CURRENT SHEATH STUDIES BY MAGNETIC PROBES ON PLASMA FOCUS PF-400

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The time resolved studies of the current sheath formation in a plasma focus discharge of Filippov type with energy stored in capacitors 60 kJ and maximum current 0.9 MA are presented. The current data received by two magnetic probes placed at radii 15 cm and 20 cm were compared with the total current detected by Rogovsky loop. It was found out in discharges with low neutron yield the formation of the extra current sheathes following one after another in 1-th, 2-th and even 3-th half-period of discharge. The single current sheath was observed in the discharges with the high neutron yield. The absolute current measurements showed that the whole discharge current goes throw paraxial area r < 15 cm during the phase of radial implosion, but at the instant of the peculiarity on the current derivative it is no more then half of value of total current. The value of the pinch current remains under the question.

PACS: 52.58.Lq; 52.57.-m

1. INTRODUCTION

When describing the neutron yield from plasma focus facilities (PF), the following two scaling lows are usually used [1,2]. One relates the neutron yield Y_n to the energy E [J] stored in the capacitor bank (1) and other – to the discharge current *I* [A] (2):

$$Y_n \approx 10E^2 \qquad (1)$$

$$Y_n \approx 10^{-13} I^4 \qquad (2)$$

These scaling lows were obtained experimentally in the last century on facilities with stored energies of 1-100 kJ and raised hope that a PF would be used as a prototype thermonuclear reactor, provided that the stored energy could be increased by two to three orders of magnitude. Later, it was found, however, that the neutron yield is saturated when passing to the megajoule energy range: instead of the expected 10^{13} neutrons per shot, the neutron yield was at least ten times lower [3], although current scaling (2) usually remained valid. There are two main reasons of the neutron yield saturation:

- slowing of current growth with the energy increase for the Mather type plasma focus [4];
- pinch current shunting by the peripheral plasma (for both Mather and Filippov types of PF).

This work deals with the study of the current shunting on Filippov type plasma focus.

2. EXPERIMENTAL SETUP

Experiments were carried out on a PF device with flat electrodes 47.4 cm and 69 cm in diameter. The isolator height is 12 cm. Electrodes were powered by 120 µF capacitor bank up to 33 kV which corresponds to the stored energy about 60 kJ. The current rise time was 4.5 µs and the current amplitude was I_{max} = 0.9MA. The working gas was deuterium at the pressure 0.2 Torr. The location of magnetic probes is shown in Fig. 1. In the every shot we recorded the total current by Rogovsky loop, the current derivative and the two probes signal. The signals were registered by the oscilloscopes TDS 3054. Also we measured the total neutron yield by the use of a neutron-activation technique (paraffin + In + Geiger counter).

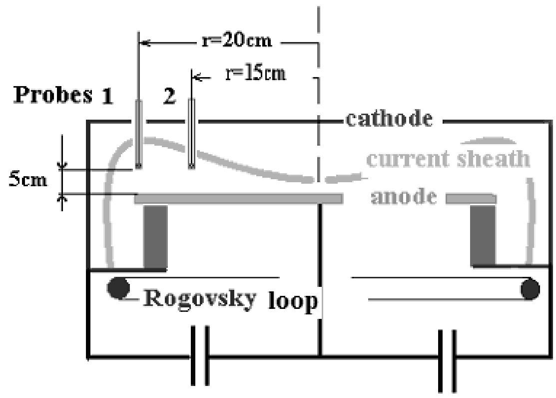

Fig. 1. The experimental setup

3. EXPERIMENTAL RESULTS

Fig. 2 shows typical oscilloscope traces taken off when stable regime of the PF device was achieved (the neutron yield about 10^9 n/pulse). The time delay between the fronts of the probe signals permits to estimate the radial current sheath velocity, which in the area $15 < r < 20$ cm amounts $5 \cdot 10^6$ cm/s. The time delay between the signal of magnetic probe 2 and time of the appearance of "peculiarity" on the oscilloscope trace of current gives the value of radial velocity 10^7 cm/s at $r < 15$ cm.

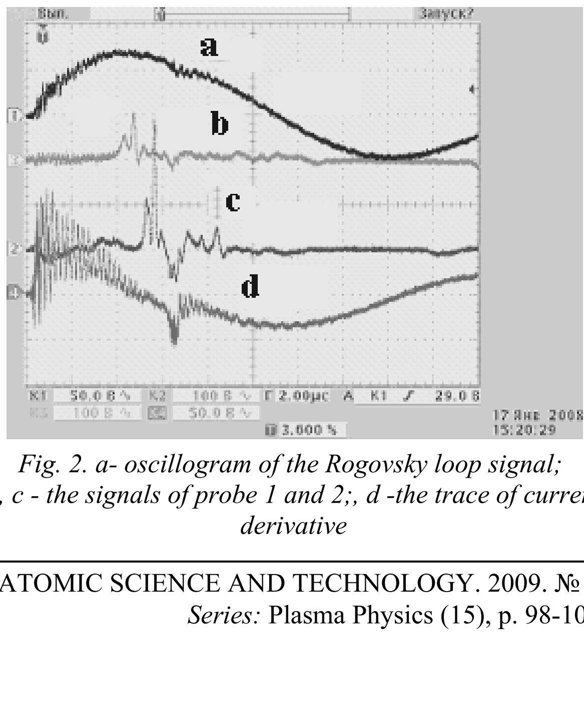

Fig. 2. a- oscillogram of the Rogovsky loop signal; b, c - the signals of probe 1 and 2;, d -the trace of current derivative

The numerical integration of the probe signals is shown in Fig. 3. As a rule, the current inside the area $r < 15$ cm at the moment 1 μs before the appearance of "peculiarity" is coincide with the total discharge current in the shots with the neutron yield about $Y \sim 10^9$ n/pulse. However, the above current at the "peculiarity" instant is 30-50% of total one. The pinch current at moment of maximum compression is under the question. Also it is interesting to see that total current drop is no more than 15%.

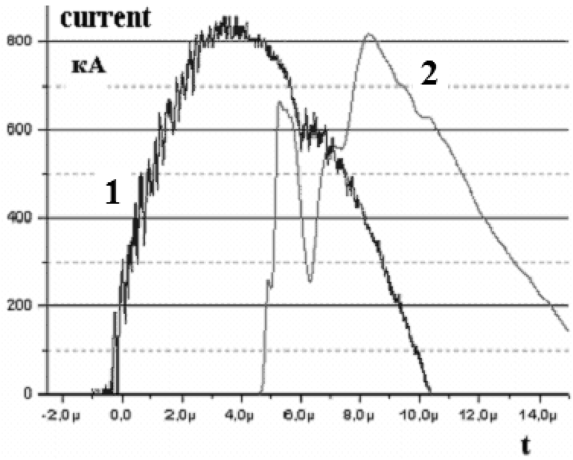

Fig.3. Comparison of current date from Rogovsky loop and probe. 1 – the Rogovsky loop signal, 2 - the numerical integration of the probe signals

Neutron measurements showed that absolute yield of neutrons corresponds with the neutron scaling if in (2) for the value of current to use the current measuring by probe 2 at the "peculiarity" instant. One can to note that the use in (2) the value of total current at the "peculiarity" instant gives neutron yield one order higher than actual yield.

In the "bad" shots (when the neutron yields is low or during the initial training discharge series) we often observed the formation of several current sheathes, following one after another in 1-th, 2-th and even 3-th half-period of discharge (Fig. 4). Obviously, in this case the good current compression is not achieved. We have shown early [3] that multi sheath structure is formed due to the low snowplowing efficiency of the working gas. The structure of the successive sheathes differs from the first one - they have no two peaks on probe oscillogram.

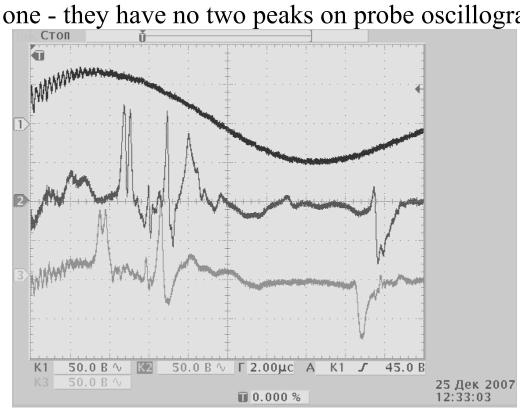

Fig. 4. The "bad" shot, when the neutron yield was low

One can see on Fig. 3 that in the 2nd half-period of the discharge the direction of total current and current $I_{r<15}$ flowing inside the area r < 15 cm do not coincide. It may be explained by the existence of toroidal plasma-current vortexes in residual gas (Fig. 5) [5,6].

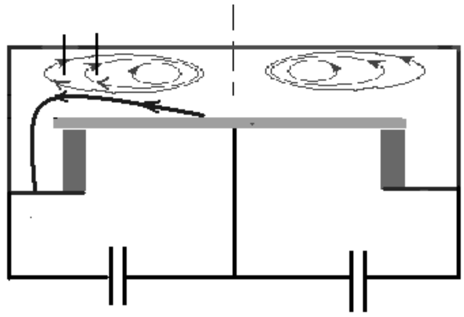

Fig. 5. The toroidal plasma-current vortexes in the 2nd half-period of the discharge

4. CONCLUSIONS

1. At the "peculiarity" instant the total current I_{tot} in 2-3 times more then current $I_{r<15}$ flowing inside the area with r < 15 cm.
2. The substitution current flows into r < 15 cm at the "peculiarity" instant $I_{r<15}$ in neutron scaling coincides with real yield.
3. The difference between I_{tot} and $I_{r<15}$ is consequence of current sheath transparency.
4. It was detected toroidal vortexes and repeated current sheathes, which complicated whole picture of current flowing in plasma focus discharge.

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Article received 22.09.08

ИССЛЕДОВАНИЕ ТОКОВОЙ ОБОЛОЧКИ ПЛАЗМЕННОГО ФОКУСА ПФ-400 МАГНИТНЫМИ ЗОНДАМИ

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Проведены исследования токовой оболочки плазменного фокуса филипповского типа с энергетикой 60 кДж и максимальным током 0.9 МА. В эксперименте сравнивались одновременные показания полного тока разряда с пояса Роговского и токов, регистрируемых двумя магнитными зондами внутри приосевой области R < 20 см и R < 15 см. Обнаружено существование вторых и третьих токовых оболочек, следующих за первой, в выстрелах с низким нейтронным выходом. При нормальном выходе существует только одна токовая оболочка. Абсолютные токовые измерения показали, что во время прохождения зондов токовой оболочкой полный ток разряда совпадает с током, текущим в ней, но в момент особенности его значение внутри R<15см в 2-3раза меньше полного тока во всех выстрелах. Обнаружены вихревые тороидальные токи в остаточном газе, окружающем пинч.

ДОСЛІДЖЕННЯ СТРУМОВОЇ ОБОЛОНКИ ПЛАЗМОВОГО ФОКУСА ПФ-400 МАГНІТНИМИ ЗОНДАМИ

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Проведено дослідження струмової оболонки плазмового фокуса філіпповського типу з енергетикою 60 кДж та максимальним струмом 0.9 МА. В експерименті порівнювались одночасні покази повного струму розряду від пояса Роговського й струмів, які реєструються двома магнітними зондами всередині приосьової області R < 20 см й R < 15 см. Спостережено наявність других й третіх струмових оболонок, наступних за першою, у пострілах з низьким нейтронним виходом. За умови нормального виходу існує тільки одна струмова оболонка. Абсолютні струмові виміри показали, що під час проходження зондів струмовою оболонкою загальний струм розряду співпадає зі струмом, що протікає у ній, але в момент особливості його величина усередині R<15см у 2-3 рази менше за повний струм за період усіх пострілів. Спостережені вихрові тороїд альні струми в остаточному газі, який оточує пінч.