LASER SHADOW AND INTERFEROMETRIC INVESTIGATION OF THE STRUCTURE AND DYNAMICS OF PLASMA IN PF-3 FACILITY

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The work presents the laser investigation of a plasma focus discharge in neon. This investigation was done in connection with the recently discussed possibility of the use of such type of discharges for the creation of the soft X-ray source and its application for the compression of the solid targets (liners). Some features of a plasma focus discharge in 2.8 MJ Plasma Focus such as a complicated structure of current-plasma sheath (CPS), its relation to soft X-ray (SXR) pulse emitted from a pinching region were studied by developed laser diagnostics.

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1. INTRODUCTION

The use of Plasma Focus installation as a driver for the magnetic compression of liners is recently discussed [1]. Therefore, the knowledge of the current-plasma sheath (CPS) characteristics during its compression is very necessary. In this work we describe the developed in P.N. Lebedev Physical Institute laser diagnostics and its application for the study of plasma focus discharge in pure neon on 2.8 MJ Plasma Focus PF-3 facility (RRC "Kurchatov Institute).

2. LASER DIAGNOSTICS AND PF-3 FACILITY

The developed laser diagnostics complex permits to conduct the shadow and interferometric investigation of pulsed plasma. The features of the PF-3 facility (total energy of 2.8 MJ, high-radiative gas - neon, large geometrical dimensions, etc.) impose some requirements for the design and the implementation of laser diagnostics. It is based on the single passage Makh-Rozdestvensky interferometer with the arm of 4.8 m by length and with the aperture of 10 cm and Nd:YAG-laser at the second harmonic with the pulse of 60 mJ for 4.8 ns (Fig.1). The obtained interferograms are entered into a computer by scanning and, then, the operation follows with a digital image. The calculation is done for an axisymmetric electron density profile [2].

3. SHADOWGRAPHY OF THE EVOLUTION OF THE CURRENT-PLASMA SHEATH

Shadow pictures were taken with the aim to determine a working-capability of diagnostics and to collect the preliminary information about spatial-temporal parameters of CPS relative to the moment of a pinch formation. Since a single-frame registration diagram was done at the first stage of the investigation, the discharge dynamics was statistically studied with the pictures taken in different discharges but under identical initial conditions.

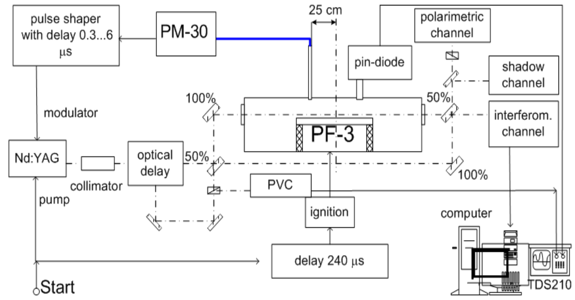
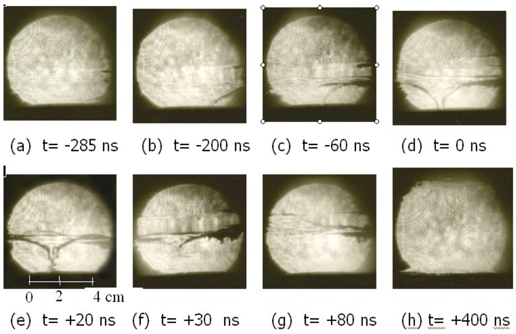


Fig.1. Scheme of the laser diagnostics and the Plasma Focus Facility PF-3

Therefore, the discharge mode with a maximal reproducibility was chosen. The time fixation of the CPS position at the registration moment was checked by the shift between a coaxial photocell (PVC) signal registering the laser pulse and a start-up of a soft X-ray pulse (accepted as a conditional beginning of the time count, t = 0). A series of the shadowgrams taken at W = 140 kJ, U = 5.5 kV, P(Ne) = 1 Torr, I ~ 1.5 MA (Fig. 2) allows one to determine the CPS configuration and to estimate its the radial and axial velocities (Figures 2 b, c, d).



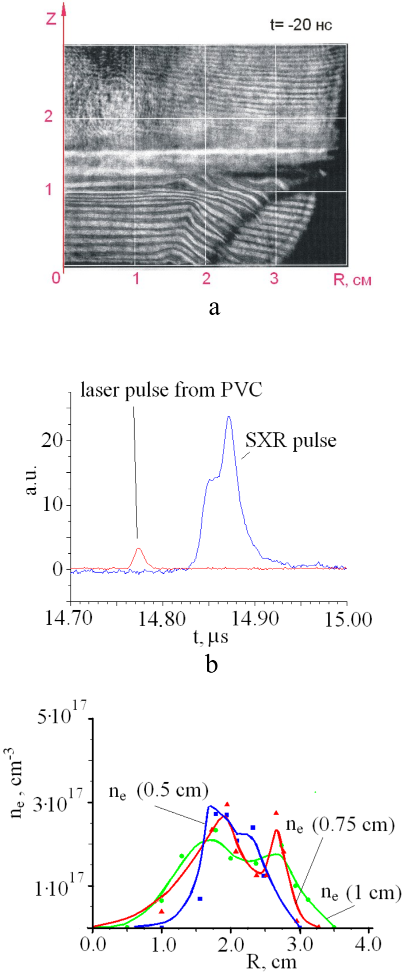
(a) t= -285 ns (b) t= -200 ns (c) t= -60 ns (d) t= 0 ns
(e) t= +20 ns (f) t= +30 ns (g) t= +80 ns (h) t= +400 ns

Fig. 2. Shadowgrams of the CPS evolution

In Figure 2 (e) one can see the development of the neck type instabilities with the wave length of ~ 0.5 cm, at the total neck length of ~ 2 cm, in ~ 20 ns after the cumulation moment. This figure also illustrates the mechanism of the two stages of compression. The equilibrium pinch radius in the 1st one is ~ 0.4 cm, and the 2nd is ~2.5 mm. It is also clearly seen that a “slow” running in the near-axial zone sheath by height about 3 cm is the characteristic one for given compression modes. The pinch decay stage is represented in Figure 2 (f); the plasma sheath motion along the axis from the anode at some later stages is given in Figure 2 (g, h). The axial sheath velocity can be estimated as (9.3 ± 0.5) · 10^6 cm/s.

4. INTERFEROMETRY OF CURRENT-PLASMA SHEATH

Some typical interferograms of a plasma focus discharge received at the different moments of time are shown in Figures 3a and 4a. In both cases, W = 375 kJ, U = 9 kV, P(Ne) = 1 Torr.



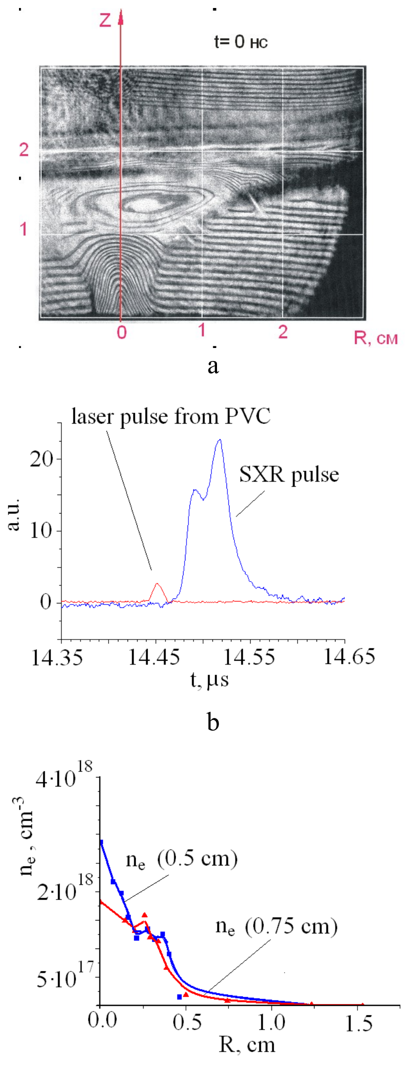
a

b

c

Fig. 3. Pulse #15 (26.12.02) u=9 kV, p=1 Torr: a)interferogram at t=-20ns, b)oscillogram SXR and PV, c)density profiles at different distances from anode

Electron density profiles at different distances from the anode are given as graphs, Fig. 3c and Fig. 4c. The profile comparison for various heights allows one to observe the phenomena related with the CPS-non-cylindricity. For example, an effect of the flowing out for the gas involved into the motion from the area between “skin-layer – shock wave front” due to the gradient nT – d(nT)/dZ towards a wide part of the funnel.



a

b

c

Fig. 4. Pulse #18 (26.12.02) U=9 kV, P=1 Torr: a)interferogram at t=0ns, b) oscillogram SXR and PV, c) density profiles at different distances from anode

Two stable maxima in the electron density profile are observed in Figs. 3c, 4c. The SXR-pulse also has a similar structure. The oscillograms of the corresponding SXR-pulses are shown in Fig. 3b, 4b. The pulse from the PVC was used for synchronization.

In the oscillograms (Fig. 3b and Fig. 4c) the PVC and SXR pulses are shown without the account of the pulses delay in cables, i.e. in the case of their coincidence in the Figures, actually the signal from the PVC advances the SXR-pulse by 43 ns. All the time data shown in interferograms and shadowgrams are reduced to the real time.

The observed two peaks of the SXR and the time shift between them may be explained by the two density maxima in the CPS. Proceeding from the value of CPS-velocity near the axis, obtained by shadowgraphy (≥ 10^7 cm/s), the time shift in the arrival of various density maxima to the axis has to be $\sim$ 30-40 ns, that coincides – by the order of magnitude – with the time between two SXR pulses.

5. CONCLUSIONS

The data measurements of the CPS-structure and its evolution in one of the PF-3-operation modes were conducted in the energy range between 150 … 500 kJ. It was found that: - the CPS-thickness is 0.4 cm – 2 cm, dependent on the gas pressure and the charging voltage; - the electron density in the shell attains $3 \cdot 10^{18}$ cm^{-3} at a moment of the arrival of the CPS front at the axis. It has two maxima. This fact can serve as one of the possible explanations to the presence of two peaks in the SXR-pulse; - the CPS-velocities near the axis are in the range from $(8.6 \pm 0.5) \cdot 10^{6}$ cm/s to $(1.3 \pm 0.1) \cdot 10^{7}$ cm/s.

A time correlation between the SXR-pulse generation start-up and the moment of the convergence of the CPS front at the axis is confirmed

An analysis of the oscillograms and of the shadowgrams allows one to note the following plasma focus discharge profile at the PF-3-facility: -the current plasma sheath is different thick in height that can be provided by the mass outflow as a result of the CPS-non-cylindricity; - the CPS-thickness depends on the initial pressure in the chamber: the greater the pressure, the thicker the sheath. With an increase of the charging voltage under the same pressure, the sheath thickness is reduced; - a peculiar feature of the plasma focus discharge in neon is, probably the formation of a phase-inhomogeneous zone at the axis at the moment of cumulation providing a picture similar to the speckle distribution in a coherent light (an effective dull plate with a characteristic inhomogeneity size of ~ µm is produced); -the CPS-motion towards the axis is accompanied by an intense production of peculiarities, like “tails” upon a vast part of the external CPS-surface. The probable mechanism of a given phenomenon is a plasma flow out into the zone of a weaker magnetic field. Similar peculiarities are also observed under registration with electron optics converters.

ACKNOWLEDGEMENTS

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ЛАЗЕРНОЕ ТЕНЕВОЕ И ИНТЕРФЕРОМЕТРИЧЕСКОЕ ИССЛЕДОВАНИЕ СТРУКТУРЫ И ДИНАМИКИ ПЛАЗМЫ В УСТАНОВКЕ ПФ-3

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В работе представлено лазерное исследование плазмофокусного разряда в неоне на установке ПФ-3. Исследования были выполнены в связи с обсуждаемой в последнее время возможностью использования такого типа разрядов для создания мощных источников мягкого рентгеновского излучения и применения их для сжатия твердых мишеней (лайнеров). Некоторые особенности плазмофокусного разряда в установке ПФ-3 такие, как сложная структура токово-плазменной оболочки и ее связь со свойствами импульса мягкого рентгеновского излучения, излучаемого из области пинчевания плазмы, исследованы с помощью разработанной лазерной диагностики.

ЛАЗЕРНЕ ТІНЬОВЕ І ИНТЕРФЕРОМЕТРИЧНЕ ДОСЛІДЖЕННЯ СТРУКТУРИ І ДИНАМІКИ ПЛАЗМИ В УСТАНОВЦІ ПФ-3

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У роботі представлене лазерне дослідження плазмово-фокусного розряду в неоні на установці ПФ-3. Дослідження були виконані в зв'язку з обговорюваною останнім часом можливістю використання такого типу розрядів для створення могутніх джерел м'якого рентгенівського випромінювання і їх застосування для стиску твердих мішеней (лайнерів). Деякі особливості плазмово-фокусного розряду в установці ПФ-3 такі, як складна структура струмо-плазмової оболонки і її зв'язок із властивостями імпульсу м'якого рентгенівського випромінювання, випромінюваного з області пінчування плазми, досліджені за допомогою розробленої лазерної діагностики.