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Skin Explosions of Stepped Cylindrical Copper Conductors

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Introduction

Electrical Explosion of Conductors (EEC)

- Slow explosion mode (current density $j < 10^7$ A/cm^2)
- Fast explosion mode (current density $j > 10^7$ A/cm^2)

- Uniform current distribution mode
- **Current skinning mode**

The skin explosion of conductors is of much current interest primarily in the context of electromagnetic energy transport to a load from multi-terawatt generators with a current of 30–50 MA rising in less than 100 ns which are expected in Z-pinch controlled thermonuclear systems.

At such currents, the electromagnetic energy density in magnetically insulated transmission lines and load region is so high that the surface of conductors may explode forming a plasma and decreasing the efficiency of energy transport.

Experiments on the high-current MIG generator at a current of up to 2.5 MA rising in 100 ns were performed to study the electrical explosion of cylindrical copper conductors with circular steps in a magnetic field of 200–800 T.
Such a stepped load allowed us to analyze the plasma dynamics at different values of magnetic induction in the same experiment.

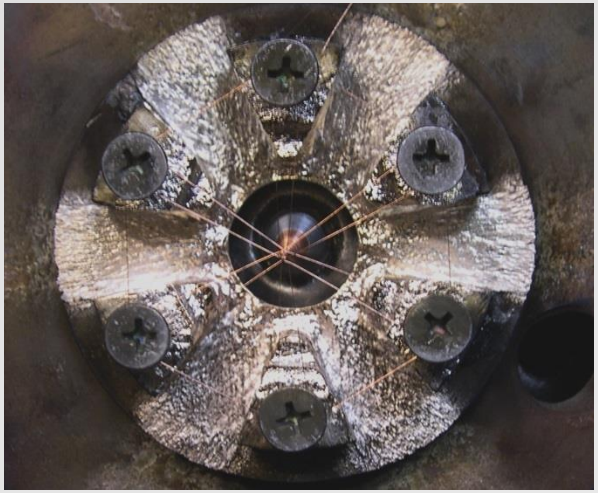
Objective

Our study is focused on the dynamics of plasma (which forming when the surface of conductor explode) in magnetic fields at which its evolution is dictated by nonlinear magnetic diffusion and growth of large-scale instabilities.

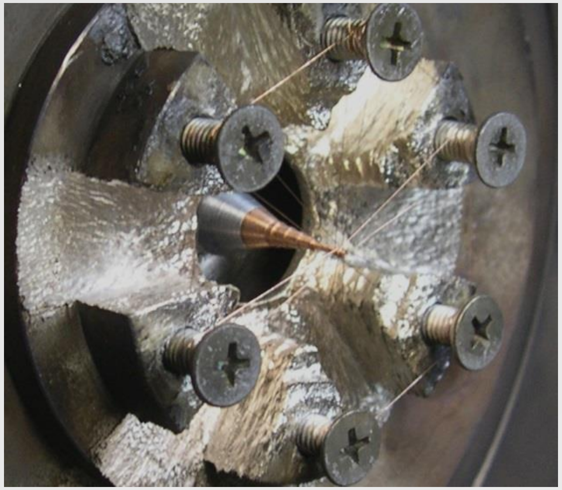
Estimates are presented for the instant of surface plasma formation and for the velocity of plasma expansion depending on the diameter of stepped cylindrical conductors.

- The profiled conductor was a copper cylinder with five turned circular steps
- Used two type of anode:
  - solid disk anode (sliding contact)
  - wire anode
- B-field values was 200–800 T at the conductor surface

profiled load with wire anode



front view



side view

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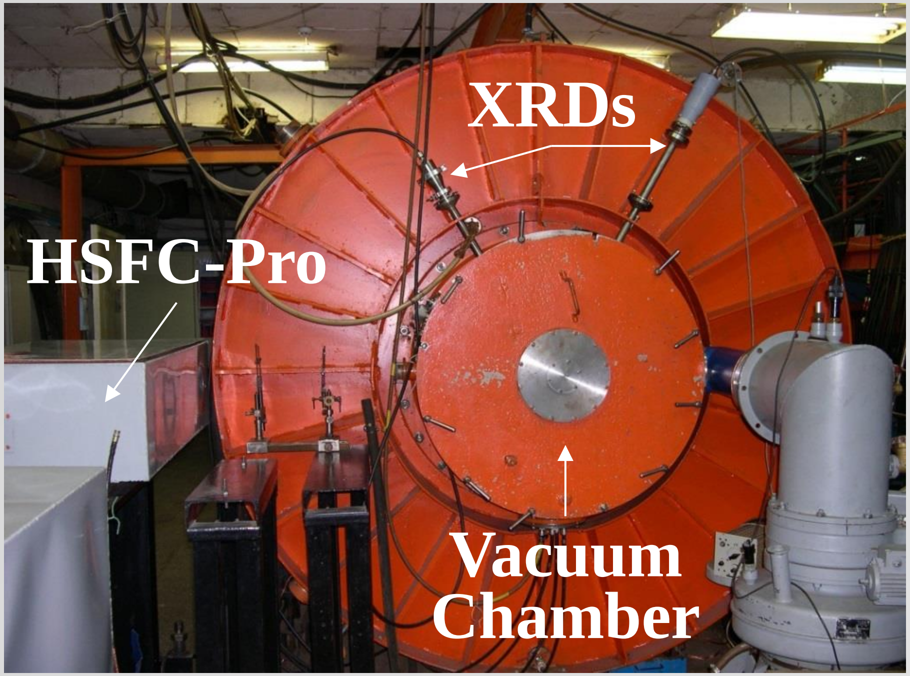
Experimental Technique

MIG Generator



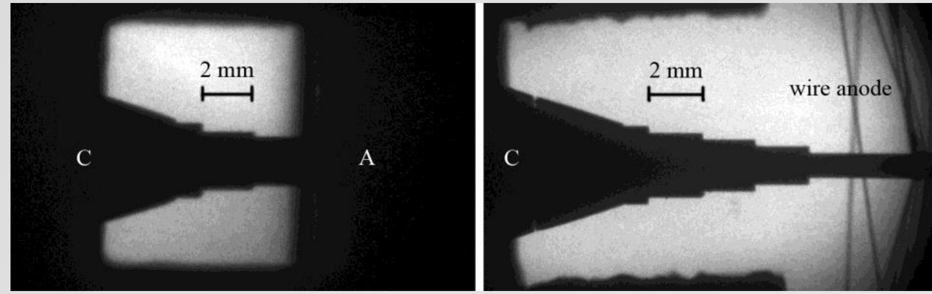
Current amplitude: up to 2.5 MA

Current rise time: 100 ns

Diagnostics

- Rogovsky coils
- B-dot probes, inductive grooves
- X-ray diodes with bare aluminum cathode (XRDs)
- HSFC Pro four-frame optical camera (exposure 3 ns)

Generator Load View



(a) (b)

Stepped copper load with

(a) solid disk anode

(b) wire anode

wire anode composed of 12 copper wires of diameter 90 μm

Generator Load Parameters

Step	Diameter, mm	Width, mm
1	3	1
2	2.5	2
3	2	2
4	1.5	2
5	1	5

steps numbering starts from the load cone

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Experimental Results

By the time 110 ns, the load current was about 2 MA, and the magnetic field at the metal surface of load steps 1, 2, 3, 4, and 5 was 250, 300, 370, 480, and 740 T, respectively

solid disk anode
(with no external illumination)

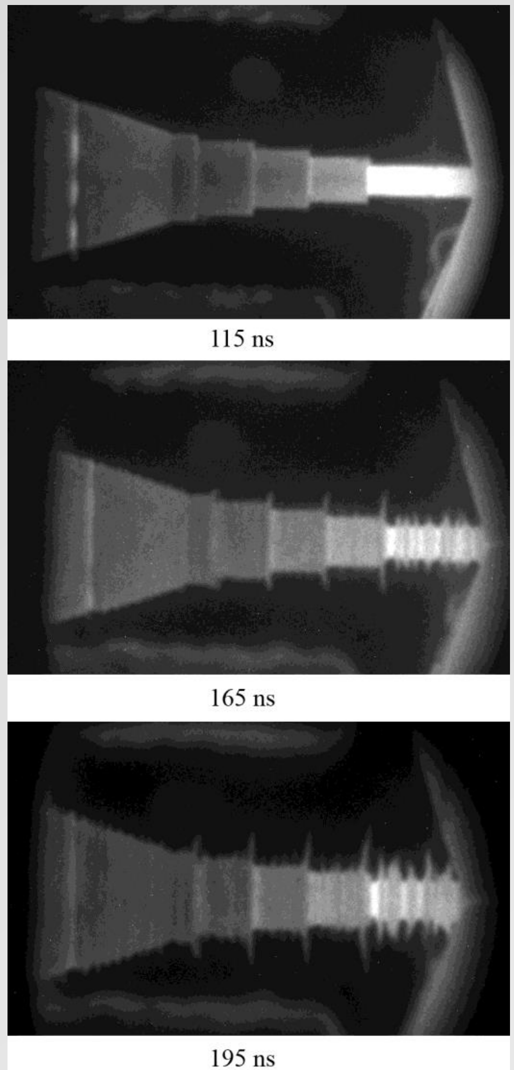
90 ns: no glow at all steps
(except for a weak light at the junction with the cathode bushing)

110 ns: bright glow at step 4
very weak glow at step 3
no glow at steps 1, 2

130 ns: glow at step 3
150 ns: glow at step 2
345 ns: no glow at 1

Thus, it can be concluded that no bright plasma is formed at the load surface in a magnetic field of ~ 250 T (step 1) and that the surface is exploded when the magnetic field goes above 300–400 T

wire anode
(composed of 12 copper wires of diameter 90 μm)



Because the stepped load, in this case, is illuminated by the exploding anode wires, it is possible to observe the plasma dynamics with weak self-radiation or with no visible radiation at all

As can be seen from optical frames, the junctions of the load steps start glowing earlier than the steps, and besides, rapidly expanding plasma jets propagate from the junctions to distances far larger than the step size

The expansion velocity of such plasma jets is much higher than that of the load surface plasma

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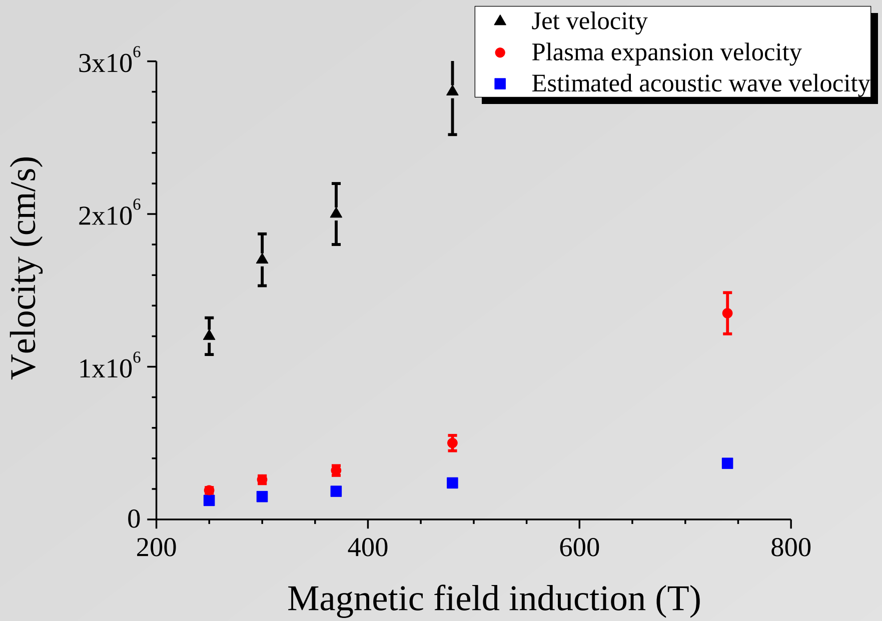
Discussion

Velocities of load plasma expansion and plasma jets measured at 155÷195 ns



The ion acoustic wave velocity estimated on the assumption that the thermal energy density is equal to the magnetic field energy density [1]:

$$\boxed{C_v T \approx \frac{B^2}{2\mu\mu_0}}$$

where C_v is the heat capacity at constant volume, T – metal surface temperature, B – magnetic field induction

The velocity of load plasma expansion is slightly higher that of acoustic wave, and the velocity of plasma jets is 5÷6 times higher than the ion acoustic wave velocity, i.e., it is supersonic

Our analysis of experimental data shows that the load plasma expands such that the initial difference of the load step diameters becomes smoothed, and this, in particular, is due to the development of plasma instabilities

[1] H. Knoepfel, Pulsed high magnetic fields: physical effects and generation methods concerning pulsed fields up to the megaoersted level. Amsterdam: North Holland Publishing Company, p.372, 1970.

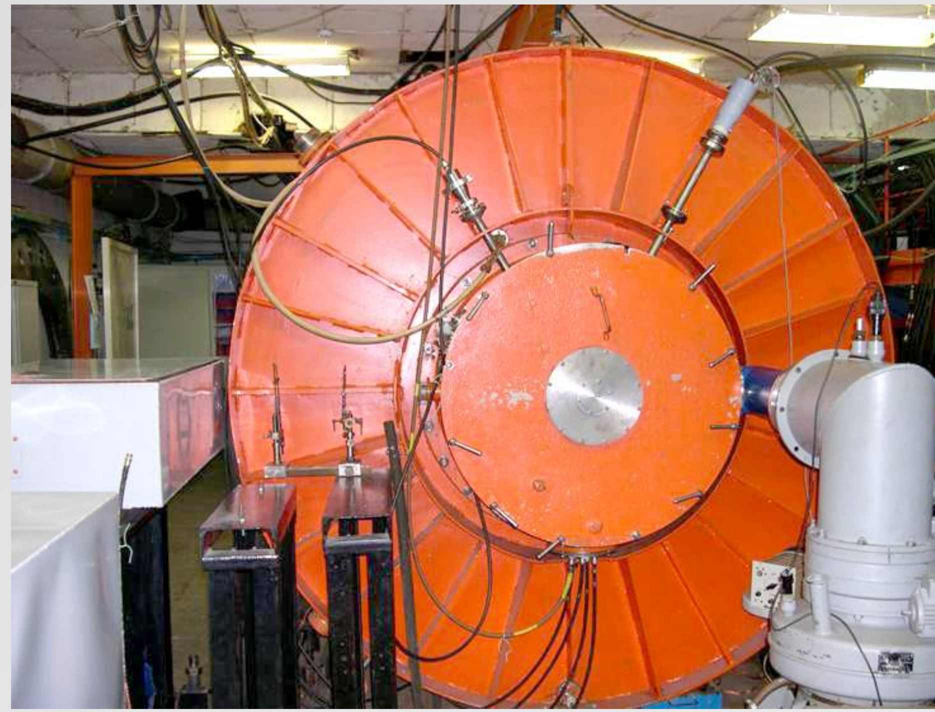
Conclusion

Our skin explosion experiments on the MIG generator (current amplitude 2.5 MA, rise time 100 ns) show that the plasma of stepped cylindrical copper conductors expands such that the initial difference in the diameters of their circular steps is smoothed

At the induction of magnetic fields about 300÷400 T, visible radiation from the conductor surface appeared, and when the conductor was illuminated by an external radiation source, radial plasma jets from the edges of its steps were detected

From the load step junctions, radial plasma jets propagate with a velocity of up to $2.7 \cdot 10^6$ cm/s, which is 5÷6 times higher than the velocity of surface plasma expansion. What drives the generation of such collimated plasma jets is yet to be explained

Thank Your for Attention!



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