Electrical Erosion of the Magnetoplasma Accelerator Channel

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Abstract – Experimental research of accelerating channel electric erosion of a hybrid coaxial magneto plasma accelerator was carried out. The general rules of erosion distribution along the barrel were determined. It was calculated that the optimum barrel length is equal to the length of an external induction system solenoid, and up to 90% of eroded material mass located there is carried away by a hypervelocity stream. It is shown that the most important factor determining erosion is specific supplied energy (per volume unit of accelerating channel. Integral specific erosion m_e/W is directly proportional to the energy dissipated in the unit of barrel volume.

1. Introduction

The characteristic feature of electro-dynamic accelerators with plasma piston is great electric erosion of electrodes surfaces in the accelerating channel. This phenomenon has a negative character for macro bodies accelerators. It prevents getting high kinetic parameters of launch and excludes any repeated barrel use. On the other side this phenomenon is the basis of technological use of accelerators. Such accelerators refer to the type of electro erosion impulse accelerators of dense low temperature plasma. They are used for getting powder like materials and marking functional metal and composite coatings on hard surfaces [1, 2]. Getting the working material from the surface of an accelerator channel with the help of electroerosion method during the acceleration process is the distinctive feature and the advantage over other types of accelerators, for example, electro thermal ones [3]. The hybrid coaxial magneto plasma accelerator (HCMPA) considered in the present paper refers to this type [4]. High efficiency of hybrid system is provided by simultaneous use of all the main mechanisms (electro thermal, conduction and induction electrodynamics) of electromagnetic energy transformation into kinetic energy of mass movement. Under the condition of electro discharge plasma acceleration the CMPA provides getting hypervelocity impulse plasma streams with the appearance and carrying away of some tenths of grams of eroded material. Conditions in the compact plasma structure of high current discharge make it possible to realize the dynamic synthesis of super hard materials (TiC, SiC, WC). Great kinetic parameters of the HCMPA stream allow to place different metal and composite functional coatings on hard surfaces with the resultant mutual mixture boundary of materials layer. The appearance of the phenomenon of super deep penetration of stream material micro particles into hard surfaces was found [5]. As a consequence the research of electro erosion process of appearance and carrying away eroded mass from the acceleration channel is a very urgent task from the point of view of determining the most meaningful factors and character of their influence on the process as well as of searching possible opportunities of its reduction.

2. Investigation Methods

The construction and the operation principle of HCMPA under the condition of electro discharge plasma acceleration, when powered from the capacitor *C*, are shown in Fig. 1 [6]. The research is carried out with the application of electrodes-barrels *2* made of stainless steel, having the diameter of acceleration channel 16–24 mm. This material is the most appropriate for the channel of macro bodies' accelerator. The problem of locating corrosion-proof and strengthening coating of stainless steel on the surfaces of various metals (aluminium and its alloys, copper and black steel). The capacitor energy (*C*) and energy *W* supplied to the HCMPA were changed due to the variation of the charging voltage U_c up to 4.0 kV and the capacity of a capacitor bank up to $48 \cdot 10^{-3}$ F. W was changed by cutting off the tail-end of the working current impulse with the help of a shunting system of HCMPA in order to store the regime of energy supply. The working current $i(t)$ and the voltage on the HCMPA electrodes $U(t)$. Energy supplied to the accelerator was determined by power curve integration $i(t) \cdot U(t)$.The dynamic parameters of acceleration and stream in free space were determined by high speed framing photography by VFU. Integral electric erosion barrel wear was determined by weighing the barrel before and after shooting. The character of wear along the acceleration channel was studied by cutting the tried out barrel into equal parts (10–20 mm), weighing them, drawing and analysing differential wear epures.

3. The Dynamics of Acceleration and Electric Erosion Processes

The switch *K* (Fig. 1) is closed at the moment $t = 0$, and the current $i(t)$ starts flowing along the HCMPA, this is shown on the oscillograms (Fig. 2). The current getting some level at the moment t_1, the conductors *4* electro explode. This moment is considered the start of the accelerator work.

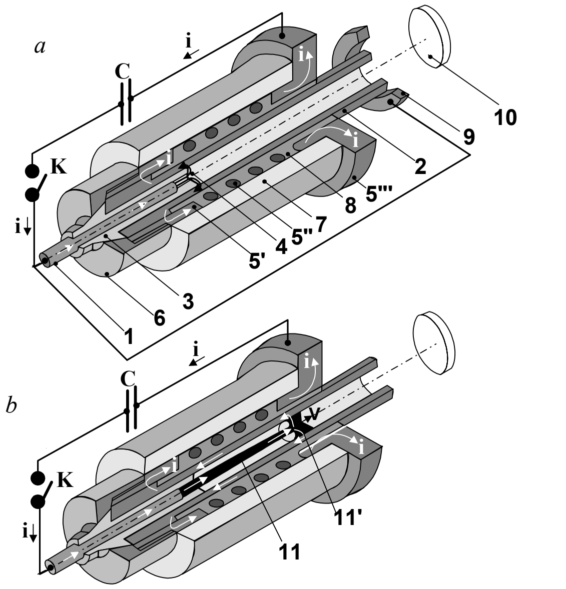

Fig. 1. The construction and operation principle of the CMPA: *a* – initial state; *b* – during the work state. *1* – the central electrode; *2* – the electrode-barrel; *3* – the central electrode insulator; *4* – the electro explosive conductors; *5′* – the contact inductor cylinder; *5′′* – the inductor solenoid; *5′′′* – the contact inductor flange; *6* – blank flange; *7* – barrel frame (glass-reinforced plastic); *8* – solenoid insulator (glass-reinforced plastic); *9* – the shunting system ring electrode; *10* – the target; *11* – plasma material; *11′* – the circular plasma link

The voltage of an electro explosive impulse decreases up to the level of the arc phase during the time of the *U* charge formation of a Z-pinch type *11* (Fig. 1) with a spout-like circular plasma link *11′* decreases up to the level of the arc phase and there happens limitation of current increase speed. The discharge plasma obtains initial acceleration due to electro explosion. Then an electro thermal mechanism is switched on. The acceleration is provided due to the expansion of gaseous products thermal decomposition of a gas generating substance (industrial petrolatum), which is used for filling the insulator channel at the top of the central accelerator electrode *1*. Compacting the plasma structure is provided by the magnetic field of its own current and axial field of external induction system solenoid. The further highly efficient acceleration of the circular plasma link happens under the influence of electro-dynamic power of Lorenz. The researches with the help of high-speed photography showed that, depending on the conditions (Table 1), the time of the plasma material passing the acceleration channel does not exceed 100 micro seconds, and the speed at its front part on the barrel section exceeds 7.0 km/s. The erosion of the acceleration channel surface appears both due to its being heated and metals melting in the moving support spot of the plasma link, and to the. plasma material radiation. The eroded surface consists of numerous longitudinal tracks, it proves that the circular plasma link is not a continuous conducting disk, but a combination of discrete radial channels.

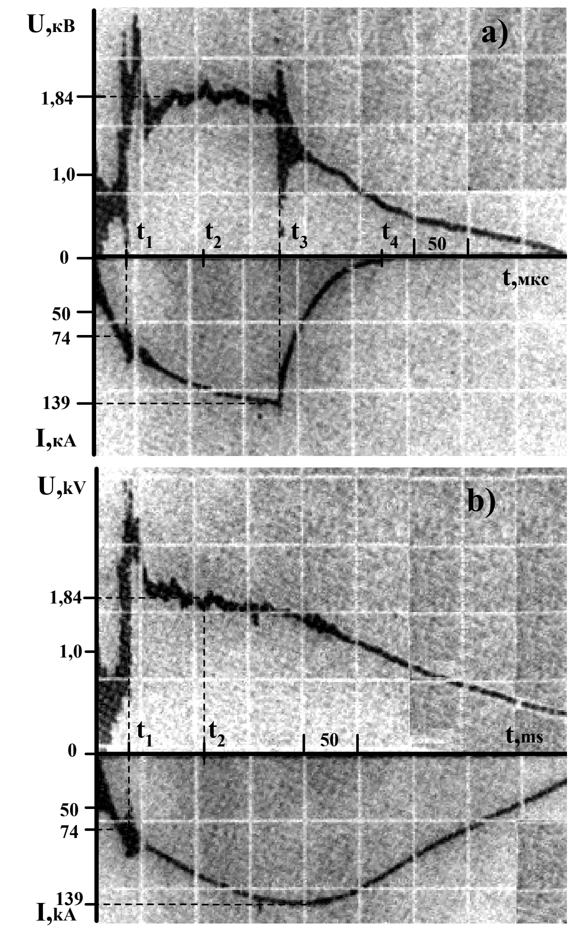

Fig. 2. The oscillograms of working current *i*(*t*) and voltage *U*(*t*) on the electrodes of the CMPA: *a* – under the shunting condition with cutting off the current tail-part impulse; *b* – under the condition of the full current impulse. t_1 – the moment of the conductors explosion, the starting moment of the accelerator work; t_2 – the moment of the front plasma stream part outlet from the barrel; t_3 – the moment of crossing the gap between the barrel section and the circular shunting system electrode; t_4 – the moment of the current flow stoppage

The data of the high speed photography support this statement. That is, the track structure of the eroded surface is observed during a single passage of the plasma material along the acceleration channel and during a full working current impulse. Oscillograms illustrate the regime when the tail-part of the current impulse is cut off, and the regime of the full impulse, other conditions being equal (experiments 1 and 2, Table 1). The epures *1* and *2* of the differential erosion of the acceleration channel (Fig. 3) correspond to these experiments.

From the data analysis of Table 1 and the epures in Fig. 3 it becomes clear that the metal mass eroded and carried away from the surface of the acceleration channel grows, when the supplied energy *W* increases. The diameter increase leads to the erosion decrease even if *W* increases. The erosion character along the length of the acceleration channel has some common features. The high level at the initial stage is conditioned by the close location of the channel at the top

Table 1. Experimental data on electric erosion

Experiment №		1	2	3	4	5
Accelerator channel diameter, *d*	mm	16	16	16	19	24
Accelerator channel length, *l*	mm	271	272	272	270	274
Charging voltage , U_0	kV	4	4	3	3	3
Capacitor capacity, *C*	F	$12 \cdot 10^{-3}$	$12 \cdot 10^{-3}$	$48 \cdot 10^{-3}$	$48 \cdot 10^{-3}$	$48 \cdot 10^{-3}$
Maximum current, I_m	kA	139	139	159	140	140
Arc voltage, $U_д$	kV	1.80	1.78	1.80	2.08	2.19
Supplied energy, *W*	kJ	30.0	50.0	117.4	140.0	152.7
Eroded mass, m_e	g	1.10	3.47	37.05	34.4	26.6
Streams speed at the channel section, ϑ	km/s	6.0	6.0	7.5	7.0	5.8
Charge, q_0	C	20	42	94	92	109
Acceleration time	μs	75	72	60	66	80

of the central electrode, which serves as the source of the maximum energy dissipation. Then, at the passage (40–70 mm) erosion decreases, as the central electrode becomes more distant. Erosion increases up to some maximum at a bigger distance, the energy *W* being proportional.

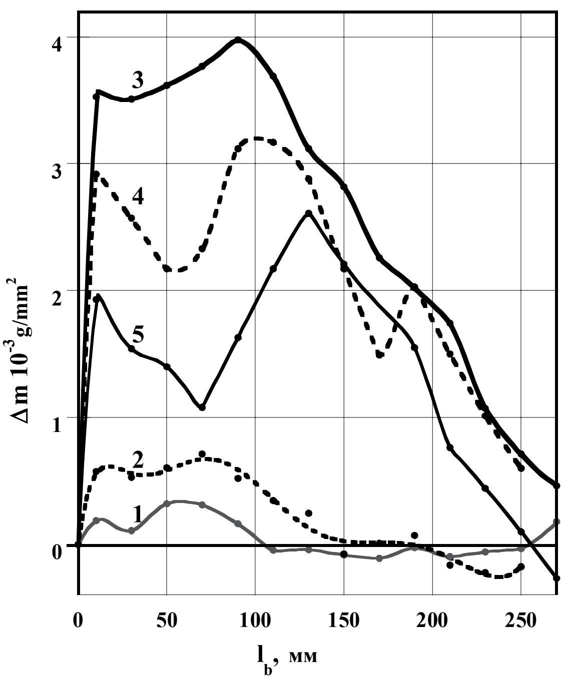

Fig. 3. The epures of differential erosion along the acceleration channel. The number of the curves correspond to the experiments numbers in Table 1, the curves *1* and *2* correspond to the oscillograms *a* and *b* in Fig. 2

The position of the maximum shifts to the right when *W* and the acceleration channel diameter *d* increase, but it does not exceed 150 mm, which corresponds to the position of the external system solenoid face. Erosion smoothly decreases at any further distance increase. Erosion is not observed, when the energy *W* = (40–50) kJ is relatively low at the length of more than (100–180) mm, there is a coating of the previously eroded metal on the acceleration channel surface. When the energy *W* = (100–150) kJ, erosion appears on the length (270–280) mm. The most uniform barrel wear and coating (80–90)% of eroded mass is provided on the length 160–180 mm. It can be explained by the fact that at the passage influenced by the solenoid, the plasma material is very compact and has the maximum current density and temperature. This passage becomes bigger at the solenoid length increase. The presence of the second erosion maximum can result from the braking influence of the face solenoid field, and from the oncoming shock wave process in the plasma stream.

4. Specific Erosion of the Acceleration Channel

The analysis of the received experimental data in the wide range of changing energy and construction parameters of the HCMPA has shown that the most significant factor determining the value of specific electric erosion of the acceleration channel surface is the value of the energy dissipated in it. However, other factors have essential influence, for example, the geometry of the acceleration channel. Considering all these factors it is possible to synthesize the data in the form of specific erosion dependence m_e/W on the value of specific supplied energy W/V_b (V_b – the volume of the barrel acceleration channel), this dependence is shown in Fig. 4.

The dependence has an obvious linear character and is approximated by a linear function

$$m_e / W = A\left(\frac{W}{V_{st}} - B\right), \quad (1)$$

$$A = 0.16; B = 0.281.$$

Thus, the integral erosion m_e in the acceleration system is considered proportional to the square of the energy supplied to the accelerator. Coefficient *A* determining the declination of the straight line depends on the dynamic characteristics of the flow in the channel and on the plasma properties.

Experimental proof is the declination of points 2 (Fig. 4), which is obtained in the experiments without using gas generating substance (industrial petrolatum) from the general pattern. The dependence analysis shows that erosion is equal to zero, when the supplied energy value is equal to

$$W = V_{st} \cdot B. \quad (2)$$

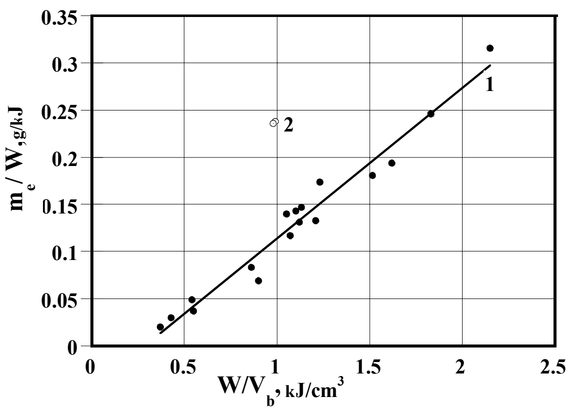

Fig. 4. Synthesizing dependence of specific integral erosion m_e/W on specific energy W/V_b

This ratio does not avoid any physical sense, and is proved experimentally. Under such conditions there are some traces of melting at the initial passage of the acceleration channel with the length of 40 mm, but there is no metal carrying away. Therefore, *B* is the critical value of specific energy (kJ/cm³) when erosion is practically absent.

5.Conclusion

The experimental researches made it possible to determine the most significant factors influencing the electric erosion value of the HCMPA acceleration channel and to find out the patterns of its electro erosion wear.

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