STUDIES OF LIGHT LINER COMPRESSION DYNAMICS IN PLASMA FOCUS

M.A. Karakin, E.Yu. Khautiev, V.I. Krauz, A.N. Mokeev, V.V. Myalton, V.P. Smirnov
RRC "Kurchatov Institute", Institute of Nuclear Fusion, Moscow, 123182, Russia

The study is devoted to the investigation of plasma focus systems as a driver for magnetic compression of liners. The experiments on the comparative analyse of the foam and multiwired liners compression were done on the Filippov-type plasma focus facility PF-3. The compression of the light (linear mass 0.3-0.6 mg/cm) liners with velocity (2-3)$\cdot 10^6$ cm/s was obtained. It is shown that under conditions of considerable radiation fluxes at the usage of strongly-radiating working gases a preliminary heating of the target can be attained. This results in acceleration of the transition of initially – condensed substance into plasma state, that assists in overcoming "cool start" problem.

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INTRODUCTION

The main goal of this study is the investigation of plasma focus (PF) systems as driver for the magnetic liner compression. The first studies shown the principal opportunity of a similar approach were made in the joint Russian-Polish experiment in Warsaw at the PF-1000-facility [1]. The compression of the foam liner with the linear mass of 200 μg/cm, at the discharge current amplitude of 1 MA, was observed in that experiment. Later on, the similar experiments were made at the PF-3-facility, RRC "Kurchatov Institute", using the multiwired [2] and foam [3] liners. This study is devoted to the comparative analyse of the foam and multiwired liners compression on the Filippov-type plasma focus facility PF-3.

EXPERIMENTAL SETUP

The experiments were done on the PF-3 facility (Plasma Focus Filippov-type) at the energy level 450÷550 kJ and discharge current amplitude up to 3 MA. Scheme of the experiments is shown in Fig.1. Discharges were performed at the conditions of stationary filling by neon at the pressure 1 Torr.

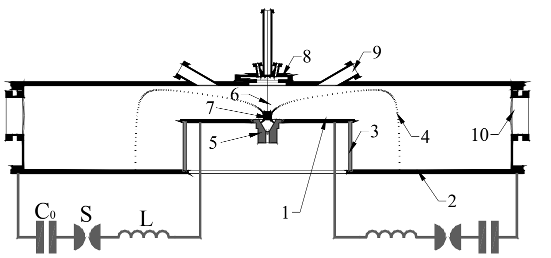


Fig.1 Scheme of the liner experiments
1 – anode; 2 – cathode; 3 – insulator; 4 – plasma current sheath; 5 – anode insertion; 6 – suspension ware; 7 – liner; 8 – loading unit with a vacuum lock; 9, 10 – diagnostics ports; C_0 – capacitor bank; S – low pressure spark gap switch; L – external inductance

A special device (Fig.2) with a vacuum lock has been developed for liners delivering to the compression zone. This allows one to execute the preliminary "training" of a discharge chamber for improving the parameters of a plasma current sheath and to perform the replacement of the liner without violation of a vacuum in the chamber. The device is located upon the upper cover (cathode) of the discharge chamber. All the design elements are located outside the discharge volume and they do not introduce heterogeneity violating the PCS-dynamics. The liner (11) is suspended upon a thin (~ 60 μm) polymeric (fishing-line) or metallic filament (10) and descended to the necessary position at the system axis with the mobile rod located in the cylindrical column sluice.

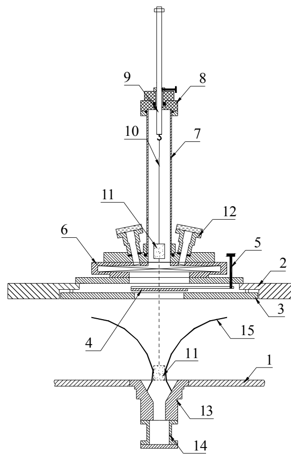


Fig.2. Design of a loading unit:
1 - anode; 2 - cathode; 3 - stationary protective flange; 4 - rotary barrier; 5 - handle of a rotary barrier; 6 - vacuum lock; 7 - sluice column; 8 - vacuum - tight input; 9 – metallic rod; 10 – suspension wire; 11 - liner; 12 - diagnostic ports; 13 - anode insertion; 14 - volume for spent liners; 15 - PCS

The technology of wire array and foam liners production has been developed at TRINITI (Troitsk). The wire array design is a cylinder formed of 60 tungsten wires, 6 ÷ 8 μm in diameter, 15 mm long. Wires are pulled between two metallic discs along the diameter of 20 mm with a step of ~ 1 mm.

Two variants of foam liners made of agar-agar with different diameters, 10 and 20 mm, were used in the experiments. The specific foam density, $\rho = 1$ mg/cm^{-3}. The working liner surface height is 15 mm. A discernible feature of liner design is the presence of a central supporting dielectric rod, 3 mm in diameter, in some cases. The introduction of this rod was a forced and unavoidable measure for light liners of large diameter.

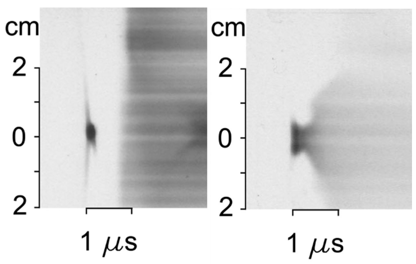
DIAGNOSTIC TECHNIQUES

In those experiments the main emphasis was done on the compression dynamics study. The presence or absence of the compression effect was considered as the main factor in finding the prospects for the PF-3-facility implementation for these goals. Therefore the main diagnostics at that stage were:

1. Measurement of a discharge current and that of its derivative with the Rogowski coil and with the magnetic probes;
2. Photographing of a pinch in the X-rays with the two pin-hole cameras placed on the side chamber surface at the angle 90° to the system axis and on the upper flange at the angle of 60°;
3. Measuring of the X-ray radiation with Pin-diodes. The time resolution is 1.5 ÷ 3 ns;
4. Study of the PCS-dynamics and of the pinch formation in a visible light with a streak-camera and with a 4-channel diagnostics based on frame cameras at the frame exposure of 10 ns and with time delay between frames of 150 ns long;

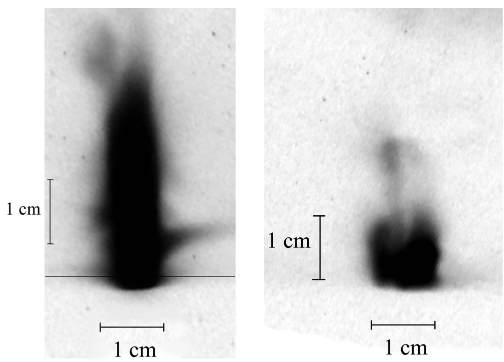
EXPERIMENTAL RESULTS

Streak camera images of the discharges with the foam liner of a small diameter 10 mm are given in Fig.3 b. A streak camera image of a discharge without liner is given for comparison in Fig.3a. The compression is observed rather clearly. In a number of cases, the X-ray luminosity takes place at the axis in zone the liner location (Fig.4) that directly shows the pinching there.



a) b)

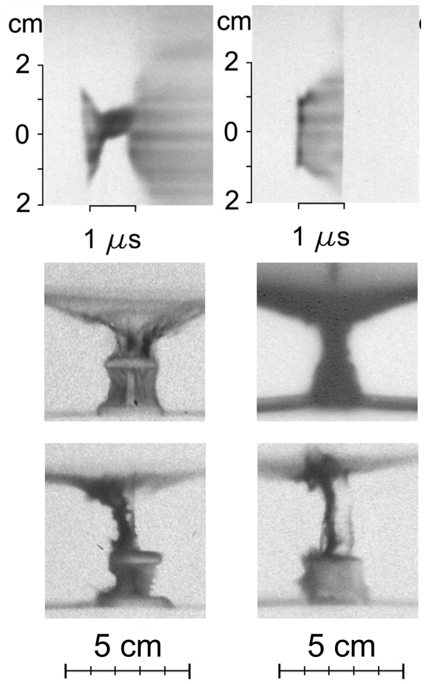
Fig. 3. Streak camera images of the discharges without liner (a) and with liner (b); liner diameter is 10 mm, m = 0.4 mg/cm, I = 2 MA



a) b)

Fig. 4. Pin-hole pictures of the pinch without liner (a) and with liner (b); direction of registration is 90° to the system axis, diaphragm is 0.2 mm covered by Be 10 μm filter

The very first experiment with the light liner (300 μ g/cm) of a large diameter has reliably shown a compression effect (Fig. 5a). A better space resolution has allowed us estimate the compression rate: V ~ 2.5. 10^6 cm/s. In difference from the experiment in Warsaw [1], we don't observe a delay at the beginning of compression, necessary for the transition of a foam substance into a plasma state. Moreover, an initial radius of the substance under compression somewhat exceeds the initial liner radius. We consider it to be an encouraging factor, confirming our assumption about the possible preliminary liner heating by the sheath radiation. This results in its expansion, on the one side, and alleviates the discharge current "over-capture", on the other one.



a) b)

Fig. 5. Streak-camera and frame camera pictures of the discharges with 20 mm liner:
a) m=0.3 mg/cm, I = 2 MA, time shift between upper and lower frame camera pictures, τ=150 ns;
b) m=1 mg/cm; I= 2 MA, τ=150 ns

The compression is stopped at the diameter of 6 – 7 mm, that can be explained by a stabilizing effect of the central rod (liner armature, central rod included, is well seen on the first frame camera picture). The very fact that the plasma is located in the compressed state for a long time (≥ 0.5 μs) is worth of attention. Subsequent fast pinch destruction and the emergence of a luminosity in a great zone we refer to the arrival of plasma fluxes and/or of vapours of copper from a conical anode insertion.

We couldn't detect the compression of a heavy liner (1-4 mg/cm) at this value of a discharge current. The plasma expansion occurs immediately after the sheath shock at the liner (Fig. 5b).

Wire array liners possess of a number of peculiarities in comparison with the foam ones:

- the presence of an initial conduction;

- the usage of the wires of different materials allows one to change the radiation spectrum and the intensity of a yield;
- the presence of the ordered structure, where the wires are located with a step of ~ 1 mm in difference from foam liner having the chaotic structure with the characteristic non-homogeneity size of about 30 μm.

One of the premises for performing the experiments with the wire arrays was their successful implementation in the recent experiments with fast systems [4].

It has been shown that, after current sheath contact with the liner, an essential portion of a current continues to flow in the vicinity to the wires during the period necessary for transferring the current to the liner. But some portion of a current is "dropped" down to the axis, producing a pinch. The very wires remain to be immobile during ~ 150 ns for the light liner and during ~ 300 ns for the heavy one, then a rather fast compression of the liner to the axis occurs. The rate of this compression, estimated from the streak camera pictures, is about 3.10^6 cm/s for the light liner, and ~ 2.10^6 cm/s for the heavy one (Fig.6). Thus the time of the current switching on the wire array and velocity of its consequent compression to axis depend from linear mass of the liner. Later on, a comparatively-slow pinch expansion takes place at the rates approximately-lower than the compression ones by the order of magnitude.

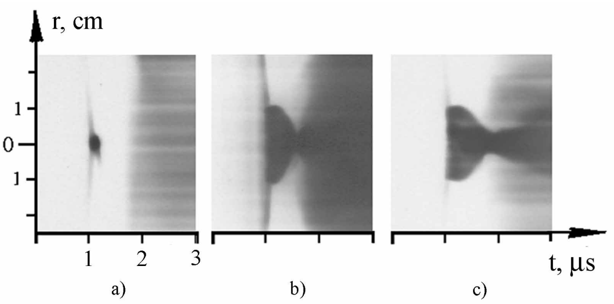


Fig. 6. Streak camera pictures:
a) discharge in neon without liner;
b) wire array, 330 μg/cm; c) wire array, 600 μg/cm

CONCLUSIONS

The main result of these experiments is, first of all, the conclusion about an opportunity to realize the liner compression at the PF-3 facility. The compression of the light liners, both foam and multiwire ones, with velocity (2-3) 10^6 cm/s was obtained. The final result can be affected by the shape and symmetry of the sheath, as well as by the quality of a given liner manufacture. Along with the identity of many physical processes in a plasma focus, Mather's type and Filippov's type, there is a number of the differences in a plasma current sheath dynamics which can essentially affect the process of interaction between the current sheath and the liner. One of them is the presence of a long duration radial compression stage (~ 10 μs) in the flat electrode geometry. Under conditions of considerable radiation fluxes at the usage of strongly-radiating working gases (neon, for example) a preliminary heating of the target located at the axis and acceleration of the initially – condensed substance transition into plasma state can be attained. Therefore, in such discharge one can effectively control over the process of the liner evaporation and ionization by changing the liner parameters that assists in overcoming "cool start" problem.

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ДОСЛІДЖЕННЯ ДИНАМІКИ СТИСНЕННЯ ЛЕГКИХ ЛЕЙНЕРІВ В ПЛАЗМОВОМУ ФОКУСІ

М.А. Каракін, Е.Ю. Хаутієв, В.І. Крауз, А.М. Мокеєв, В.В. Мялтон, В.П. Смірнов

Робота присвячена дослідженню плазмового фокусу (ПФ) в ролі драйвера для магнітного обтиснення лайнерів. Проведено експерименти з порівняльного аналізу стиснення пінних й багатодротових лайнерів на установці типу Філіппова ПФ-3. Отримано стиснення лайнерів з погонною масою 0.3-0.6 мг/см зі швидкостями (2-3).10^6 см/с при амплітуді розрядного струму 2 МА. Показано, що в умовах значних радіаційних потоків при використанні сильновипромінюючих робочих газів може бути здійснений попередній нагрів мішені. Це призводить до прискорення переходу первісно конденсованої речовини у плазмовий стан, що дає змогу подолати проблему «холодного старту».

ИССЛЕДОВАНИЕ ДИНАМИКИ СЖАТИЯ ЛЕГКИХ ЛАЙНЕРОВ В ПЛАЗМЕННОМ ФОКУСЕ

М.А. Каракин, Э.Ю. Хаутиев, В.И. Крауз, А.Н. Мокеев, В.В. Мялтон, В.П. Смирнов

Работа посвящена исследованию плазменного фокуса (ПФ) в качестве драйвера для магнитного обжатия лайнеров. Проведены эксперименты по сравнительному анализу сжатия пенных и многопроволочных лайнеров на установке типа Филиппова ПФ-3. Получено сжатие лайнеров с погонной массой 0.3-0.6 мг/см со скоростями (2-3).10^6 см/с при амплитуде разрядного тока 2 МА. Показано, что в условиях значительных радиационных потоков при использовании сильноизлучающих рабочих газов может быть осуществлен предварительный нагрев мишени. Это приводит к ускорению

перехода первоначально конденсированного вещества в плазменное состояние, что способствует преодолению проблемы “холодного старта ”.