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Letter to the Editors

Discharge cleaning and wall conditioning in a Novillo Tokamak

R. Valencia [a,*], J. de la Rosa [b], E. Camps [c], G. Contreras [d], S. Muhl [e]

[a] *Laboratorio de Física de Plasmas, Instituto Nacional de Investigaciones Nucleares, Apdo. Postal No. 18-1027, 11801 México DF, Mexico*

[b] *ESIME-ZACATENCO-IPN, C.P. 07738, México DF, Mexico*

[c] *ININ Departamento de Física, Apdo. Postal 18-1027, 11801 México DF, Mexico*

[d] *ESFM- ZACATENCO-IPN, C.P. 07738, México DF, Mexico*

[e] *IIM-UNAM, Apdo. Postal 70-360, C.P. 04510, México DF, Mexico*

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Abstract

Our Novillo Tokamak is a small toroidal device magnetically confined defined by the main design parameters: $R_o = 0.23$ m, $a_v = 0.08$ m, $a_p = 0.06$ m, $B_T = 0.05$–0.47 T, $I_p = 1$–12 kA, $n_e = 1$–2×10^{13} cm^{-3}, $T_e = 150$ eV, $T_i = 50$ eV. For the initial discharge chamber cleaning we have often used vacuum baking up to 100 °C and then conditioning using Taylor discharge cleaning (TDC) in H_2 and He. In this work we report that vacuum baking is effective for obtaining a final total pressure of the order of 1.6×10^{-7} Torr. We have found that a single parameter, the performance parameter (PP), can be used to optimize the TDC method. This parameter represents the quantity of electron and ion energy incident on the chamber wall during the Taylor discharge, it is equal to $(I_p\tau)$, where I_p is the peak-to-peak plasma current and τ is the plasma current duration. In graphs of PP versus the gas pressure for different oscillator powers, the maximum value of PP indicates the best cleaning conditions when using TDC. The results of the vacuum chamber wall conditioning using this criterion are reported.

1. Introduction

Vacuum baking, discharge cleaning (DC) glow discharge wall conditioning, ECR-DC and Taylor discharge cleaning (TDC) in H_2 and other gases are methods commonly used for wall cleaning of tokamaks [1–8]. It is generally considered that high temperature vacuum baking is the primary technique for treating materials for use in ultra-high vacuum systems while low or moderate temperature vacuum baking has little benefit as a stand-alone conditioning method [2,3]. On the other hand, TDC [1] using hydrogen and helium as working gas is considered as one of the best methods for removal of oxygen and carbon by chemical reactions in tokamaks when the first wall is made of stainless steel.

We have applied vacuum baking and TDC methods in the ohmically heated Novillo Tokamak [9]. However, owing to the use of viton vacuum seals in this device, the vacuum baking could only be performed at temperatures up to 100 °C. Nevertheless, this method proved to be useful for obtaining a low base pressure in a short time using a turbomolecular pump of 500 l/s (N_2). We have successfully applied TDC in the Novillo Tokamak as routine cleaning technique [10] and have gradually improved the system to generate plasma discharges at an audio frequency (AF) of 17.5 kHz and a pulse length of 50 ms with a repetition time of 500 ms. For this experiment, the chamber was pumped for about 48 h,

* Corresponding author. Tel.: +5-5329 7200x2238; fax: +5-5329 7301.

E-mail address: rva@nuclear.inin.mx (R. Valencia).

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followed by a vacuum baking of 24 h, and immediately afterwards the TDC is initiated for 24 h; once this procedure is completed, we found that a daily application of TDC for 2 or 3 h is sufficient to clean the chamber in order to obtain reproducible plasma currents of low resistivity in the tokamak discharges.

In the literature concerning TDC, to our knowledge, there is no criteria for optimization of the cleaning efficiency based on the experimental parameters: gas pressure, oscillator power, confining magnetic field, current and plasma duration. In this paper we propose a simple technique to optimize the TDC method that consists in evaluating a 'performance parameter' (PP) from the $I_p\tau$ versus p graphs for different oscillator powers; here I_p is the peak-to-peak discharge current, τ is the plasma duration and p is the working pressure. Some results of such a wall conditioning process in Novillo Tokamak are reported using this PP.

2. Experimental procedure

The main design parameters of our Novillo Tokamak are: $R_o = 0.23$ m, $a_v = 0.08$ m, $a_p = 0.06$ m, $B_T = 0.05$–0.47 T, $I_p = 1$–12 kA, $n_e = 1$–2×10^{13} cm^{-3}, $T_e = 150$ eV, $T_i = 50$ eV. The discharge chamber of this device is made from four readily available 316/L stainless steel 90° bends of 3.2 mm wall thickness. The interconnection is made by means of flanges containing viton O-rings seals to provide four voltage breaks. An effort was made to provide the torus with a large number of access ports in order to give flexibility for future purposes and more sophisticated diagnostic set-ups. The total area of the 28 different ports is 617 cm^2 and the wall surface area without ports is 7265 cm^2. The vacuum chamber can be heated by means of ohmic heaters wound on the torus to a maximum of 100 °C; to avoid damage to the viton seals in different parts of the vacuum chamber.

To provide DC in the system the Taylor's method was used. For this purpose we employed a 17.5 kHz and 5–20 kW AF oscillator in pulsed mode to energize the primary coil of the ohmic heating transformer [11]. This resulted a plasma current of up to 400 A in a 2 Hz repetitive operation with a toroidal magnetic field of 800–200 G and a pulse length between 5 and 50 ms. Such discharges were established at pressures from 6.5×10^{-5} to 4.5×10^{-4} Torr, using hydrogen and helium as the working gases. Occasionally, a hot filament was used to help start the discharge.

Under these conditions, we obtain plasmas with a low electron temperature, of about 2 eV [12], that is insufficient to dissociate water molecules. On the other hand, the low toroidal magnetic field allows ions to strike the wall causing the desorption of impurities by physical and chemical sputtering. In this process, all the reaction products such as hydrocarbons, H_2O, CO and CO_2 are volatile and are removed from the discharge chamber by the vacuum system.

The diagnostics used for the wall conditioning process include Rogowski coils for measuring the plasma current and duration, a single coil to measure the loop voltage, as well as a differentially pumped mass spectrometer to carry out the residual gas analysis.

3. Taylor discharge cleaning in hydrogen and helium

The base pressure obtained using a moderate vacuum baking temperature (100 °C) for 24 h proved to be effective to improve the final base pressure, only when the initial base pressure (without any heating) was lower than 4×10^{-7} Torr, for base pressures higher than this value, it was necessary to operate the vacuum baking for much longer times [13]. The results of long pumping times in comparison to those obtained using vacuum baking are shown in Fig. 1. The experimental procedure to obtain the partial pressure spectra was the following: (1) the chamber was vented and left for 12 h at atmospheric pressure (this stage was used to start the cleaning from the same conditions); (2) the chamber was pumped for 12 h and in this way a total base pressure of 8×10^{-7} Torr was attained. The first mass spectrum shown in black bars in Fig. 1 corresponds to the partial pressures at this pressure. It can be seen that this is a typical spectrum of a chamber recently vented to the atmosphere where the partial pressure of water vapor is large. The second mass spectrum, shown in white bars in Fig. 1, was recorded after an additional 48 h of continuous pumping; the total pressure reached was 4×10^{-7} Torr. In this case, the pressure reduction is due mainly to a general decrease of all the partial pressures shown in the figure. The third spectrum shown in hatched bars in

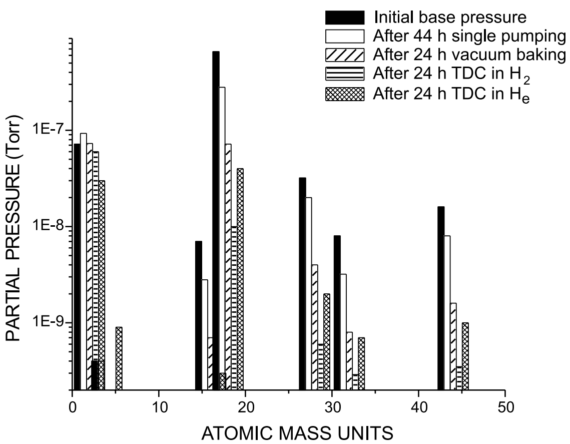

Fig. 1. The partial pressures of the residual gases before and after vacuum baking, and TDC in the Novillo Tokamak.

Fig. 1 was obtained after 24 h of vacuum baking. Here, the base pressure was 1.6×10^{-7} Torr, and the mass spectrum shows that the reduction of the pressure is due to a decrease in the partial pressures of the all the hydrocarbons, oxygen, carbon monoxide and dioxide and to a small reduction of the water vapor. The fourth spectrum shown in grid squares bars in Fig. 1 shows the partial pressures at the final pressure of 7.2×10^{-8} Torr, obtained after 24 h of TDC in H_2, in combination with moderate baking to avoid the re-deposition impurities, a large reduction in carbon and oxygen was observed. It can be seen than this method leads to an important reduction of masses 12 and 32 corresponding to carbon and oxygen that are associated with the decrease of the partial pressures of the carbon monoxide and carbon dioxide. The fifth spectrum shown in gridded squares bars represents the final partial pressure of 7.49×10^{-8} Torr at the end of 24 h of TDC in He.

To study the effectiveness of TDC in H_2 and He, we performed a series of extensive DCs, experiments each one of 10 h, under the following conditions; gas pressures from 6.5×10^{-5} to 4.5×10^{-4} Torr, different toroidal magnetic fields B_T from 200 to 800 G, pre-ionization currents I_{pf} from 25 to 50 μA, peak-to-peak plasma currents I_p from 200 to 400 A, plasma duration times τ from 5 to 50 ms and AF oscillator powers W_o, from 5 to 20 kW [14]. In Fig. 2 (only TDC in H_2), we plot the final base pressure and the partial pressures of hydrogen, water vapor and CO, versus the PP, $I_p\tau$, for $B_T = 744$ G and $I_{pf} = 50$ μA. It can be seen that for the larger values of PP the efficiency of the cleaning process for lowering the partial pressures of the impurities is enhanced. In Fig. 3, we show the values of PP as a function of the oscillator power and the working pressure. The maximum value of the parameter indicates the optimum efficiency for TDC method is at gas pressures between 1.0×10^{-4} and 3.0×10^{-4} Torr and reaches its largest values for AF powers greater than 16 kW.

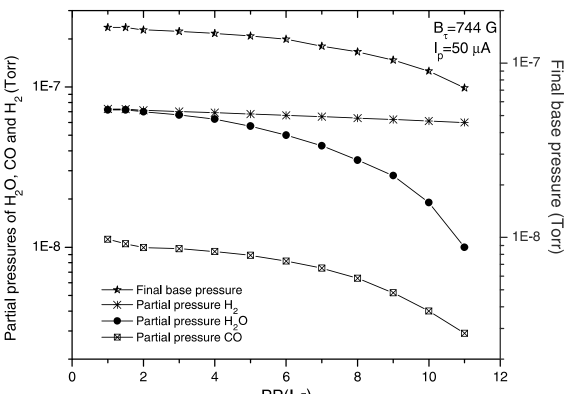

Fig. 2. The base pressure and partial pressures of hydrogen, water vapor and carbon monoxide versus the PP at 19 kW AF power, toroidal magnetic of 744 G and 50 μA current preionization.

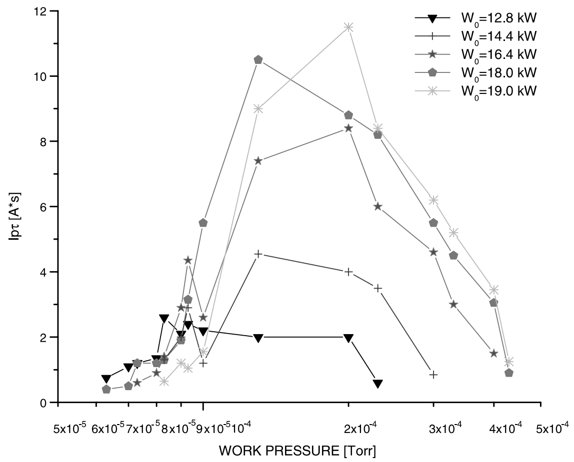

Fig. 3. The calculated PP versus the working pressure for different oscillator powers.

Results obtained in wall conditioning using the TDC method, proved to be effective and necessary to improve and maintain the discharge chamber in good condition for the use of our tokamak discharges.

4. Reaction products by TDC in H_2 and He

Fig. 4 shows the partial pressure spectra of the elements and compounds obtained as a result of the interaction of the plasma with the chamber wall during the application of the Taylor discharge. The whole cleaning process was initiated after the chamber was exposed to the atmosphere. In this figure, the white bars represent

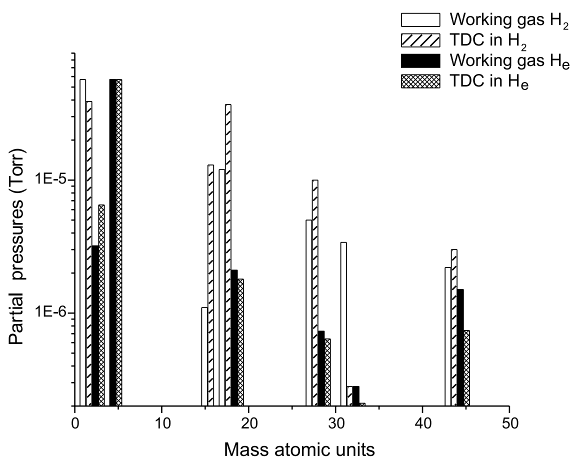

Fig. 4. The partial pressures of the gaseous reaction products for TDC in H_2 and He.

the hydrogen partial pressures (i.e. of the working gas), and the partial pressure of the other compounds of the residual atmosphere, before the Taylor discharge was applied. The hatched bars, next to the white ones, show the partial pressures of the reaction products generated by the Taylor discharge. As it can be seen, the hydrogen and oxygen partial pressures are slightly reduced, due to the recombination of these elements with carbon, yielding to the formation of methane, water vapor, carbon monoxide and dioxide, which are represented in this figure by masses 16, 18, 28 and 44. The black bars in Fig. 4 show the partial pressures of the residual atmosphere, when helium is used as the working gas, the hatched bars next to the black ones, show the partial pressures of the residual atmosphere, when the Taylor discharge is used in helium as working gas. From this plot it is seen that the discharges in helium, practically did not produce methane, water vapor and carbon monoxide and dioxide, so that, in terms of the cleaning process, the discharges in hydrogen are more efficient to remove from the wall those undesirable compounds.

5. Discussion

Using the oscillator and associated equipment described before, discharges could be initiated and maintained in Novillo over a wide variation of parameters such as toroidal field, working gas pressure and oscillator power. These parameters were varied initially in order to ascertain the optimum values in terms of maximizing the plasma current I_p.

In this kind of discharge the energetic particles (H^+, H^o and e^-) that strike the wall either knock-off adsorbed atoms or chemically combine with them.

6. Conclusions

TDC in H_2 is an efficient method to remove carbon and oxygen from the stainless steel walls when the plasma temperature is about 2 eV, under these conditions, the discharge releases considerable amounts of water, hydrocarbons, carbon monoxide and dioxide, as represented in Fig. 4, these reaction products are then pumped out by the vacuum system.

Due to the fact that our discharge chamber has a leak rate of 2.4×10^{-6} Torr l/s, this continually renews the oxides in the chamber, however, we have had excellent results applying the TDC method as an efficient deoxidizing system.

In our experiments, vacuum baking is very effective for obtaining low base pressures in a short time, but only when this process is used in a system which has an initial pressure lower than 4×10^{-7} Torr, since at this pressure thermal desorption of the hydrocarbons and water vapor is relatively easy.

To establish the optimum wall conditioning process using TDC, the use of the PP, $I_p\tau$, obtained from graphs of the parameter against the gas pressure and the oscillator power is proposed. The TDC method in hydrogen resulted in an important reduction of carbon and oxygen impurities in our system.

The results suggest that for effective wall conditioning of a tokamak, it is better to first perform vacuum baking at an initial low base pressure to obtain an improved base pressure in a short time and then to use the TDC method in hydrogen to enhance the removal of carbon and oxygen from the wall chamber.

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