# TEST OF PURE HYDROGEN INFLOW SYSTEM DURING DISCHARGE CLEANING AND WORK REGIMES OF THE URAGAN-3M TORSATRON

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The tests of the pure hydrogen inflow system had been carried out during pulsed discharge cleaning and work regimes of the Uragan-3M torsatron. It had been shown that the inflow system provides required steady flows of hydrogen over the pressure range from $5x10^{-7}$ Torr to $10^{-4}$ Torr. The special cyclic procedures of membrane heating and pumping to provide the long life time of membranes, and required reliability and stable flow are described.

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## 1. INTRODUCTION

Earlier the simple construction of the diffusion membrane module system for pure hydrogen inflow in the Uragan-3M (U-3M) torsatron had been suggested and simulation experiments with experimental module were carried out [1]. The results obtained in that work had shown the principal possibility of such system creation with the required characteristics for the U-3M torsatron. Then the real construction have been designed, manufactured and mounted in the U-3M device. In this work the tests of the system were carried out during pulsed RF-discharge cleaning and work regimes of the U-3M torsatron at the typical parameters [2, 3].

## 2. EXPERIMENTAL

The principle scheme of inflow system is shown in Fig.1. System comprises a block of diffusion membranes, which includes seven diffusion modules M1-M7, each of other is attached through valves to independent heating system (not shown), to hydrogen input line (V1-V7, $V_H$) and to pumping line ($V_0$) to provide the functioning of diffusion modules. There was the possibility to control membrane heating and pressure in the U-3M vacuum chamber from the diagnostic room. The diffusion module comprises a diffusion membrane (Pd-99.98 grade pipes 0.6 cm in diameter, 19cm length, 0.025 cm in thickness) which was hermetically brazed at the one end. The outer surface of pipe was presented to the vacuum chamber, while the inner surface was in contact with hydrogen from high-pressure cylinder. The membrane was heated by directly running the current through it. In order to decrease arc ignition probability during plasma experiments and to prevent heavy impurities incoming in plasma, the palladium pipes were coated with a 2-4 µm thick TiN layer. Earlier the TiN-coatings were successfully applied in the U-3M to protect RF antenna frames [4] from erosion and it was shown earlier [5] that TiN-films have very low level of arc ignition probability and rather high barrier for molecular hydrogen penetration. The latter required to examine comparison characteristics of hydrogen permeability (isobars and isotherms, activation energies $E_a$) of such membranes and bare Pd-membranes. It is seen in Fig.2 and in the Table that at the medium high temperatures (300-500°C) these performances are nearest ones. For comparison the activation energy values $E_m$ for activated palladium [6] are presented in the Table, too.

*Activation energy values of hydrogen permeability for Pd and (2µ TiN)-Pd*

| Membrane material | $E_a$, Kcal/mol | $E_m$, Kcal/mol | Ref. |
|---|---|---|---|
| Pd | 10.4 | 3.7 | [6] |
| (2µ TiN)-Pd | 5.46 | 3.6 | [5] |

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.2). For bare palladium the activation energy E was calculated to be (10.4±0.52) kcal/mol that is much higher than 3-4 kcal/mol reported in [6]. It could be explained by higher carbon concentration on the inner surface of Pd-pipes and nonactivated state of palladium.

The tests were carried out under typical parameters for RF-discharge cleaning and work regimes in the U-3M [2, 3]: for the former it was 1 pulse per 5 s, RF input power was ~ 50kW, discharge duration was up to 60ms, the stationary magnetic field was over the range from 250-350 Gs; for the latter it was 1 pulse per 5 minute, RF power was about 240 kW, discharge duration was 50ms, magnetic field was 0.7 Gs.

The tests had been shown that the inflow system provided steady flows of hydrogen over the pressure range from $5x10^{-7}$ Torr to $10^{-4}$ Torr. Under RF-discharge cleaning regime in the Uragan-3M torsatron (hydrogen pressure was $10^{-4}$ Torr) five or six diffusion modules were required to provide the necessary flow about 10 Torr·l/s.

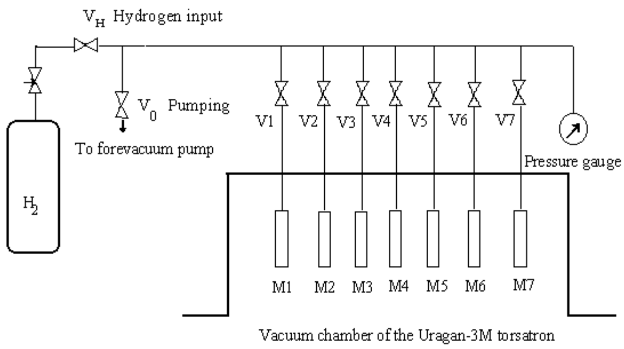


*Fig.1. The scheme of the hydrogen inflow system*

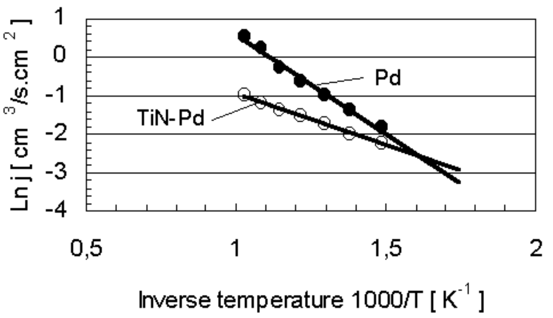


*Fig.2. Permeability isobars (hydrogen pressure P=760 Torr): closed circles – bare Pd, open circles – (2μ m TiN)-Pd bimetallic system.*

Under plasma experiment condition (required hydrogen pressure was $10^{-5}$ Torr) only one or two modules were used, providing hydrogen flow about 1Torr·l/s. The maximum power consumption at the work of one and six diffusion modules (without power of forevacuum pump) was not more than 60W and 400W, consequently.

As the construction of the diffusion modules is not gas-flow, the decay of permeation properties of diffusion modules was observed caused by impurity release (mainly, carbon) on the inlet surface of Pd-membrane. To provide the required stable flow, the special cyclic procedure of membrane heating in hydrogen atmosphere and pumping was applied. It allowed to have steady state hydrogen flow through experiment.

The second problem was the utilizing of the rather thin palladium tubes (0.25mm thickness) in diffusion modules. It was caused by the necessary to provide high hydrogen flows up to 10 Torr·l/s. To provide the long lifetime and reguired high reliability of such membranes it was needed to exclude the membrane work in the temperature range of α-β transition (20-300°C) at high hydrogen pressure. So, before the system shutoff the special procedure of diffusion membranes heating and pumping of dissolved hydrogen had been anticipated.

## 3. SUMMARY

The system of pure hydrogen input had been designed, manufactured and mounted in the Uragan-3M device. The compises seven diffusion modeles, lines of forevacuum pumpdown, lines of letting-to-ballon hydrogen and seven independent systems of diffusion module heating.

The tests of the pure hydrogen inflow system had been carried out during pulsed discharge cleaning and work regimes of the Uragan-3M torsatron. It had been shown that the inflow system provides required steady flows of hydrogen over the pressure range from $5x10^{-7}$ to $10^{-4}$ Torr required reability due to the special cyclic procedures of membrane heating and pumping.

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## ИСПЫТАНИЕ СИСТЕМЫ НАПУСКА ЧИСТОГО ВОДОРОДА В РАБОЧЕМ РЕЖИМЕ И РЕЖИМЕ ЧИСТКИ ТОРСАТРОНА УРАГАН-3М


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Проведены испытания системы напуска чистого водорода в рабочем режиме и в режиме чистки высокочастотными импульсами торсатрона Ураган-3М. Показано, что система напуска обеспечивает требуемые потоки в диапазоне давлений $5x10^{-7}$ – $10^{-4}$ Торр. Для обеспечения требуемой надежности, продолжительности срока службы и стабильности потока водорода предлагается специальная процедура периодического нагрева и откачки диффузионных мембран.


## ІСПИТ СИСТЕМИ НАПУСКУ ЧИСТОГО ВОДНЮ В РОБОЧОМУ РЕЖИМІ І РЕЖИМІ ЧИЩЕННЯ ТОРСАТРОНА УРАГАН-3М


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Проведено іспити системи напуску чистого водню в робочому режимі й у режимі чищення високочастотними імпульсами торсатрону Ураган-3М. Показано, що система напуску забезпечує необхідні потоки в діапазоні тисків $5x10^{-7}$ – $10^{-4}$ Торр. Для забезпечення необхідної надійності, тривалості терміну служби і стабільності потоку водню пропонується спеціальна процедура періодичного нагрівання і відкачки дифузійних мембран.