TESTS OF TUNGSTEN LIMITER WITH CONTROLLED HYDROGEN PUFFING IN THE TORSATRON URAGAN-3M

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Working model of plasma facing W-limiter with controlled hydrogen recycling has been created. The limiter was installed in the Uragan-3M torsatron and was tested under the edge plasma conditions.

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1. INTRODUCTION

The Uragan-2M torsatron (U-2M) construction has some drawbacks which makes difficult the improvement of plasma parameters: there is no divertor, insufficient total pumping speed, possibility exists for plasma fluxes direct interactions with vacuum chamber walls, etc. In order to improve the situation it was suggested to install in the U-2M pump limiter [1] which would allow controlling plasma-surface interactions and might essentially amend vacuum-plasma conditions. To create such limiter it is necessary to choose the material for limiter receiving plate and to investigate its behavior under the edge plasma conditions. It could be both low Z materials (C, B_4C, Be, Li, etc.) and the materials with high Z but with very low erosion rate (W, Mo, etc.). This work was directed on the creation of working model of plasma facing W-limiter with controlled hydrogen recycling (hydrogen puffing at plasma edge), its installation in the Uragan-3M torsatron (U-3M) and tests under the edge plasma conditions. Besides of U-2M pump limiter creation, such experiments could also be very useful for RF plasma heating development in the U-2M torsatron in view of necessity to choose material for RF antenna limiters, the design of which is now carried out.

2. EXPERIMENTAL AND RESULTS

The working model of W limiter includes the next units:
a) diffusion membrane, b) membrane heating, c) hydrogen input, d) fore vacuum pumping to prepare for work and for diffusion membrane cleaning procedure during exploitation, e) unit of diffusion membrane moving, f) connecting pipes and flanges, g) valves, reducers, h) manometers for the control of hydrogen pressure in the system, i) vacuum gauges and devices.

The diffusion membrane was the tube made of 99.98% mass. purity palladium. The tube diameter was 10 mm, length – 200 mm and thickness – 0,25 mm. The outside surface of tube was coated with high porous (45% porosity) tungsten film of 17 μm thickness produced with vacuum-arc method in argon atmosphere with the pressure of 10.4 Pa. The details of production technology, erosion and hydrogen properties for such W films were reviewed earlier [2]. Note only, that being of high erosion resistant such films can provide high hydrogen flows through them. The palladium tube from one end was hermetically soldered on a hard solder by means of copper choke. Another tube end was soldered with a hard solder to the stainless steel tube which, in its turn, was welded on stainless steel flange.

The outside surface of tube-membrane was faced to U-3M vacuum chamber which was pumped with vacuum-arc titanium pump, turbo molecular and fore vacuum pumps with total pumping speed of 40000 l/s. The inside tube surface had contact with hydrogen at the pressure over the range from $0.5 \cdot 10^5$ to $1 \cdot 10^5$ Pa. The membrane was heated with help of nichrome heater which was placed inside the tube. Membrane temperature was controlled with chromel-copel thermocouple also placed inside Pd tube. Due to bellows joint the diffusive membrane can be moved in vertical direction on 10 cm that allows entering it to the plasma boundary during experiment (Fig.1).

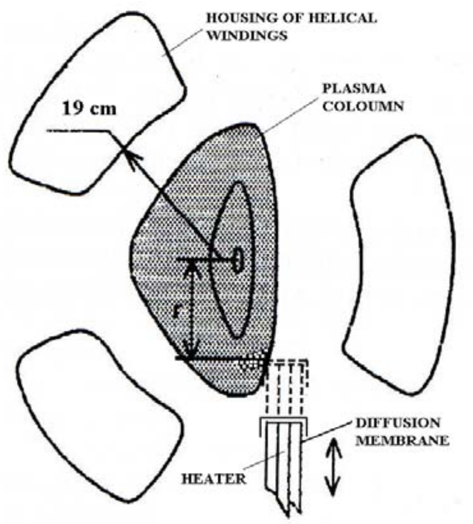

Fig.1. Scheme of diffusion membrane position in the U-3M during plasma experiments

After W-limiter aggregating and its tests on hermiticity, it was installed in the U-3M vacuum chamber using bellows joint and the movable limiter input port in the chamber bottom (Fig. 2, 3). It was connected with hydrogen input, fore vacuum pumping and systems of electric power supply and temperature measurements.

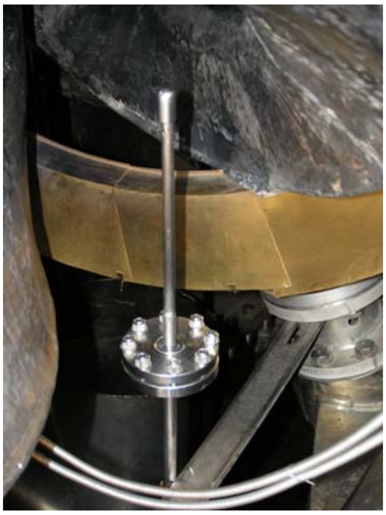

Fig.2. W-limiter diffusion membrane position in situ in U-3M vacuum chamber between two housings of helical windings of the toroidal magnetic field coils

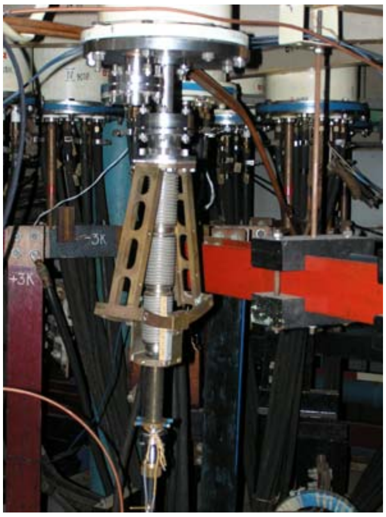

Fig.3. W-limiter input port on the U-3M chamber bottom

3. W-LIMITER TESTS IN THE URAGAN-3M TORSATRON

The scheme of the experiments during W-limiter tests in the U-3M torsatron is shown in Fig. 4. The specific hydrogen flow (permeation rate) j through membrane was measured by constant pressure method [3]. During the experiments, first the U-3M vacuum chamber was pumped out to pressure p_o of $2…3·10^{-5}$ Pa, then hydrogen pressure was increased up to $1·10^{-2}$ Pa (hydrogen input flow of about 400 Pa·l/s) and the RF discharge cleaning regime was ignited. The usual plasma parameters were: hydrogen pressure of $1·10^{-2}$ Pa, electron density ~ $2·10^{12}$ cm^{-3}, electron temperature of ~ 10-15 eV, magnetic field was ~ 0.035 T, plasma pulse duration was 50 ms, pulse frequency was 0.2 Hz, total discharge power was about 80 kW, RF generator frequency was 5.4 MHz. Then membrane heating to the temperature of 623…823K was started. After pumping out the gases, membrane-desorbed due to heating, fixed hydrogen pressure over the range from $5·10^4$ to 10^5 Pa was supplied to the inner side of the Pd-pipe. It leaded to hydrogen pressure increase in the U-3M vacuum chamber. When the gas flow to vacuum chamber eventually attained a steady-state value p, it was measured. Knowing this pressure and pumping speed S one can calculate hydrogen permeation flow, or specific hydrogen permeation flow through membrane, according to equation $j= (p-p_o)S/F$, where F is the membrane surface area.

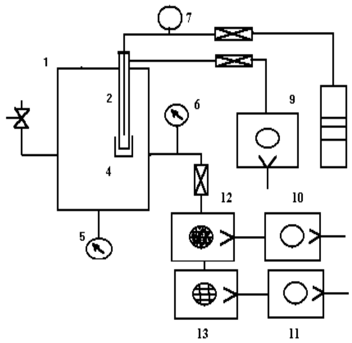

Fig.4. Scheme of the W-limiter tests in the U-3M: 1- U-3M vacuum chamber, 2- diffusion membrane, 3 – membrane heater, 4- protecting cap, 5- mass spectrometer, 6 – vacuum gauge, 7 – manometer, 8 – hydrogen volume, 9, 10, 11 – fore vacuum pumps, 12 – electric-arc titanium pump, 13 – turbo molecular pump

The typical pressure dependence of hydrogen permeation flow (isotherm) through bimetallic Pd-W diffusion system is shown in Fig. 5. Fig. 6 shows the temperature dependence (isobar) of hydrogen permeation through W-limiter diffusion membrane.

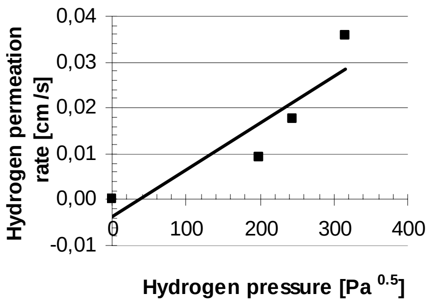

Fig.5. Hydrogen penetration through W-limiter diffusion membrane in dependence on pressure (membrane temperature is 823K)

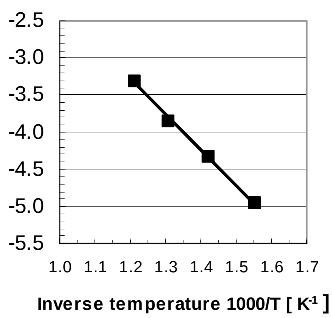

Fig.6. Temperature dependence of hydrogen permeation rate through W-limiter diffusion membrane (hydrogen pressure is 10^5 Pa)

The activation energy E of hydrogen permeability was determined from the slope of ln(j)=-b-E/RT straight lines as functions of the inverse temperature (Fig.6). The activation energy of hydrogen permeability for W-limiter was calculated to be (36.6±1.83) kJ/mole. This is much more than reported one for bare palladium (12…16 kJ/mole [4]). It could be explained by higher impurity concentration on the inner surface of Pd-pipes and non-activated state of palladium [4] in the case of using of heater (W-limiter case) instead of heating with direct current.

It is seen in Figs. 5 and 6 that total hydrogen flow values provided with W-limiter diffusion membrane can be more than 200 Pa·l/s. This is enough to provide hydrogen recycling control in the discharge cleaning regime on the level of 50%. If to take into account total pumping speed (about 40000 l/s) and hydrogen pressure of $5\cdot10^{-4}$ Pa needed during work regime, it is clear that created plasma facing diffusion system can provide sufficient hydrogen flows not only for local hydrogen recycling control during cleaning and plasma discharges but also to provide full hydrogen flow in Uragan-3M torsatron during working regime (~20 Pa·l/s).

It is planned in future to use the W-limiter during U-3M plasma experiments to measure W-coating erosion and transport, and to look the influence of local recycling coefficient change on plasma characteristics in view of the possible essential difference between states of desorbed from limiter molecular hydrogen and usually used hydrogen from pressure vessel [5, 6].

4. CONCLUSIONS

The working model of W-limiter with high pure hydrogen puffing was created. The diffusion membrane of the limiter was produced as two-layer W-Pd system using vacuum-arc technology which provided the mostly optimum membrane properties: low erosion rate to exclude plasma contamination and high hydrogen flows. The heating, pumping, hydrogen input and power supply systems were made. The W-limiter components were aggregated and tested on vacuum and hermiticity.

The W-limiter has been installed in the Uragan-3M torsatron and it was tested under edge plasma conditions with RF discharge cleaning regime.

The dependencies of hydrogen flows through limiter were measured versus membrane temperature and hydrogen pressure.

Activation energy of hydrogen permeability through W-limiter was estimated as 37 kJ/mole.

It was shown that the membrane temperature region 673....823K and hydrogen pressure of about 0.5…1 atm. are enough to provide hydrogen flows up to 200 Pa.l/s in the U-3M vacuum chamber. That will do for hydrogen recycling control both in discharge cleaning and working regimes.

ACKNOWLEDGEMENTS

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ИСПЫТАНИЯ ВОЛЬФРАМОВОГО ЛИМИТЕРА С КОНТРОЛИРУЕМЫМ НАПУСКОМ ВОДОРОДА В ТОРСАТРОНЕ УРАГАН-3М

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Создана рабочая модель обращенного в плазму W-лимитера с контролируемым рециклингом водорода. Лимитер установлен в торсатрон Ураган-3М и испытан в условиях краевой плазмы.

ВИПРОБУВАННЯ ВОЛЬФРАМОВОГО ЛІМІТЕРУ З КОНТРОЛЬОВАНИМ НАПУСКОМ ВОДНЮ У ТОРСАТРОНІ УРАГАН-3М

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Створена робоча модель зверненого у плазму W-лімітеру з контрольованим реціклінгом водню. Лімітер встановлено у торсатрон Ураган-3М і випробувано в умовах крайової плазми.