U-3M PLASMA START-UP SCENARIO SUSTAINED BY GAS PUFFING AS A DIFFERENT PLASMA CONFINEMENT SCENARIO: FIRST RESULTS

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In order to reduce flux of neutrals into the plasma confinement volume, discharge start-up scenario maintained by impulse gas puffing (GP) has been proposed. Absence of constant working gas feeding in this scenario opens a possibility to reduce working gas pressure in the U-3M vacuum vessel. It was shown that the time of entire vessel filling after sharp gas puffing pulse is about 10…20 ms. In discharges with 5…6 kV on the RF generators and proposed start-up scenario, a delay between GP pulse and plasma creation was shorter than the chamber filling time. The same level of the electron density has been achieved in the discharge under consideration and conventional 5…6 kV discharge maintained by the constant gas feeding only. The H_α emission waveform in the considered discharges is similar to its waveforms in the conventional devices where the sizes of vacuum chamber and plasma are close each other.

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INTRODUCTION

A role of neutrals in plasma confinement at small and medium size fusion devices is underestimated. Ohmic H-mode initiated by a fast pulsed additional gas puffing has been observed in the small limiter tokamak TUMAN-3 and TUMAN-3M [1]. Suppression of edge fluctuations and increase of the particle confinement time triggered by gas puffing has been reported in the small limiter tokamaks STOR-M [2] and ADITYA [3].

Neutrals can introduce additional viscosity which dominates the neo-classical ion viscosity in the gas fueling region [4,5]. Furthermore, according to these studies, the neutral flux can modify or even determine the edge radial electric field and plasma rotation. Recent experiments in large tokamaks and spherical tokamaks [6,7] have shown that neutral atoms in the tokamak edge can influence global confinement by affecting the transition from low (L) to high (H) confinement modes.

An influence of neutrals can determines ion energy confinement of the small-size torsatron U-3M with plasma volume about 0.3 m^3 and net chamber volume ~70 m^3. Evidently, a substantial flux of neutrals with mean free path longer than U-3M plasma size from large U-3M vacuum vessel sustains main channel of the ion energy loss via charge exchange (CX) collisions in the low density discharges of U-3M. According to results of the CX measurements by neutral particle analyzers, energy confinement time of the 0.5…4.5 keV ions is less than 0.5 ms [8,9]. No difference between confinements of ion energy parallel to the magnetic field and perpendicular to the magnetic field was observed in U-3M. Therefore, an ion cooling through CX collisions with neutrals is the main channel for ion energy loss in the U-3M torsatron [8].

In order to reduce flux of neutrals in U-3M, another discharge start-up scenario has been proposed. In this scenario, the feeding of the plasma volume by working gas is maintaining by sharp gas puffing only. Absence of the constant working gas feeding in this scenario opens a possibility to reduce working gas pressure inside the U-3M vessel. First experimental tests of the proposed scenario are described in present work.

1. EXPERIMENTAL SETUP

Uragan-3M is a small size torsatron with $l/m=3/9$, $R_0=1$ m major radius, $\bar{a}\approx0.12$ m average plasma radius and toroidal magnetic field $B_0 \le 1\,\mathrm{T}$. The whole magnetic system is enclosed into a large 5 m diameter vacuum tank. Two type of RF discharges with low ($n_e=1…2\cdot10^{12}\ \mathrm{cm}^{-3}$), and higher ($n_e=5…10\cdot10^{12}\ \mathrm{cm}^{-3}$) densities are induced by frame and strap RF antennas [10].

The piezoelectric valve based GP injection into the frame antenna plasma region was controlled by computer system. A remaining between pulses pressure of the hydrogen was about 10^{-6} Torr in the GP discharges and about 10^{-5} Torr in conventional gas feeding discharges. Hydrogen was used as a working gas in all described experiments.

Gas stream was injected toward top U-3M helical coil from the valve located under the plasma confinement volume. It passes U-3M plasma cross-section and becomes partially ionized. A leftover of the not ionized gas stream is scattered on a wall of the helical coil and is reflected into the plasma confinement volume for further ionization.

2. CALIBRATION OF THE GP SYSTEM

In order to control a GP efficiency it is necessary to prove that the injected gas is immediately absorbed by a plasma and it is not filled the vacuum vessel. This efficiency can be estimated by a comparison of the GP vacuum chamber filling time and the plasma response time. The chamber filling time was measured by "PMI-27" vacuum gauge located in the bottom part of the chamber vessel. A fast response time of such type of gauges (about 10 μs) [11] sustains sufficient temporal resolution of the measurements. Time of the U-3M vessel filling by the hydrogen gas after sharp gas puffing (GP) pulse is about 10…20 ms, as it is shown in Fig. 1.

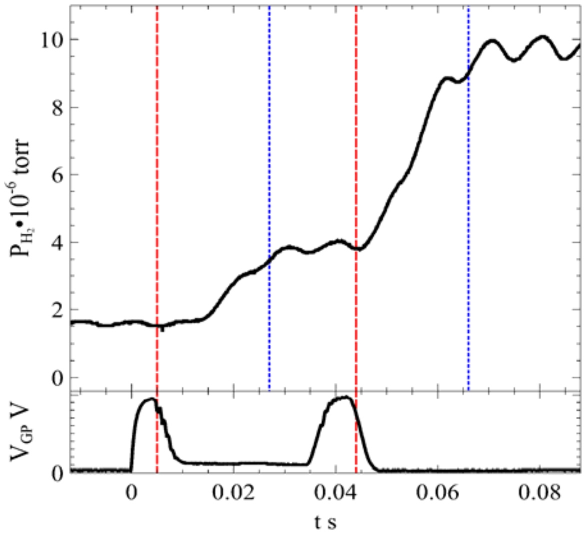

Fig. 1. Pressure evolution in the U-3M chamber after GP injections (top frame) and GP control voltage (bottom frame)

A pumping speed is very slow in comparison with the U3-M discharge durations (50…100 ms), as it is shown in Fig. 2.

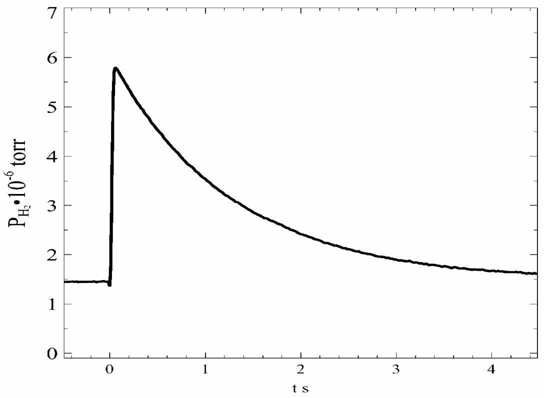

Fig. 2. Pressure evolution in the U-3M chamber after GP injections

A U-3M pump-out time corresponding to pressure decay to the initial level after GP injection is about 3…5 seconds, in used experimental conditions. Therefore the pumping can be ignored in the U-3M discharge particles balance.

3. RESPONSE TO THE GP INJECTION

Comparisons of the brightness of hydrogen spectral line H_α and the line averaged densities n_e in conventional and proposed discharges are shown in Fig.3. Proposed GP scenario has been tested only in discharges with low RF input power maintained by the voltage of 5…6 kV on the RF generators. Both frame and strap antennas were operating in these discharges. The delay between GP pulse (13…19 ms) and plasma creation time (16…18 ms) was shorter than the GP filling time in the proposed GP start-up scenario. This is an indication that GP stream injected into the plasma volume is ionized faster than gas outflow from the injection region to the U-3M vacuum vessel.

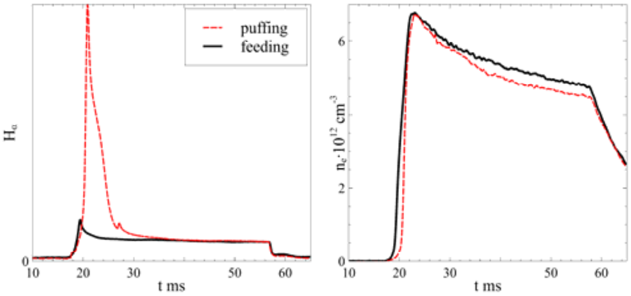

Fig. 3. H_α and n_e evolutions in conventional and GP only discharges

The same level of the line averaged electron density has been achieved in the discharge under consideration and conventional 5…6 kV discharge maintained by the constant gas feeding only, as it is shown in Fig. 3. An emission of the hydrogen line H_α was monitored in the GP injection region. Different behavior of the hydrogen emission line H_α has been observed in proposed and in the conventional discharges. The initial H_α peak during the plasma breakdown and the start-up stages is in an order of magnitude higher in the considered discharge scenario in comparison with the conventional one. This could be a clear indication that the local concentration of injected hydrogen and the plasma density in the frame antenna region are substantially higher in the proposed GP scenario in comparison with the conventional one. The H_α emission waveform in the considered GP discharges of chamberless device U-3M is similar to its waveforms in the conventional devices where chamber and plasma sizes are close each other.

An example of multiple GP injections in a flat top of the U-3M discharge is shown in the Fig. 4.

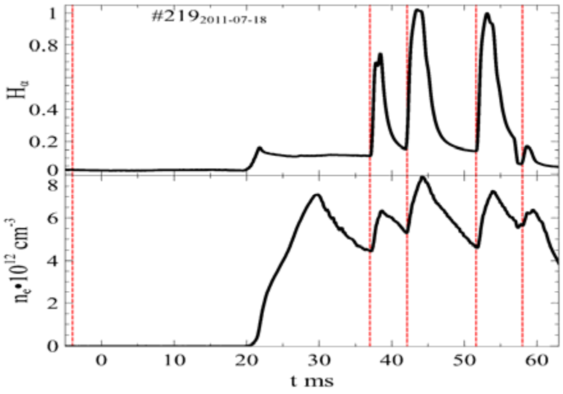

Fig. 4. H_α and n_e responses to multiple GP injections

As it is shown in this figure, the response time for each of the GP pulse, marked by dashed lines, is about few 1…3 milliseconds.

Frame antenna plasma breakdown problems were observed in conventional U-3M discharges recently. Additional plasma pre-ionization by the strap antenna has been used for the plasma start-up in these conditions. Successful frame antenna breakdown without pre-ionization was observed in the proposed GP experimental scenario. In this scenario the local hydrogen pressure and the plasma density consequently were higher in vicinity of the frame antenna than in the conventional scenario during breakdown and start-up stages. Such conditions can facilitate the plasma breakdown in the case of similar level of the line averaged density in a flat top of the discharge. Evidently, GP injection scenario can supply necessary for breakdown amount of neutrals locally, in the antenna region only.

CONCLUSIONS

Initial experiments with gas feeding by GP only and low input RF power show a possibility of discharge scenario without constant gas feeding. The considered scenario could be an alternative of chamber-less torsatron U-3M plasma start-up scenario with discharge conditions similar to conditions of the conventional toroidal device discharge.

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СЦЕНАРИЙ СОЗДАНИЯ ПЛАЗМЫ У-3М, РЕАЛИЗУЕМЫЙ ЗА СЧЁТ ИМПУЛЬСНОГО НАПУСКА ГАЗА, КАК СЦЕНАРИЙ С ДРУГИМ УДЕРЖАНИЕМ ПЛАЗМЫ: ПЕРВЫЕ РЕЗУЛЬТАТЫ

М.Б. Древаль, Э.Л. Сороковой, Ю.К. Миронов, Р.О. Павличенко, А.В. Лозин, В.С. Романов, В.К. Пашнев

Для того, чтобы уменьшить поток нейтралов в объем удержания плазмы, был предложен сценарий разряда У-3М, поддерживаемого импульсным напуском газа. Отсутствие постоянной подачи газа в этом сценарии позволяет уменьшить давление рабочего газа в вакуумной камере У-3М. Было показано, что время заполнения вакуумной камеры У-3М после резкого импульса напуска газа составляет около 10...20 мс. В разрядах с 5...6 кВ на ВЧ-генераторах в режиме предложенного сценария напуска газа задержка между импульсом напуска и созданием плазмы была короче времени заполнения камеры. Тот же уровень плотности электронов был достигнут в рассматриваемом разряде и обычном 5...6 кВ разряде, поддерживаемом только постоянной подачей газа. Форма временной зависимости эмиссии линии H_α в рассматриваемых разрядах похожа на форму этой зависимости в обычных установках, в которых размеры плазмы и камеры близки друг к другу.

СЦЕНАРІЙ СТВОРЕННЯ ПЛАЗМИ У-3М, ЩО РЕАЛІЗУЮТЬСЯ ЗА РАХУНОК ІМПУЛЬСНОГО НАПУСКУ ГАЗУ, ЯК СЦЕНАРІЙ З ІНШИМ УТРИМАННЯМ ПЛАЗМИ: ПЕРШІ РЕЗУЛЬТАТИ

М.Б. Древаль, Е.Л. Сороковий, Ю.К. Миронов, Р.О. Павліченко, О.В. Лозін, В.С. Романов, В.К. Пашнєв

Для того, щоб зменшити потік нейтралів в об'єм утримання плазми, був запропонований сценарій розряду У-3М, що підтримується імпульсним напуском газу. Відсутність постійної подачі газу в цьому сценарії дозволяє зменшити тиск робочого газу у вакуумній камері У-3М. Було показано, що час заповнення вакуумної камери У-3М після різкого імпульсу напуску газу становить близько 10...20 мс. У розрядах з 5...6 кВ на ВЧ-генераторах у режимі запропонованого сценарію напуску газу затримка між імпульсом напуску і створенням плазми була коротшою ніж час заповнення камери. Той же рівень густини електронів був досягнутий в розглянутому розряді і звичайному 5...6 кВ розряді, що підтримується тільки постійною подачею газу. Форма часової залежності емісії лінії H_α в розглянутих розрядах схожа на форму цієї залежності в звичайних установках, в яких розміри плазми і камери близькі один до одного.