Siberian Branch of Russian Academy of Science
BUDKER INSTITUTE OF NUCLEAR PHYSICS

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LONG LINEAR DISCHARGE IN CORRUGATED MAGNETIC FIELD

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Abstract

A system of creation of 12-meter-long column of hydrogen plasma for the GOL-3 facility is discussed. The plasma of $\sim 10^{15}$ cm^{-3} density is created by a linear discharge. Major features of this system are varying over the length longitudinal magnetic field (two 2-meter 10-cell end sections of 5/3.3 T corrugated magnetic field with 5 T central section of uniform field) and conductive vacuum chamber. Characteristics of the plasma and mechanism of the discharge development are discussed.

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1. Introduction

Long magnetized linear discharge in a metallic chamber is used as a source [1,2] for initial (start) low-temperature hydrogen plasma in the GOL-3 facility [3]. Then this plasma of $\sim 10^{15}$ cm^{-3} density is to be heated by a high power relativistic electron beam (~1 MeV, ~30 kA, ~200 kJ in ~8 μs pulse) up to keV-range electron temperature.

The plasma is confined in the 12-meter-long solenoid with magnetic field up to 5 T. Creation of 12-meter plasma column for further beam injection and its characterization is a complex problem to be solved. Recently the GOL-3 facility was put into new operation regime [4]. Magnetic field on part of the solenoid was made corrugated (multimirror) with H_{max}=4.7 T, H_{min}=3.3 T and cell length of 22 cm. Two studied magnetic configurations with one-sided 20-cell section of corrugated field and with two shorter 10-cell sections are shown in the Fig.1 (full magnetic system is from the cathode of the electron beam generator to the exit beam receiver).

Next important new feature is the requirement of multi-shot operation of the facility. No single-shot-living electrodes should be placed on the electron beam path up to exit beam receiver. Required initial gas density distribution over the device length is supplied by a set of fast gas-puff units (Fig.1). New regime of GOL-3 operation led to substantially redesigned start plasma creation system and to additional studies of this plasma.

2. Design of plasma source

New plasma source differs considerably from our initial design for 7-m-long discharge [1] and from previous source [2]. The design feature of the system is to produce column of hydrogen plasma with controlled density distribution

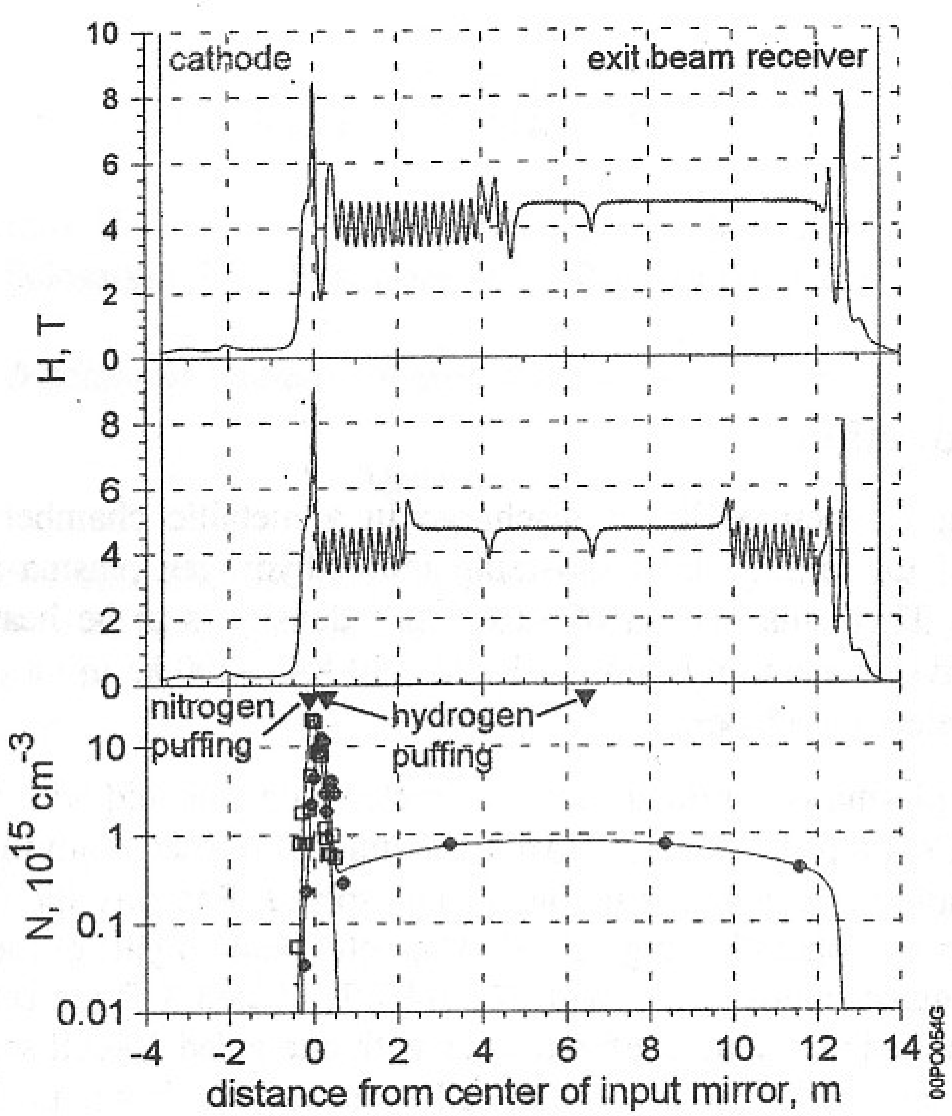

Fig.1. Magnetic field along the device (top) and initial distribution of H_2 (dots) and N_2 (squares).

(typically within 10^{14} to 10^{17} cm^{-3} density range) 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 is placed in a weak magnetic field in order to decrease the specific heat load to non-destructive level. This exit receiver is mounted on a massive insulator and connected with the ground by a set of resistors, which *de-facto* enable operation under near-to-floating potential during the short period of the beam injection.

Plasma system and magnetic field configuration is shown in Fig.2. A sets of graphite diaphragms with floating potential are placed along the magnetic force line within both exit high-field regions. Three high-voltage electrodes are

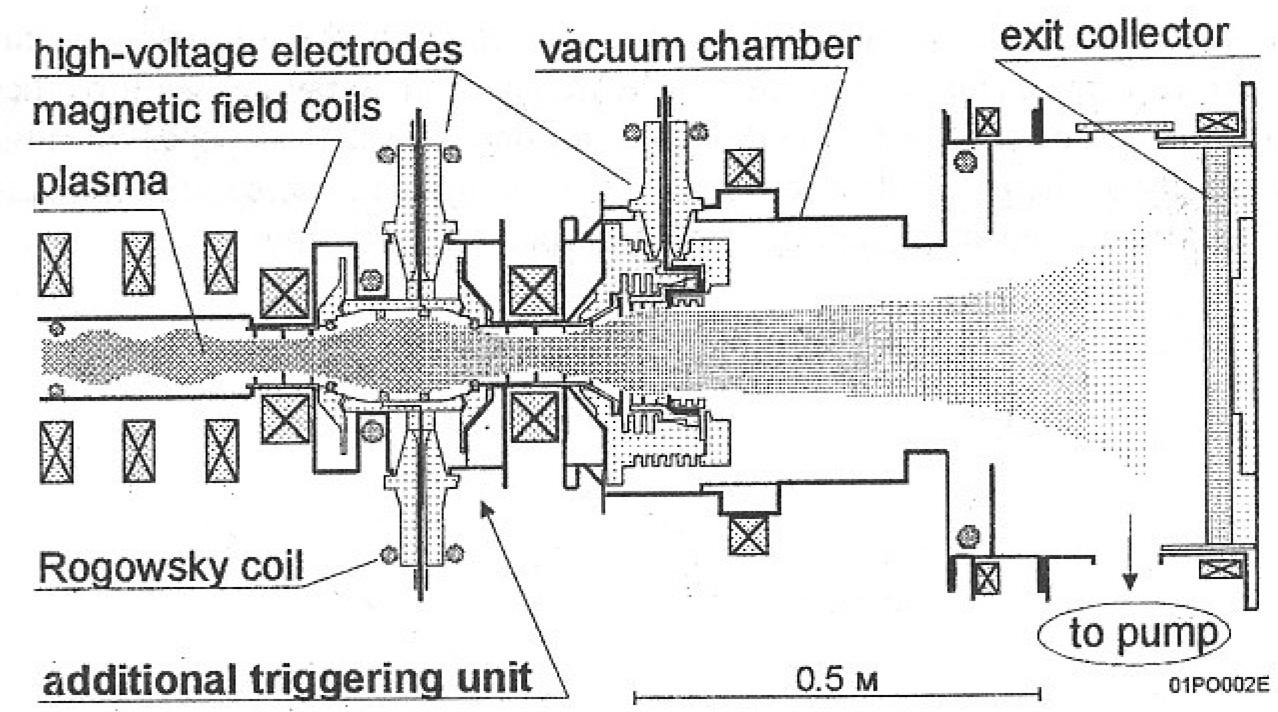

Fig.2. Layout of the plasma creation system (12-meter long solenoid is on the left).

used for a stable and reliable operation of the systen. A high voltage is applied to ring HV electrode, placed behind the last high-field coil. This electrode is a ring made from carbon fiber material. Two other ring electrodes (which are made from graphite and placed before the last high-field coil) serves as trigger of initial spark. All system is supplied with single 48 μf capacitor bank and single switch, the electrodes are fed through adjusted RLC units.

In previous versions of the system the discharge was created between last high-voltage electrode and thin metallic foil placed at the opposite "entrance" side of vacuum chamber of the facility. The breakdown occured along the magnetic force lines to the grounded entrance foil. New configuration is without this conducting entrance foil, thus some limited transverse conductivity to the wall near former location of the foil should be provided. This is done with a relatively short space with fast-puffed nitrogen (this gas is also component of the system – it is required for proper compensation of a space charge and current of the electron beam during its final compression by the magnetic field before the injection into the plasma). The discharge is spatially stabilized by a set of graphite limiters placed in several positions along the vacuum chamber.

Initial breakdown occurs between the pair of high-voltage ring electrodes. The spark plasma has limited energy and serves as an emitter of fast electrons, which accelerate by the voltage applied to the last high-voltage electrode. Fast electrons move along the magnetic force lines through the 12-meter vacuum chamber and create initial ionization of hydrogen. Soft X-ray emission of these electrons is observed - Fig.3. The degree of plasma ionisation depends on initial local density of the gas (100% ionization is made by the injected electron beam itself, and initial ionization serves as safe transport channel only).

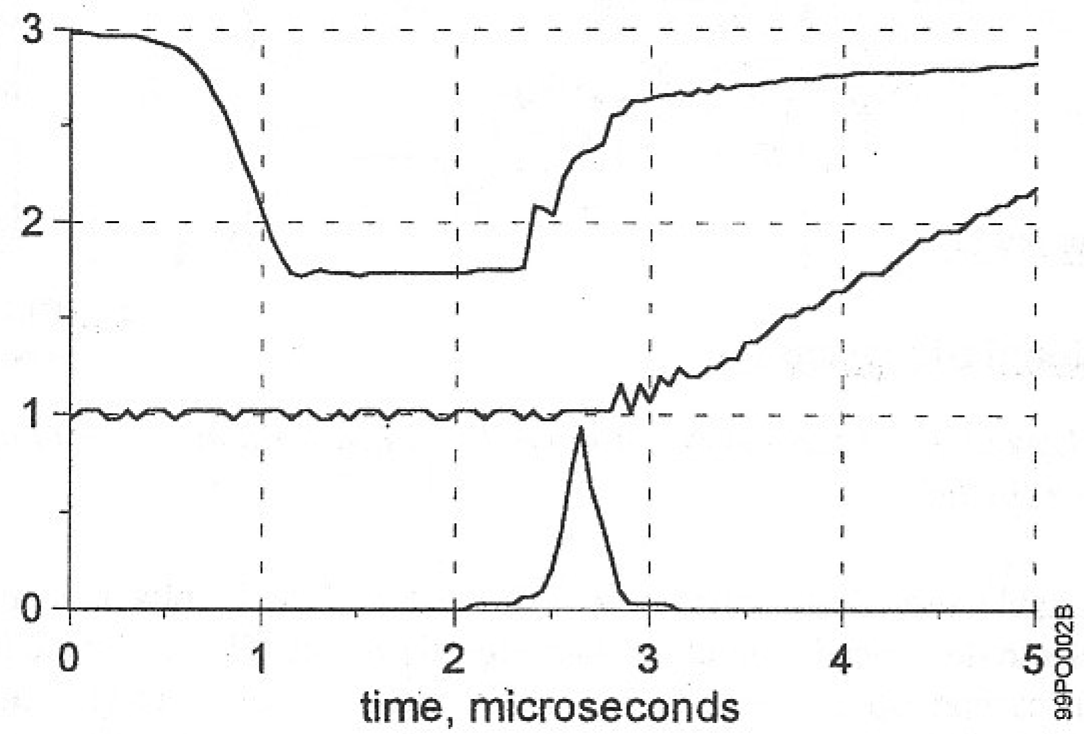

Fig.3. Initial phase of the discharge. Top to bottom: voltage, 20 kV/div; plasma current, 1 kA/div; soft X-rays E_γ> 1 keV, 60 mV/div.

3. Plasma properties

When 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 inside the long conducting chamber. There is no transverse current to the chamber wall because of no preionization outside the discharge aperture. After the breakdown the voltage on the discharge is determined by high total current which circulated within the plasma creation system (Fig.4). Initial voltage has weak affect on amplitude of the plasma current, but it should be high enough so that range of fast electrons exceeds the 12 m device length.

Main discharge current flows in solenoid in aperture which corresponds to same magnetic force tube with inner edge of fiber graphite cathode electrode. Good plasma uniformity is seen from optical brightness of the plasma column even in foilless mode of operation (Fig.5). As in experiments [1], an increase of initial hydrogen density and/or decrease of the magnetic field strength leads to a decrease of current in the plasma column. The discharge which creates 12-meter plasma column shows good reproducibility.

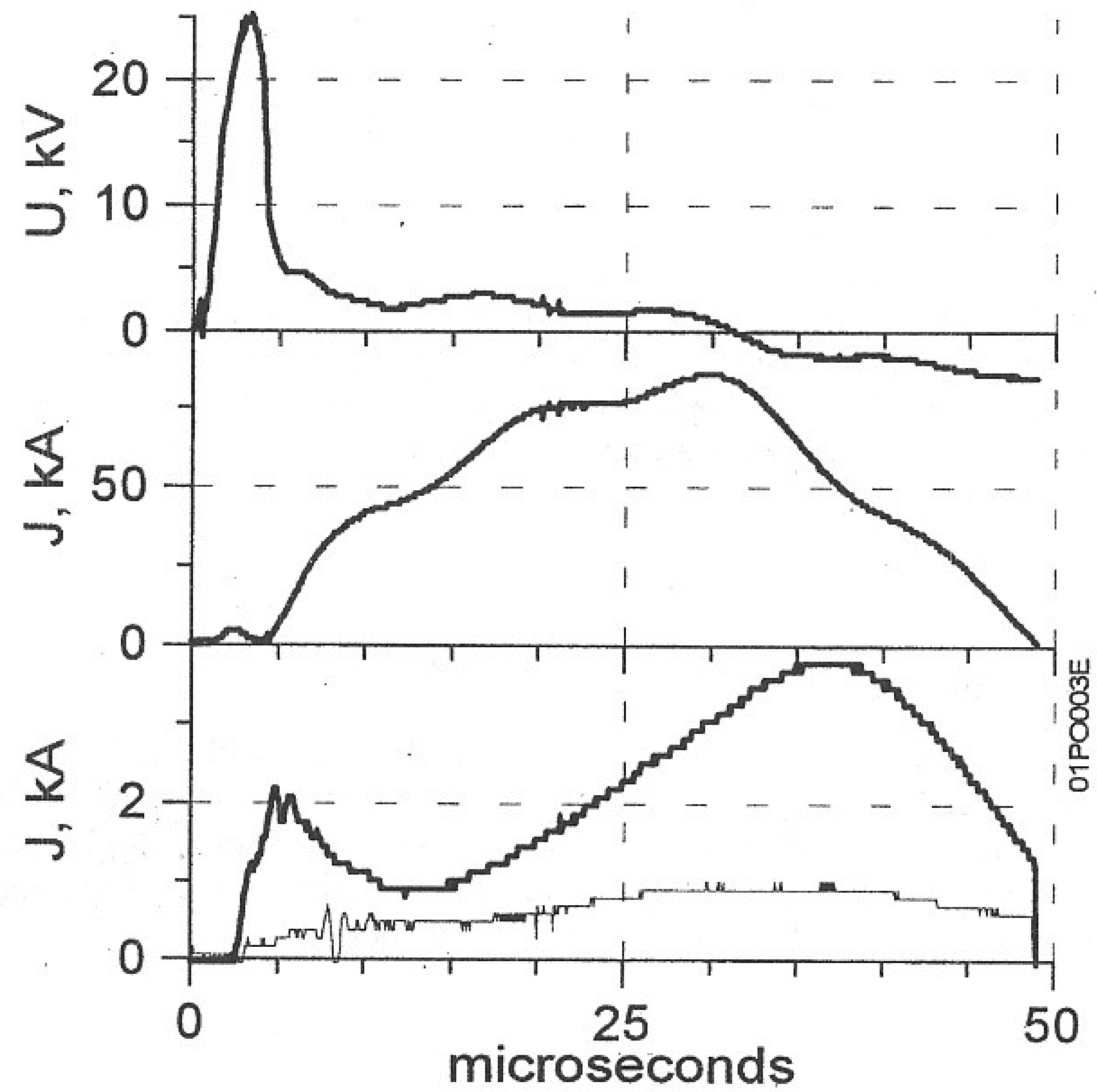

Fig 4. Waveforms (top to bottom): voltage; total current of the discharge system; plasma current, thick line – far side of the discharge column ends on the wall, thin line – foilless (no solid far end electrode).

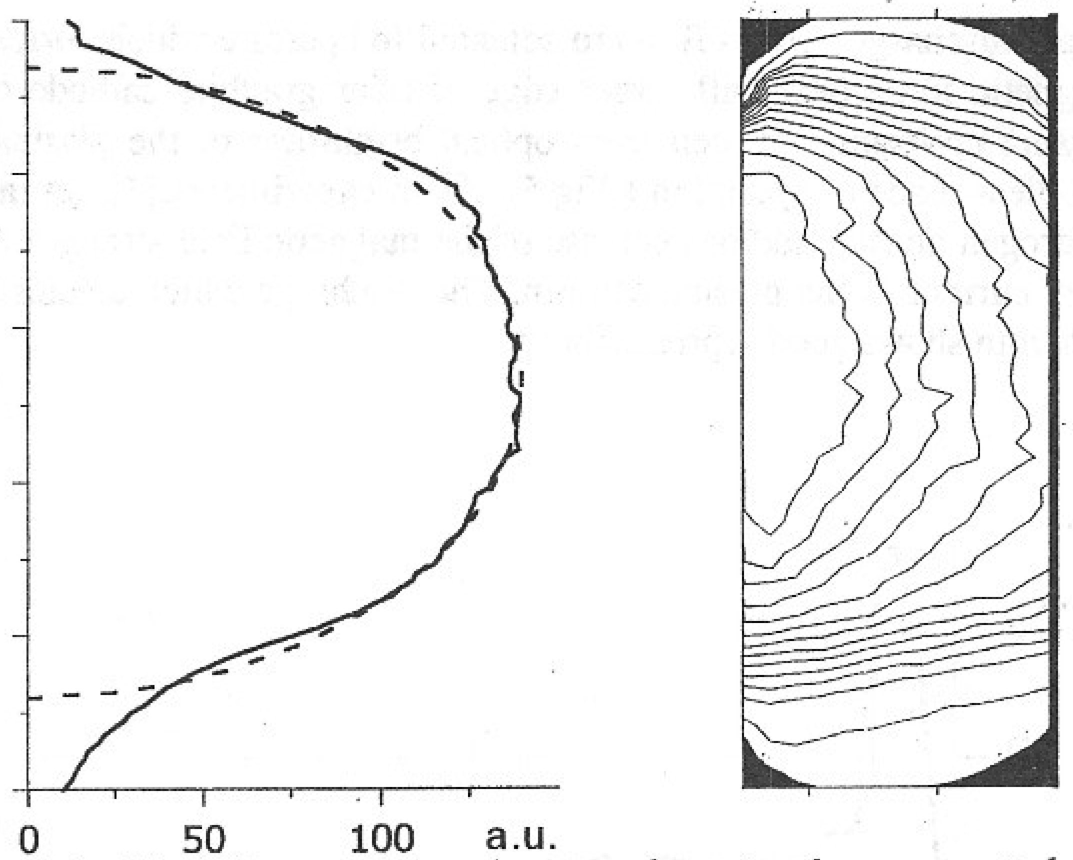

Fig 5. Optical brightness of the plasma column in the corrugated field (through the oval window at 11 meters from the plasma creation system). Right – 2D contour map, left – radial distribution of the brightness (solid line – measured, dashed – expected for uniform plasma density).

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 facility. Main features of the discharge are studied, the mechanism of discharge development is established. The plasma parameters are suitable for the experiments on beam-plasma interaction within 10^{14}-$5\cdot10^{16}$ cm^{-3} density range.

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**Long linear discharge
in corrugated magnetic field**

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**Длинный прямой разряд
в гофрированном магнитном поле**

ИЯФ 2001-17

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