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12-METER PLASMA COLUMN

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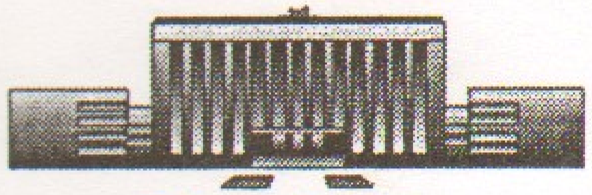

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12-METER PLASMA COLUMN

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Abstract

A system of creation of 12-meter-long column of low temperature hydrogen plasma for GOL-3-II facility is discussed. The plasma of ~10^{15} cm^{-3} density is created by a linear discharge. Major features of this system is high enough longitudinal magnetic field (5 T on full length, 10 T in end mirrors) and conductive vacuum chamber. Characteristics of the plasma and mechanism of the discharge are discussed.

1. Introduction

Long columns of low temperature plasma are used as targets for experiments with high power particle beams (see, e.g., [1]) and also can be used for other goals. GOL-3-II [2] is intended to studies of collective beam-plasma interaction. It comprises 12-meter-long solenoid with 5 T magnetic field; plasma column is created by linear discharge inside the metallic chamber placed in solenoid. Then 8-microsecond relativistic electron beam with energy content of ~0.2 MJ is injected into the plasma.

Creation of 12-meter plasma column for further beam injection and its characterization is a separate major problem to be solved. Main features of new plasma creation system as distinctive one from previous 7-meter discharge of GOL-3-I facility [3] are the following. No single-shot-living electrodes should be placed on the electron beam path up to exit beam receiver. End face of the device should allow axial plasma diagnostics. Plasma should have good axial and radial uniformity. This task led to substantially redesigned system and to additional studies of this plasma.

2. Design of plasma source

The design feature of the system is to produce uniform hydrogen plasma column with 10^{14} to 10^{16} cm^{-3} density inside the metallic chamber (12 m length and 10 cm diameter) in a magnetic field of 5 T. High power electron beam runs along this plasma column. The beam can destruct all met electrodes, that's why the special exit beam receiver serves as one of the discharge electrodes (cathode). The place for this electrode was chosen in a weak magnetic field in order to lower specific heat load to non-destructive level.

A plasma system and configuration of the magnetic field is shown on Fig.1. A groups of graphie diaphragms with floating potential are placed along the magnetic force line within both exit high-field regions.

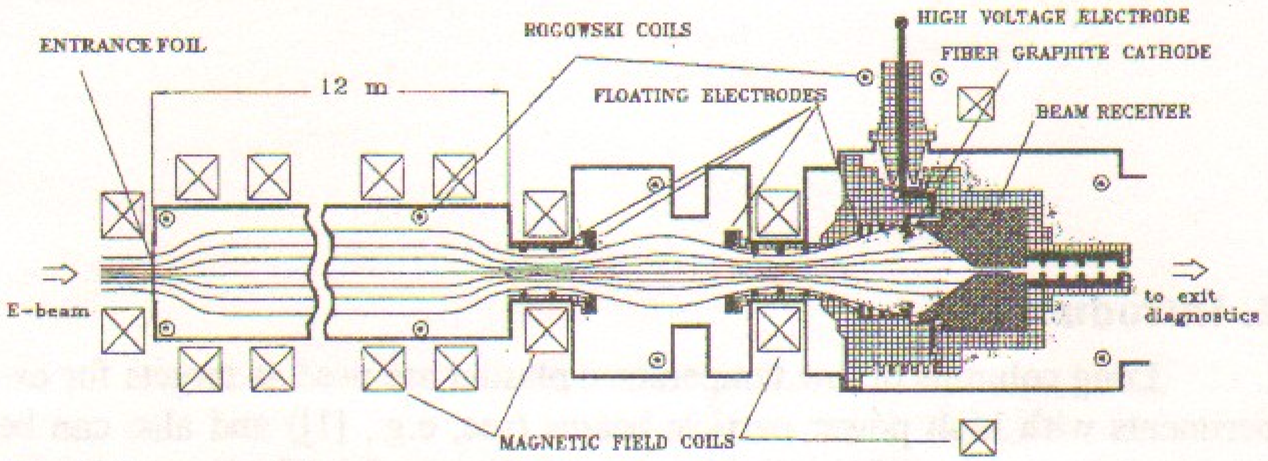

Fig.1. Layout of the experiment.

A high voltage is applied to ring high-voltage electrode, placed with a small gap with beam receiver. This electrode is a ring made from carbon fiber material and it serves as cold cathode. The beam receiver is not connected with other conducting parts of the device, thus it also has floating potential. The features of this system are 1 cm axial hole in the beam receiver which used for particle and radiation transport to special volume for exit axial diagnostics. Exit volume has separate pumping.

The discharge is finally created between a high-voltage electrode and thin metallic foil placed at the opposite entrance end of vacuum chamber. At the maximum of the magnetic field the negative voltage is applied to the electrode and the breakdown occurs along the magnetic force lines to the grounded entrance foil. Graphite limiters are placed in several positions along the vacuum chamber. After the high voltage feeds to the fiber graphite cathode a breakdown from this electrode to the nearby beam receiver occurs. As a result the beam receiver get the same potential. The spark plasma becomes an emitter of fast electrons, which accelerate to the energies corresponding to applied voltage. Fast electrons move along the magnetic force lines through the whole 12-meter vacuum chamber and create initial ionization of hydrogen. Soft X-ray emission of this electrons was observed - Fig.2. The plasma density is basically determined by initial hydrogen pressure. A 18 μF capacitor charged usually to 25 kV serves as discharge driver. Plasma properties are measured by diagnostics described in [1-3].

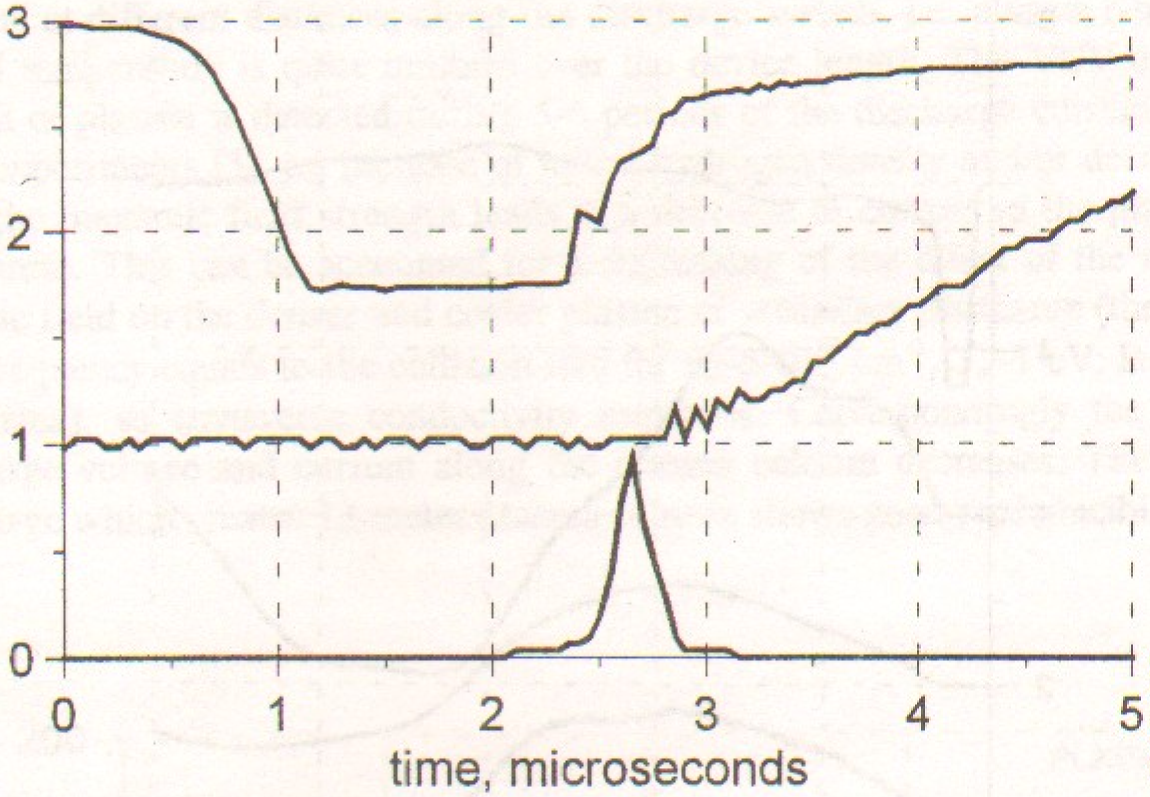

Fig.2. Initial phase of the discharge. Top to bottom: voltage, 20 kV/div; plasma current, 1 kA/div; soft X-rays $E_\gamma > 1$ keV, 60 mV/div.

3. Plasma properties.

As the initial ionization is created then the discharge current starts to flow along the plasma column. The electric field becomes reconfigured comparing with pre-breakdown one. The plasma column acts as a resistive divider, which creates within occupied space a longitudinal electric field which maintains current in a long conducting chamber. There is no transverse current to the wall because of no preionization outside the discharge aperture. This fact is confirmed by coincidence of currents, measured by ~10 Rogowski coils distributed over device length.

Besides of the current through 12-m-long discharge a secondary branch of the discharge develops for which anode is a chamber wall just after the first group of floating electrodes (see Fig.1). The current in this curcuit is substantially higher in our conditions than current in the plasma, so it determines the voltage on the discharge and current decay time. Initial voltage has weak affect on amplitude of the current flowing along the system, nevertheless it should be high enough so that range of fast electrons

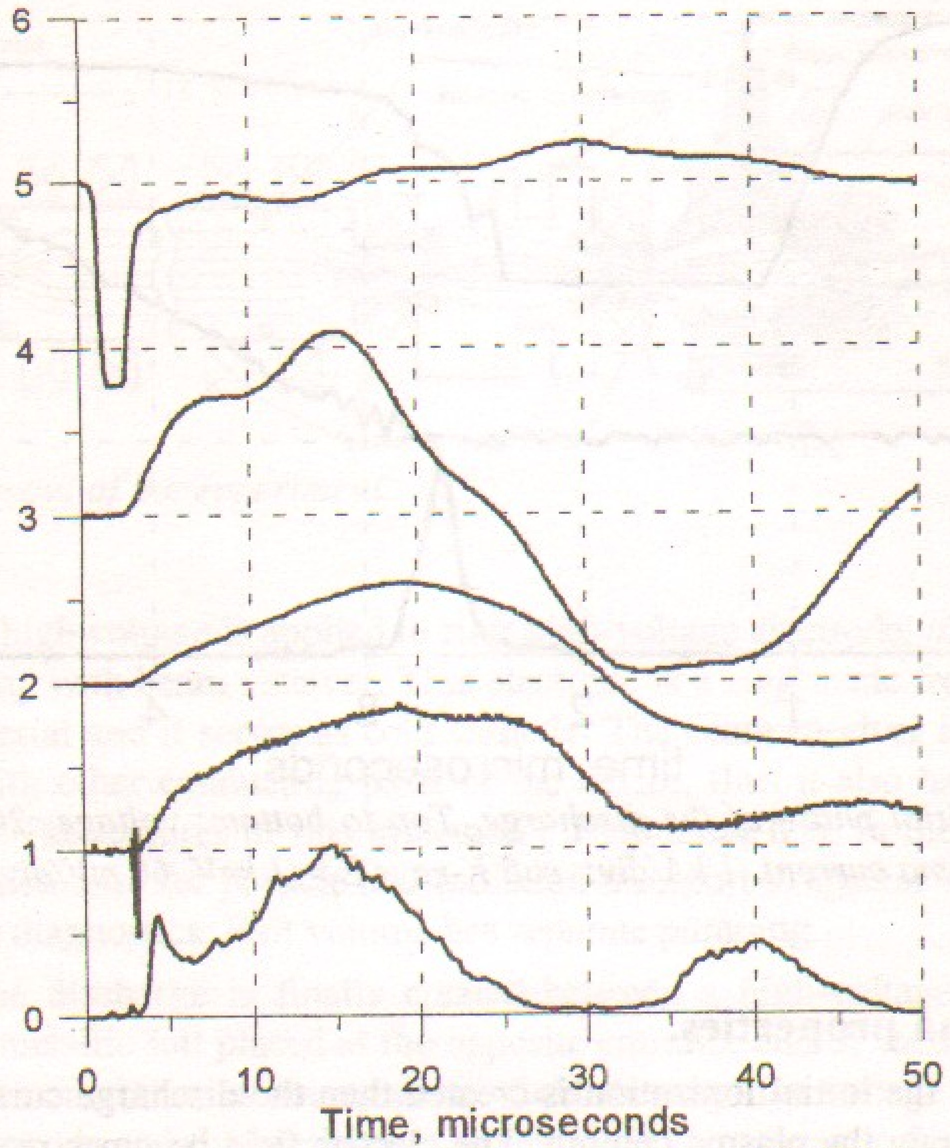

Fig 3. Typical waveforms (top to bottom): voltage, 20 kV/div; total current, 50 kA/div; plasma current, 5 kA/div; plasma VUV 10-100 eV emission; 121.6 nm L_α *emission from plasma between high field coils.*

exceeds the 12 m device length. Time evolution of discharge parameters is shown on Fig.3.

Measurements with movable collector show, that main discharge current flows in solenoid in 6 cm aperture. This corresponds to same magnetic force tube with inner edge of fiber graphite cathode electrode, i.e. main current of the discharge flows from the surface of exit beam receiver. Good plasma uniformity is also seen from optical brightness of the plasma column (measured by digital photography- Fig.4).

Measurements of VUV emission show that plasma is practically the same at different distances along the discharge system, i.e. plasma density and temperature is quite uniform over the device length. The VUV emission of plasma is detected during 5-6 periods of the discharge current. As in experiments [3], an increase of initial hydrogen density and/or decrease of the magnetic field strength leads to a decrease of current in the plasma column. This can be accounted for a decreasing of the effect of the magnetic field on the denser and cooler plasma of secondary discharge (the hyrofrequency equals to the collision rate for n_e~$5\cdot10^{15}$ cm^{-3}, T_e~1 eV, B~5 T plasma), so transverse conductivity improves. Correspondingly the discharge voltage and current along the plasma column decreases. The discharge which creates 12-meter plasma column shows good reproducibility.

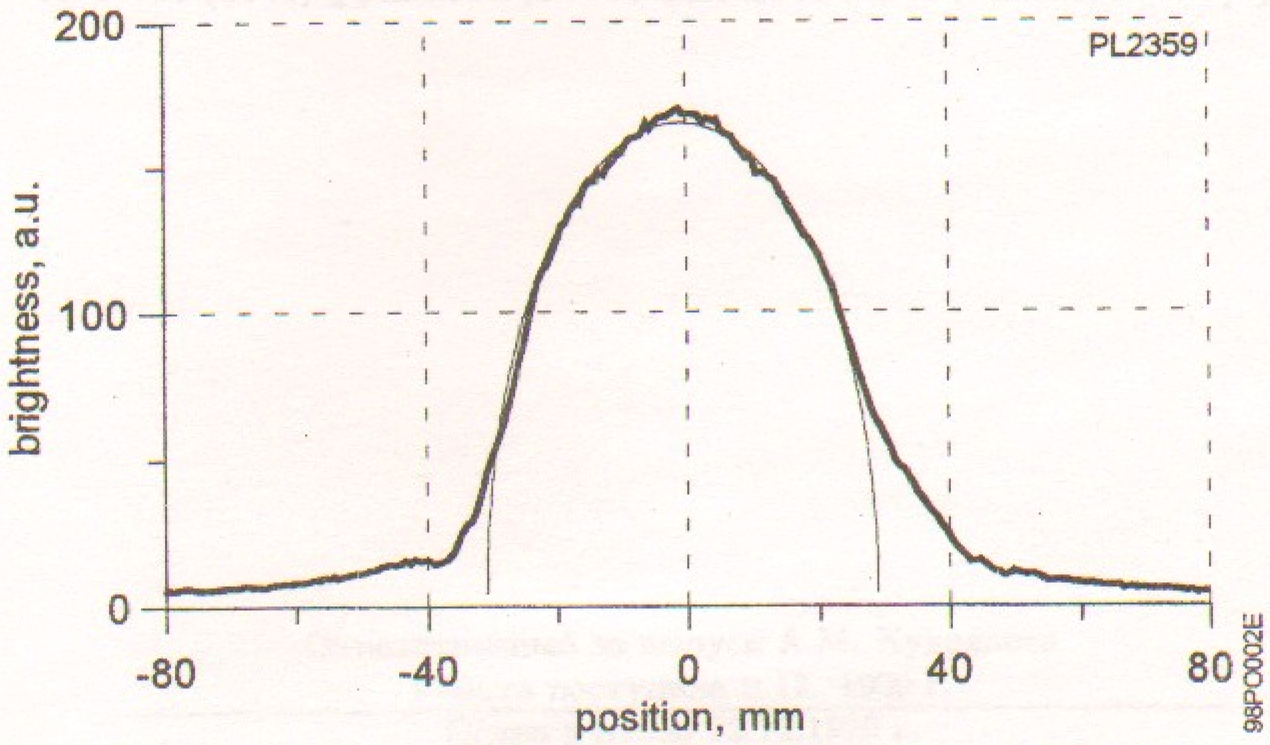

Fig 4. Optical brightness of the plasma column (at 8 meters from the plasma creation system). Bold line - experiment, thin line - calculated for uniform emission within 60 mm diameter. Measured "tails" are reflections from the opposite wall.

4. Conclusion.

The method of 12-meter plasma column generation with the help of the linear magnetized discharge in hydrogen is developed on upgraded GOL-3-II facility. Main features of the discharge are studied, the mechanism of discharge development is suggested. The plasma parameters are suitable for the experiments on beam-plasma interaction within 10^{14}-$5\cdot10^{15}$ cm^{-3} density range.

References

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12-meter plasma column

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