. The resultant

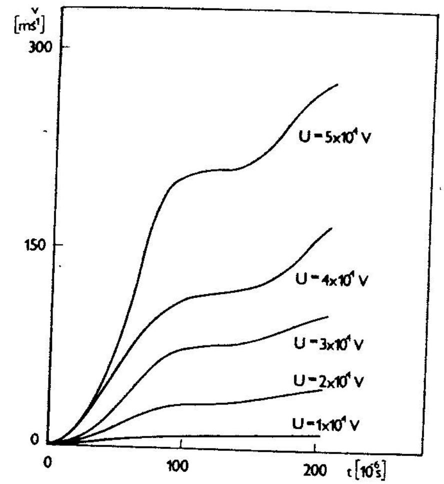

Fig. 1. The velocity dependences without the pressure term.

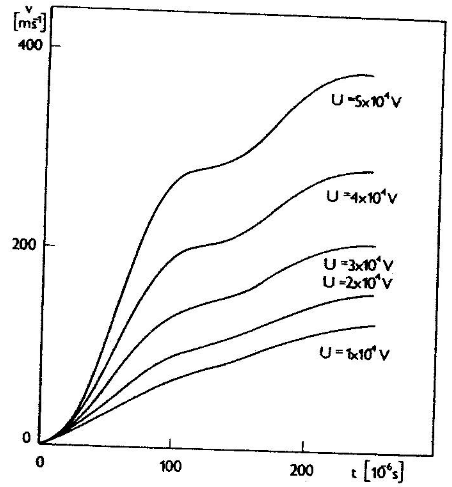

Fig. 2. The velocity dependences with the pressure term.

velocity is plotted against time for various values of the initial voltage of the condenser battery in fig. 2.

4. EXPERIMENTAL DEVICE

A basic scheme of the proposed experimental device is indicated in fig. 3. Both the external electrical circuit connected with the rail accelerator and the conception of the accelerator alone can be seen in this figure. The parameters of our experimental device are given in tab. 1.

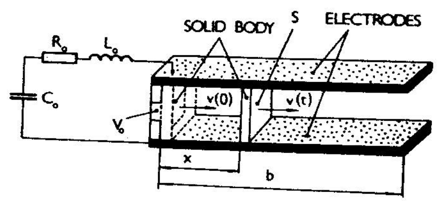

Fig. 3. The accelerator scheme.

The accelerated body was made of alcamid, which is only slightly eroded in the discharge. The mass of the body was 4.95 g and its cross section area was 18 × 18 mm. The wire for the initial explosion was a part of the accelerated body.

5. CONCLUSION

At the beginning of the discharge process the pressure force dominates (F_l: $F_P \approx 0.1$). On the other hand, it follows from the theoretical analysis that for big values of C_0, U_0 the electarodynamical force can prevail (F_l: $F_P > 1$). The share of the pressure term onto the acceleration was investigated with the open end of the accelerator ($F_P \approx 0$).

In contradistinction to the case of plasma alone, the solid body is in the accelerator for several periods of the discharge current, though the accelerating force has its maximum at the first half-period of the discharge current ($F_l \approx 500$ N).

In our device the final velocity of the solid body 206 ms^{-1} was reached. The efficiency of the process can be increased by means of an inductance serial in the outer circuit, which must be magnetically connected with the accelerator. It is supposed that with a similar experimental device for the initial parameters $U_0 = 3 \times 10^4$ V, $C_0 = 10^{-2}$ F and $m_0 = 5 \times 10^{-3}$ kg velocities about 5 kms^{-1} could be reached.

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УСКОРЕНИЕ ТВЕРДЫХ ТЕЛ В ПЛАЗМЕННЫХ УСКОРИТЕЛЯХ РЕЛЬСОТРОННОГО ТИПА

В работе обсуждается ускорение твердых тел в плазменных ускорителях рельсотронного типа при атмосферном давлении. Рассмотрено воздействие электродинамической силы и силы давления от взрыва проволоки, возбуждающей разряд. Проведено сравнение теоретических результатов с экспериментальными.