VACUUM SYSTEM AND CLEANING TECHNIQUES IN THE FTU MACHINE

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Abstract

FTU (Frascati Tokamak Upgrade) is a high magnetic field (8T) tokamak under construction at the Frascati Energy Research Center (ENEA). Its vacuum system has been already manufactured and is presently being assembled. It consists of an all metallic fully welded vessel, pumped by six turbomolecular pumps. The vacuum system has been dimensioned to allow a base pressure lower than 2.6 x 10^{-6} Pa. The paper reports the design philosophy of the vacuum system. The results of the cleaning techniques performed on a 1:1 scale toroidal sector of FTU are also presented and discussed.

Riassunto

FTU (Frascati Tokamak Upgrade) è un tokamak ad alto campo magnetico (8T) in costruzione presso il CRE Frascati dell'ENEA. Il sistema da vuoto è stato costruito ed è attualmente in fase di assemblaggio. Consiste di una camera da vuoto metallica interamente saldata evacuata da 6 pompe turbomolecolari. Il sistema da vuoto è stato dimensionato per ottenere una pressione inferiore a 2.6 x 10^{-6} Pa. L'articolo riporta le caratteristiche del progetto del sistema da vuoto. Sono inoltre riportati e discussi i risultati sulle tecniche di pulizia esaminati su un settore di prova di FTU in scala 1:1.

1. INTRODUCTION

FTU (Frascati Tokamak Upgrade) is a high magnetic field (8T) tokamak with a lower hybrid auxiliary heating (8 GHz, 8 MW) [1,2].

The FTU vacuum vessel is a completely welded stainless steel structure composed of 12 toroidal sectors and 12 thicker connecting rigid sections which include the access ports (Fig. 1).

As a consequence of the large power flux foreseen in FTU [3], the toroidal sectors were protected by thermal shields as shown in Figure 2.

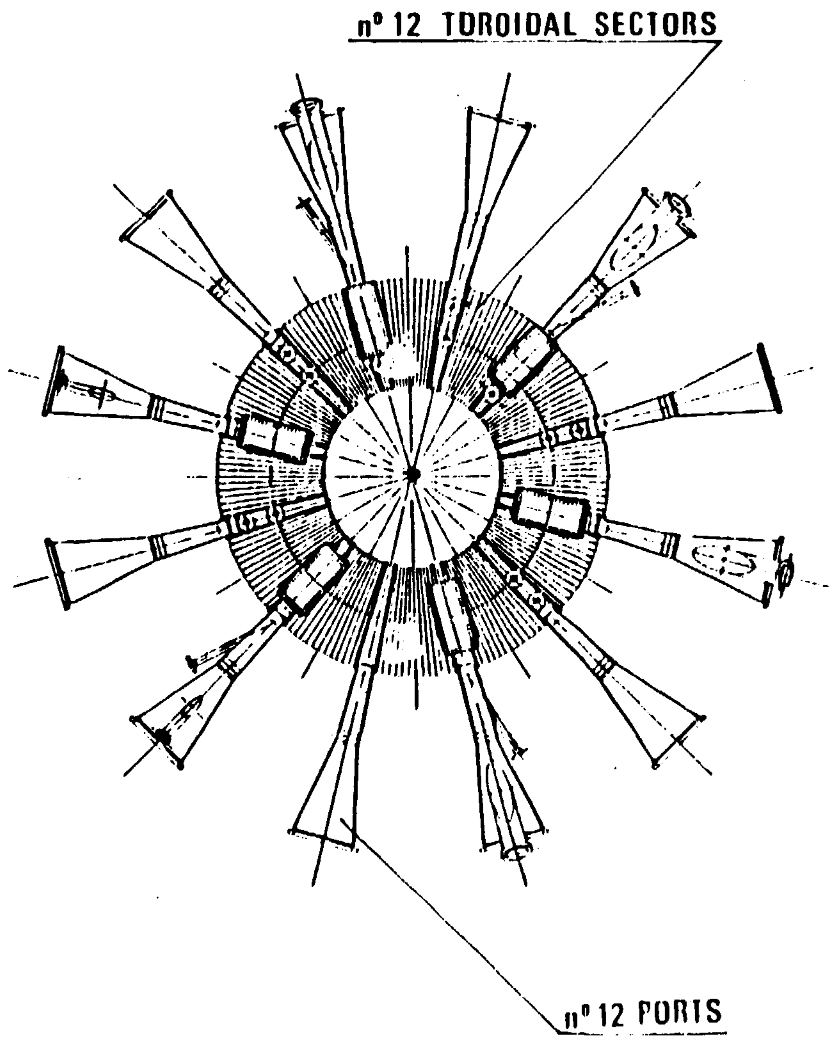

Fig. 1 FTU vacuum vessel

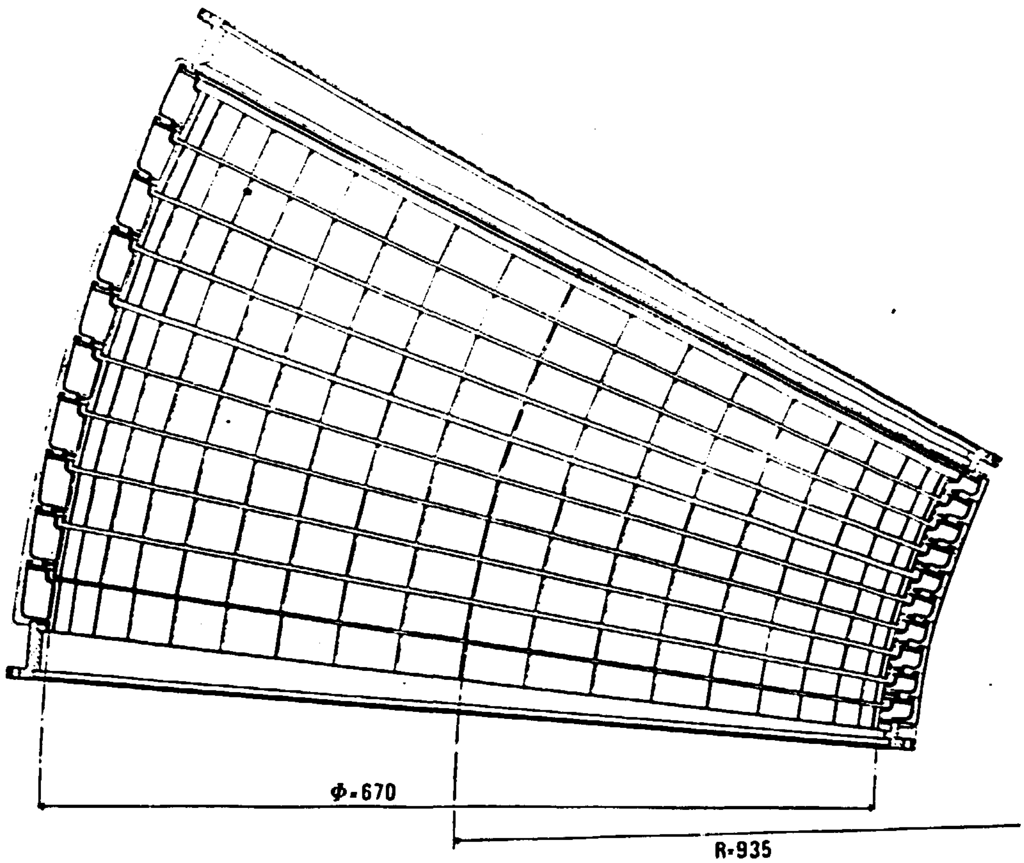

Fig. 2 Toroidal sector of the vacuum vessel

These shields originate hidden regions that could trap neutral gas and impurities. Hence, knowledge of the vacuum behaviour before and during discharges and the optimization of the surface conditioning and cleaning techniques acquire relevant importance [4].

The FTU vacuum parameter are summarized in ***Table I***

Based on the parameters reported in Table I, the pumping system was designed for reaching the base pressure foreseen, taking into account elastomer seals and all losses due to port duct pipes and flanges and considering the installation position of the pumps in areas where the magnetic fields do not effect their performance.

In realizing the vacuum vessel, all efforts were devoted to achieving a very high leak tightness, and the specified figures are $< 1.10^{-10}$ mbar ℓs^{-1} for

Table I - *Vacuum vessel parameters*

Minor radius	0.335 m
Major radius	0.935 m
Plasma chamber volume	2.5 m^3
Plasma chamber area	74 m^2
Total area (including RF structures)	123 m^2
Effective pumping speed (in the chamber)	1.98 m^3/s
Outgassing rate	$< 2 \times 10^{-8}$ W.m^{-2}
Base pressure	$< 2.6 \times 10^{-6}$ Pa

the total system and $< 1.10^{-10}$ mbar ℓs^{-1} for each individual component to be assembled.

A thorough cleaning procedure before, during and after assembly of the machine had to be followed. To obtain the outgassing rate, cleaning techniques (chemical and electrochemical) were used before assembly, while backing, glow discharge and pulse discharge cleaning are foreseen for the vessel during the life of the machine

2. THE FTU VACUUM SYSTEM

Figure 3 shows the layout of the FTU pumping system. The basic philosophy behind the arrangement is to use identical modules as far as possible.

The main vacuum chamber is pumped by 6 turbopump units (PFEIFFER) with a pumping speed of 1400 ℓ/s for air and 1320 ℓ/s for hydrogen.

One pump unit is used to evacuate the limiter extraction chamber . (In FTU the limiter can be extracted without breaking the vacuum). This pump will also contribute to the torus pumping when the limiter is inserted. A rotary vane pump (60 m^3/h) is used as a roughing station to rough down the torus pressure.

Each pump unit consists of a turbo pump, a high vacuum valve, a forevacuum valve, a vent valve, a trap, a rotary vane pump, and two vacuum gauge assemblies. The unit is controlled by its own control cabinet which operates and provides protection and interlocks for the pump. The vacuum gauge assemblies consist of Pirani and Ion-type vacuum gauges.

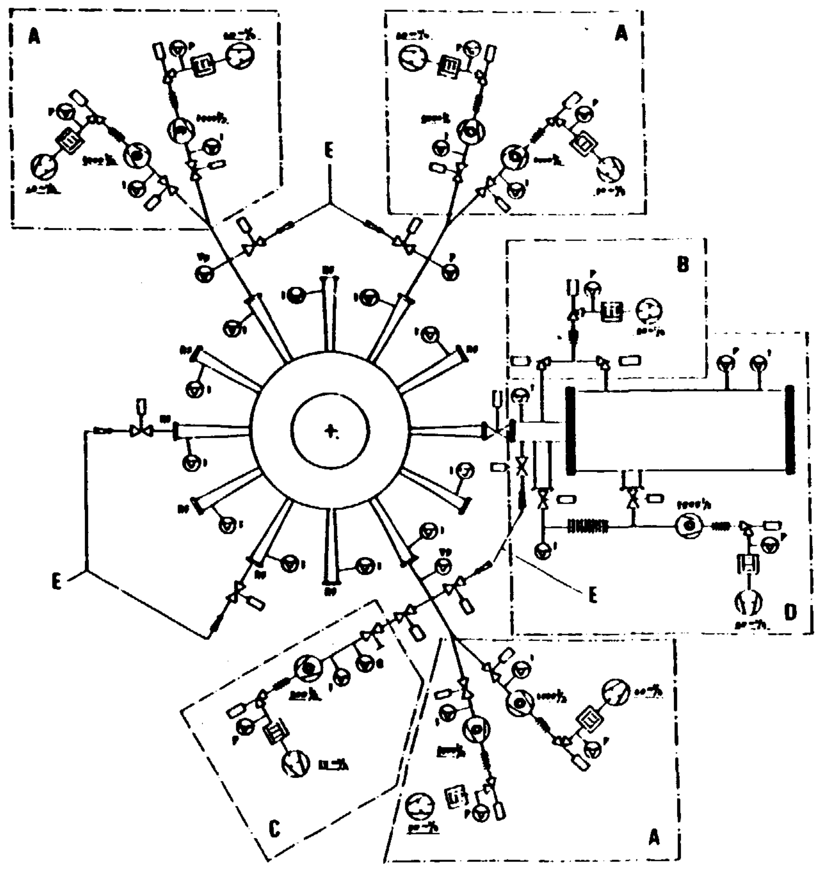

Fig. 3 FTU vacuum system: A) Pump units; B) Roughing pump unit; C) Residual gas Analysis system; D) Limiter extraction chamber; E) Gas immission lines.

Figure 4 shows two pump units as fitted to a pumping chamber which is itself connected to the torus port.

The control cabinets housing the electronic controllers to run the pump units are located in the basement, outside the torus hall. Special precautions were therefore taken in order to have a reliable control over long distances up to 60 m. Special care was also required to ground the different parts of the system to avoid ground loops and interference with other systems. Isolation breaks have been inserted in the forevacuum lines to separate the pumps electrically from the cabinet.

The controls of the pump unit are computer controlled but have built-in safety provisions to protect the individual system. All status information is monitored by the computer. Hence, the installation has a twinfold control

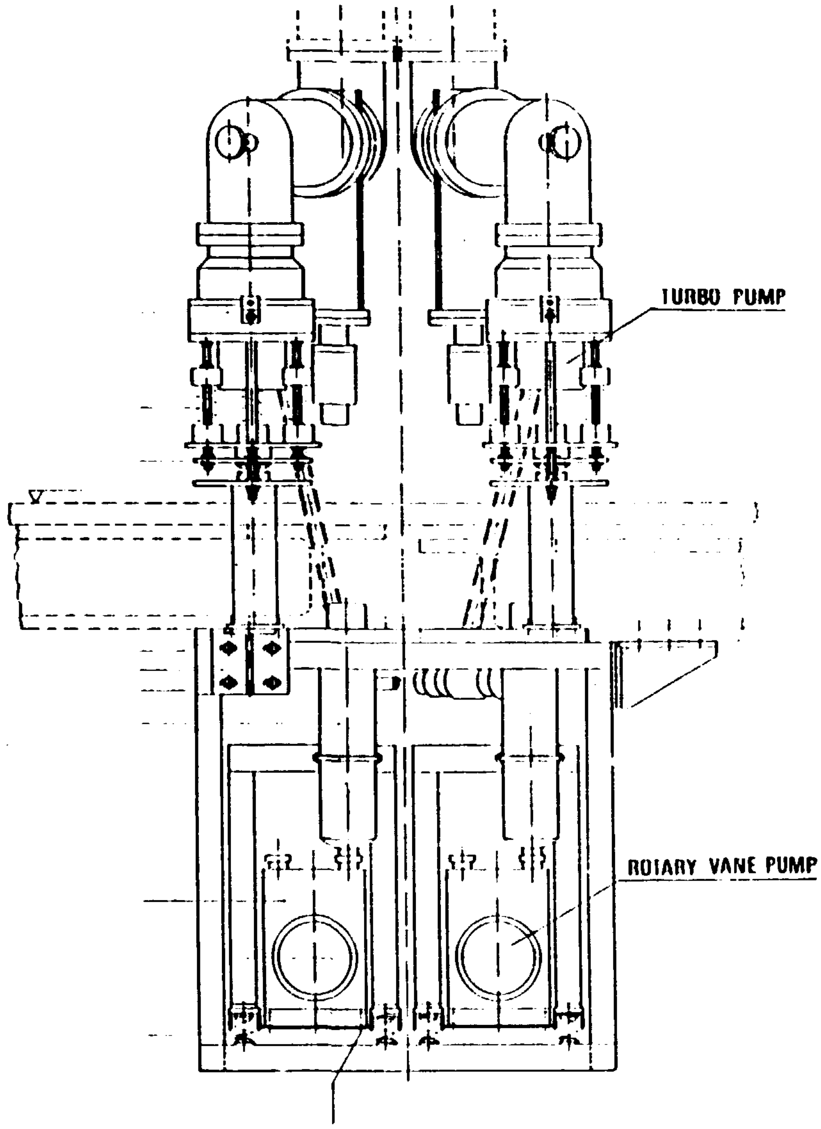

Fig. 4 Pump units connection to a torus ports

facility for a local control from the cabinet itself and for remote control where all actions are taken via computer.

The purpose of the local control is to enable the commisssioning and testing of the system without the computer, and each systems has a local operation facility. A switch allows the transfer from local to remote control and vice versa.

The vacuum measurement in FTU can be divided into two sections:

1) Measurements related to the pump unit control. They include Pirani gauges in the range between 10 mbar and 10^{-4} mbar and ion gauges between 10^{-3} mbar and 10^{-11} mbar

2) Torus vacuum measurement system which includes Pirani and ion gauges. A piezo-resistive manometer in the range between 1000 and 1 mbar to control fault conditions and a residual gas analyzer system (Figure 3) which contains a quadrupole mass spectrometer.

3. WALL CONDITIONING

The reduction of the outgassing rate and related impurity content is of primary importance in FTU. As in other machines three methods are foreseen.

a) backing up to 200 °C

b) glow discharge cleaning.

c) pulse discharge cleaning.

With reference to point a), the baking is realized by means of electrically heated jackets on the ports, while the toroidal sectors will be heated by joule effect.

The geometry of the toroidal sectors (Fig. 2) can play a role in the efficiency of the forementioned techniques. For such a reason systematic tests have been performed on a prototype of the FTU toroidal sector.

The vacuum vessel used for the *in situ* degassing treatment and glow discharge cleaning is composed of a stainless steel sector of FTU (scale 1:1) and two sealing covers which contain portholes for the pumping system and for a quadrupole mass spectrometer [4].

The turbomolecular pumping speed on the chamber is scaled from the FTU parameters without RF structures.

Hydrogen glow discharge was produced between a stainless steel central electrode and the grounded sector walls.

Initial tests were performed using a pulsed power supply (a control unit for a Vac Ion Pump) producing a quasi-steady discharge (pulse period = 10 ms) with high peak voltage (1-2 kV) and high hydrogen pressure (1.3 ÷ 13 Pa).

In these regimes the pumping during d.c. was excluded to avoid the damage of the turbomolecular pump rotor.

To reduce the operational hydrogen pressure and operate at full pump efficiency, continuous discharges were also produced and are still in progress. In this case, pressu ≥ in the range of 0.66 ÷ 2.6 Pa with a sheath potential of 300-400 V were obtained.

No particular differences exist between the two types of discharges when the walls are at room temperature. In both cases the cleaning efficiency is very low and there are no significant changes of pressure after the treatment.

When the temperature of the walls increases, the effect of the glow discharge becomes evident and more efficient with respect to the thermal treatment alone.

In Figs 5,6 the results obtained with the thermal conditioning of the walls and pulsed d.c. are shown.

The measure of cleaning efficiency is given by the final pressure of the system when the walls return to room temperature at the end of the process.

After one day's backing at 140 °C and a further day at 190 °C, an ultimate pressure of 6.2×10^{-9} Torr or mbar was obtained (Fig. 1), but an improvement of a factor 8 was possible by using glow discharge in H_2 for only five hours during two days' baking at 100 °C.

These results show that a short period of discharge cleaning becomes more efficient than a prolonged thermal treatment only when the wall temperature is increased above room temperature.

The effect of the H_2 pressure on the H_2O production, which is the most prominent peak during d.c., is shown in Fig. 7 at 25 °C and 100 °C. The results refer to pulsed discharge where pumping speed was excluded.

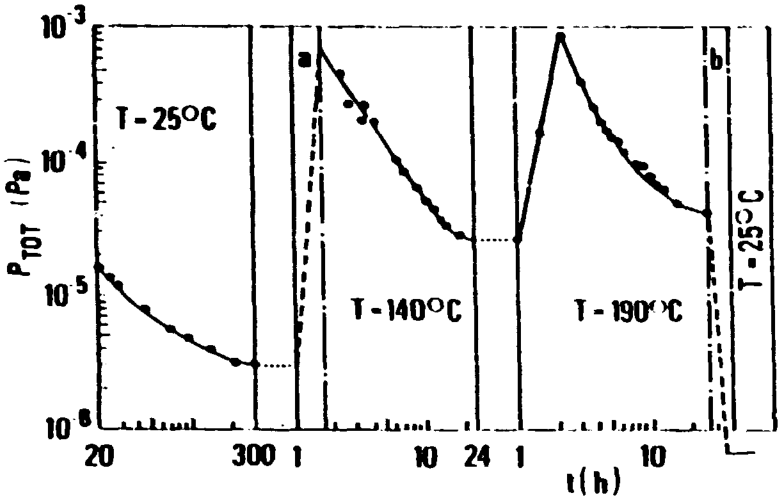

Fig. 5 Pressure vs time evolution during thermal outgassing.
a) heating period 5 h;
b) cooling period

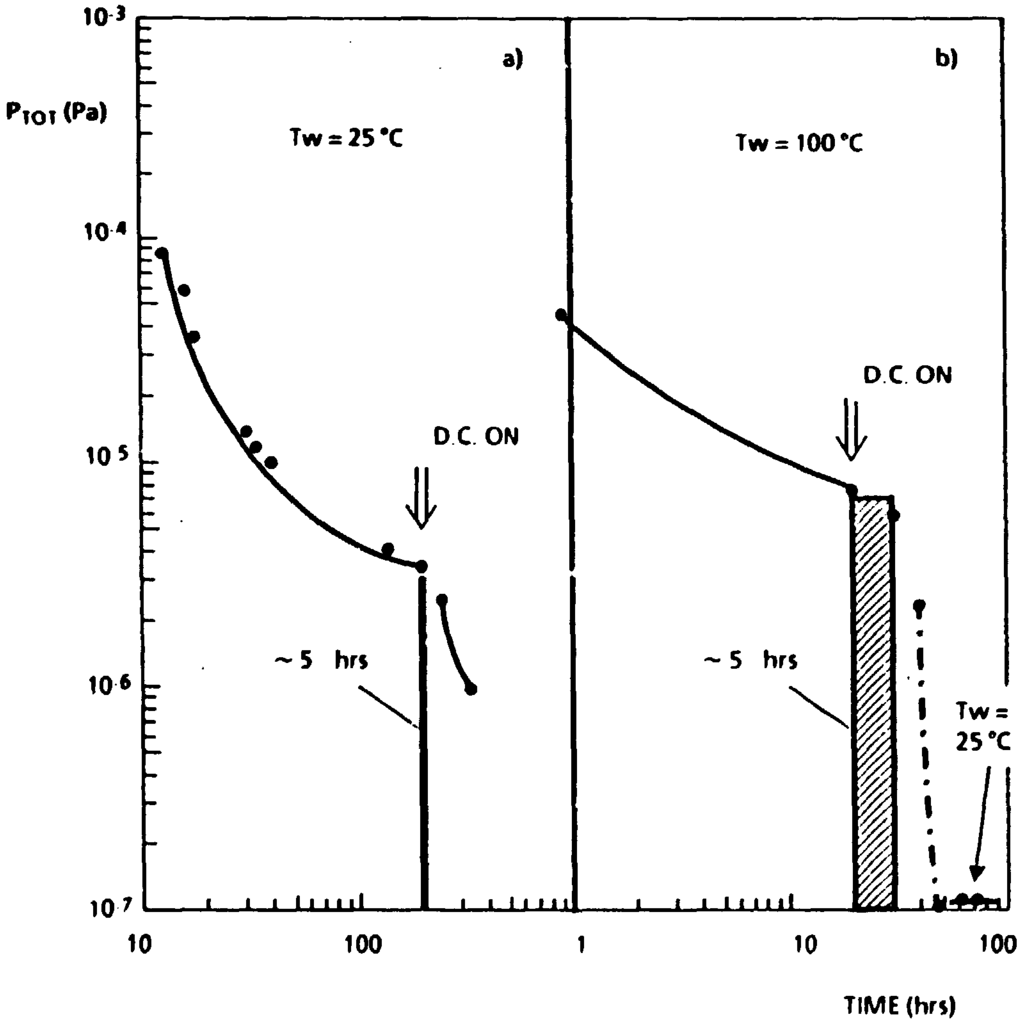

Fig. 6 Effectiveness of glow discharge vs wall temperature

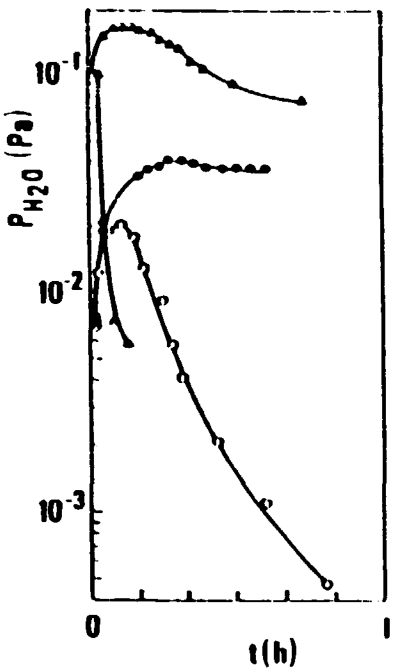

Fig. 7 Water partial pressure during dc; I_{DC} = 100 mA.
▲ T_w = 100 °C, P_{H_2} = 5.8 Pa, $(P_{H_2O})_e$ = 1.1 x 10^{-4} Pa
● P_w = 100 °C, P_{H_2} = 21.0 Pa, $(P_{H_2O})_e$ = 4.2 x 10^{-5} Pa
△ T_w = 25 °C, P_{H_2} = 12.1 Pa, $(P_{H_2O})_e$ = 1.0 x 10^{-4} Pa
○ T_w = 25 °C, P_{H_2} = 15.8 Pa, $(P_{H_2O})_e$ = 1.0 x 10^{-5} Pa

From the area under these curves it is easily seen that the water release strongly depends on temperature and increases with the H_2 pressure.

This trend agrees quite well with a model [4] that explains the pressure dependence as due to the particular geometry of the vacuum vessel internal surface (Fig. 2).

According to this model, the penetration of the discharge into the regions between the wall and the thermal shields which can produce a satisfying level of cleanliness is obtained only at high pressure (> 10^{-2} Torr).

Other measures are now in progress to verify the efficiency of continuous discharge at high temperature up to the limit pressure for the pumping system.

CONCLUSION

The FTU vacuum system has been completed and will be installed in Frascati at the end of 1987.

The vacuum vessel has been manufactured and is presently being assembled at the Frascati Center. Outgassing tests have shown that all components have an outgassing rate within the values of the design parameters. In spite of the geometry of the first wall of vacuum vessel, experimental data on the laboratory scale have shown good efficiency of the glow discharge cleaning within the temperature range allowed in FTU.

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