# Influence of Screening on Electrical Erosion of the Channel Surface Coaxial Magnetoplasma Accelerator

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**Abstract-The researches influence of screening degree acceleration channel (AC) coaxial magneto plasma accelerator (CMPA) on the character and value of its surface electroerosive wear were carried out. The screening degree changes at the expense of changing the acceleration channel diameter, the metallic wall thickness and the use of additional tubular copper, brass and duraluminium screens. Absolute screening was imitated in the experiments on a classical pinch accelerator, the parameters of the power supply circuit the same. The screening degree was determined experimentally by an induction sensor indexing the magnetic field intensity Hz(t) changes on the longitudinal system axis, without the high-current discharge, but during the pulse current transmission through the solenoid. The main factors exert significant influence on the electroerosive wear value of its AC in the CMPA are as follows: the plasma rotation in the AC at the presence of external magnetic field and the current density increase in discrete conductivity channels in the plasma structure. The researches carried out shown essential increase of AC surface electroerosive wear at the decrease of its screening degree, it makes it possible to increase the effectiveness of using the energy supplied to the electro erosive material used for coating deposition. The possibility of leveling the electroerosive wear by means of partial screening of the AC initial part was shown.**

In the CMPA, Fig.1, the use of the external induction system provides the increase of dynamic parameters and effectiveness conversion of the electromagnetic energy into the kinetic energy accelerated mass [1]. In general it is conditioned amplification by the space-time stabilization of the steady state in the plasma structure of the high current discharge Z-pinch type with a circular plasma crosspiece due to additional compression of external induction system solenoid by means of axial field, increase of current density and, consequently, increase of the Lorentz's power and its performance effectiveness in the coaxial magneto plasma system similar to the coaxial railgun [2].

CMPA refers to the erosive type of plasma accelerators and is the basis of developed techniques of receptions superhard materials and superdispersed of powders of metals, as well as deposition coating on metallic surfaces [3] by means of electroerosive plasma hypersonic stream influence. The experiments [4] show that the specific integral electroerosive wear value m/W (m - eroded mass, W - the power supplied to the accelerator) is proportional to the value of specific supplied power W/V (V - AC volume). It is justified to suppose that the external magnetic field (EMF) penetrating the AC must affect both the dynamic characteristics of the plasma stream and the electro erosive process on the AC surface. In fact, the scheme under consideration is an air transformer, the solenoid being its primary winding, the short-circuited turn barrel wall coil being the secondary winding. The transversal current induced in the barrel is proportional to the derivative of the accelerator pulsed working current I(t) flowing in the solenoid. Thus, EMF passing into the AC is a superposition of solenoid field and field induced in the barrel wall transversal current. The character of change and this current value and, therefore, the value of penetrating current are determined not only by the primary current pulsed parameters and system geometry, but also by the time constant of the barrel wall transversal τ, short-circuited turn.

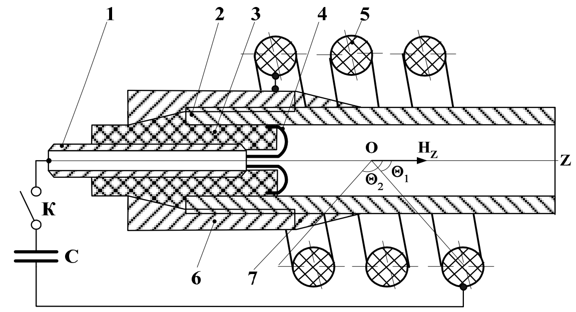


Fig.1. Coaxial magneto plasma accelerator construction: 1) central electrode, 2) electrode-barrel, 3) central electrode insulator, 4) electro explosive conductors, 5) solenoid, 6) Fixing flange, 7) additional screen.

The experimental researches were carried out during the process improvement of technology of deposition coating the stainless steel on the metal surfaces with the help CMPA. The AC screening degree was changed by changing its diameter $d_{ac}$, the barrel metal wall thickness, and the application of additional tubular copper, brass Л-62 and duraluminium АЛ-2 screens. Absolute screening was imitated in the experiment by a classical pinch accelerator (without a solenoid), the parameters of the power supply circuit being kept the same.

The change in time of axial magnetic field intensity Hz(t) on the longitudinal system axis Z was registered by an induction sensor placed in the center of the solenoid (point 0, Fig.1) at the absence of high current discharge, but the pulsed current passing in the solenoid. Typical oscillograms Hz(t) are shown in Fig.2.

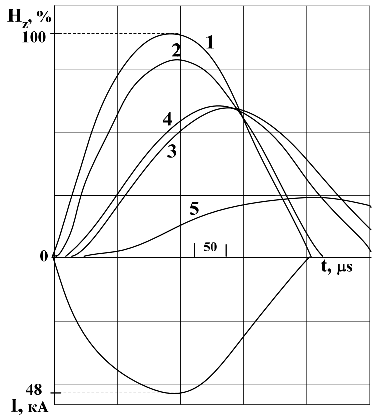


Fig.2. Axial EMF intensity and solenoid current oscillograms: 1–100 % axial magnetic field without the screen, 2-inside the stainless steel barrel AC 12X18H9T d=25 mm, δ=2 mm, τ=13,7 μH/Ω, 3-inside the brass barrel AC d=17 mm, δ=1 mm, τ=15,4 μH/Ω, 4-inside the stainless steel barrel AC d=16 mm, δ=7,75 mm, τ=67,7 μH/Ω, 5-inside the copper barrel AC d=20 mm, δ=12 mm, τ=13,7 μH/Ω.

Comparing the oscillograms it is possible to see that with increase of transversal conductivity the barrel wall the axial magnetic field intensity Hz decreases, and the curves peaks are displaced to the right. The axial EMF in the AC of thick-walled brass and copper barrels exists even after the discontinuance of current flow in the solenoid owing to slow attenuation of the current.

The EMF intensity was analytically determined using the equation [5]:

$$H_Z = \frac{NI}{4 \cdot \ell_c} \cdot \operatorname{ctg} \frac{P}{\pi \cdot \alpha} \left( \cos\theta_2 - \cos\theta_1 \right) \qquad (1)$$

where N and $\ell_c$ – are the number of turns and the solenoid length, I – the solenoid current, P - the distance between the turns, α - the average solenoid radius, $\theta_1$ and $\theta_2$ - adjacent angles between the solenoid axis and the lines connecting the determination point Hz with the solenoid ends (fig.1). In the used solenoid at the current of 100 kA, the axial magnetic field intensity in its center calculated by equation (1) is $Hz=3{,}44\cdot10^{-6}$A/m.

The criterion characterizing the degree penetration EMF of the solenoid in to the AC of the CMPA is the field coefficient $K_п$ equal to:

$$K_{пi} = \int_0^t H_{Zi}(t)dt \Big/ \int_0^t H_{Z0}(t)dt \qquad (2)$$

where $Hz_i$ (t) - the axial magnetic field inside the AC with the screen, $Hz_0$ (t) - axial magnetic field without the screen.

The $K_п$ values were determined experimentally in practically appropriate range of barrel walls (δ= 1…4mm) made of stainless steel, copper, brass, duraluminium and titanium. The experiments proved that the current pulses amplitude changes in the range of 50…200 kA has practically no influence on the $K_п$ value. The data received are summarized in the form of experimental of $K_п$ on the value of time constant of the short-circuited turn τ (Fig.3).

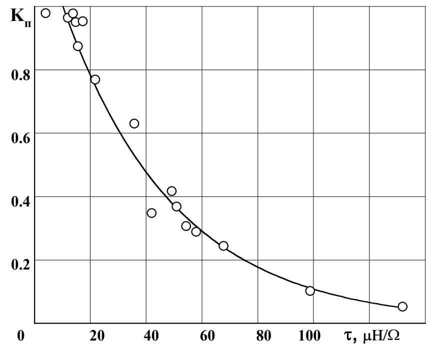


Fig.3. The dependence field coefficient $K_n$ on the time constant τ.

The experimental dependence $K_п$(τ) (fig.3) has an exponential character and is approximated by the equation:

$$K_п = 1{,}28 \cdot e^{-0{,}025 \cdot \tau} \qquad (3)$$

Theoretically, the transversal resistance tending to infinity, $K_п$ must be close to the unity. However, the experimental curve does not reach the unity. It can be explained by the fact that the determining τ was used specific resistance of metal under normal conditions, i.e. its increase at heating from the flow of pulsed currents with the density of 200…500 A/mm$^2$ was not taken into consideration. The data and average results of the comparative series of experiments on the CMPA (1) and the pinch-accelerator (2) carried out under the same conditions are shown in the table: capacitor battery capacitance C=48 mF, charging voltage $U_{ch}$=3,0 kV, D=25 mm, $d_{ac}$=19 mm. The axial EMF direction coincided with the plasma flow direction.

Fig.4a shows the diagrams of the specific differential electroerosive wear of the AC surface made of stainless steel along its length $\Delta m(\ell_{ac})$ with different screening degrees. The diagrams numbers coincide with the experiment numbers in the table. Comparative analysis of the submitted data shows sufficient decrease of both differential (Δm, g/mm$^2$) (Fig.4) and integral (m, g) electroerosive wear at the presence of the EMF (experiment 2, Table) or at its sufficient screening by an additional copper screen, for example, copper pipe put on the stainless steel barrel.

Table. Experimental data of the EMF influence on the electroerosive wear of the AC surface.

| Characteristic | Unit | 1 | 2 |
|---|---|---|---|
| $K_п$ | – | 0,95 | 0 |
| $\ell_{ac}$ | mm | 272 | 274 |
| $U_{max}$ | kV | 1,84 | 1,78 |
| $I_{max}$ | kA | 187 | 193 |
| W | kJ | 140 | 135 |
| m | g | 24,5 | 18,3 |
| V | $mm^3$ | 77,1 | 77,6 |
| m/W | g/kJ | 0,17 | 0,14 |
| W/V | $kJ/cm^3$ | 1,79 | 1,74 |

We consider it necessary to point out two main factors having great influence on the value of the electroerosive wear of the CMPA AC surface: plasma rotation in the AC at the presence of the EMF and the increase of current density in discrete conductivity channels in the plasma structure. The plasma rotation in the AC at the interconnection of axial EMF and azimuth current fields flowing along discrete channels can be seen from comparing the structures of plasma erosion traces on the AC surface, shown in fig, 4b. The numbers correspond to the experiments numbers in the table.

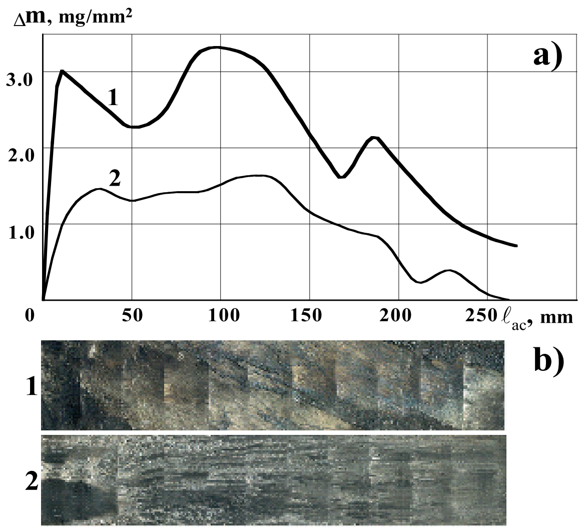


Fig.4b. Diagrams of the specific differential electroerosive wear along the AC (a), photos of the plasma-erosive traces on the AC surface (b):
1) $K_п$=0,954, 2) $K_п$ = 0.

When there is no EMF (experiment 2), the tracks of plasma erosive traces are practically parallel to the longitudinal axis of the AC, when there is EMF, they have an obvious slope decreasing along the AC length due to the flow speed increase.

Fig.5 shows comparative dependences of the specific integral electroerosive wear m/W on the specific supplied power W/V, for the CMPA with stainless steel barrels with $K_п$=0,92…0,98 and $K_п$=0. Their comparison provides rendition of the AC screening influence degree on the integral electroerosive wear value of the AC surface and on the value of the mass for coating deposition.

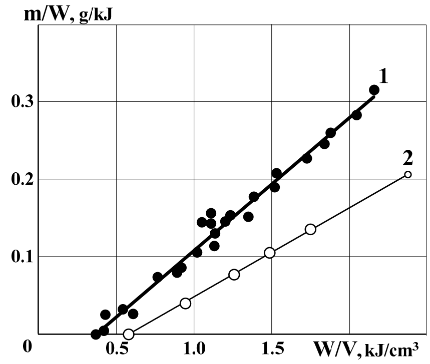


Fig.5. The dependence of the integral electroerosive wear on the supplied power: 1) $K_п$ = 0,92….0,98 2) $K_п$ = 0.

In the accepted co-ordinates the dependences 1 and 2 are approximated by the linear function:

$$\frac{m}{W} = A \cdot \left( \frac{W}{V} - B \right) \qquad (4)$$

where: A – integral electric erosion coefficient, B – critical specific supplied power value.
For $K_п$ = 0,92…0,98: A=0,125 [$gcm^3/kJ^2$], B=0,390 [$kJ/cm^3$], for $K_п$ = 0: A=0,1116 [$gcm^3/kJ^2$], B=0,575 [$kJ/cm^3$].

The generalized empirical equation for stainless steel barrels taking $K_п$ (3) into consideration is:

$$\frac{m}{W} = 0{,}120 \cdot \left( \frac{W}{V} + 0{,}185 \cdot K_п - 0{,}575 \right) \qquad (5)$$

The experimental data show that when there is no EMF, m/W decreases considerably and the critical value of the specific supplied power $W_*/V$ increases sufficiently. It emphasizes the idea, that when there is no plasma rotation and the current density is lower, the AC surface erosion starts with the greater value of the supplied power rather than with the presence of the EMF. The received equation (5) makes it possible to determine the eroded mass value depending on the field coefficient $K_п$, power and constructional parameters of the CMPA by calculations.

One of the disadvantages of the considered system as a technological installation is the inequality of the electroerosive wear along the AC length. There can be a barrel wall fusion in the formation place of the maximum erosion at the repeated frequency acceleration operation. This would decrease the barrel application effectiveness as a spent material. In particular, in titanium barrels (BT1-0) used for getting nano-disperse powders (TiC, TiN, TiCN, $TiO_2$) the erosion peak exceeding its average value takes place at the initial part of the barrel with the length of 40-45 mm (curve 2, Fig.6).

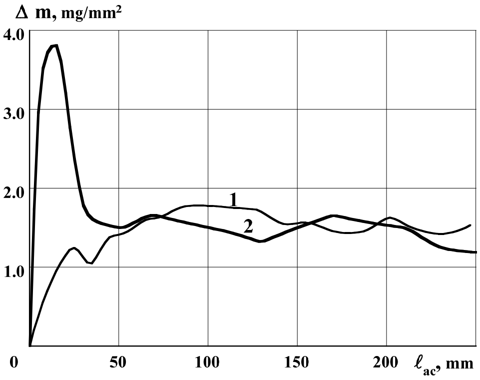


Fig.6. Diagrams $\Delta m(\ell_{ac})$: 1)with the initial AC part screening, 2) without the screening.

The received data on the screening influence make it possible to think about the possibility of the erosion peak removal by the screening increase at the initial barrel part. It is necessary to provide smooth decrease of the screen wall cross-section at that part of the barrel for the purpose of excluding the "magnetic plug" effect. It is achieved by creating an additional electromagnetic screen (7, Fig.1) with an external conoidal surface.

A series of experiments on titanium barrels with the use of additional screen (the conic base diameter d = 40 mm, length $\ell$ = 50 mm) and without the screen were carried out under the following conditions: $C = 42\cdot10^{-3}\Phi$, $U_{ch}$ = 3,2 kV, AC length $\ell_{ac}$ = 275 mm, $d_{ac}$ = 21 mm. The experimental results are shown in Fig.6. in the form of diagrams $\Delta m(\ell_{ac})$. It is evident from the curves comparison that in case of the technical decision offered the erosion peak at the initial part of the barrel is removed. It provides the leveling of the electroerosive wear and maximum application of the titanium barrel in the technological process.

The researches carried out showed sufficient of the AC surface electroerosive wear increase when the screening degree is reduced. It makes it possible to increase the effectiveness of the power application supplied to the electro erosive material used for coating deposition.

The possibility to level the AC surface electroerosive wear by means of its screening at the initial part is shown.

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