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NEUTRAL-FUELING PRESSURE MEASUREMENTS AND MODELING
NEAR THE PLASMA EDGE IN TMX-U

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ABSTRACT

Large variations in pressure from external gas-fueling sources and from plasma-induced wall reflux along the TMX-U plasma have been observed. These pressure variations can produce locally high neutral density in the plasma, which strongly affects the plasma parameters. These local pressure measurements include data from a newly installed neutral-pressure diagnostic system of fast magnetron gauges. The plasma-induced warm-wall reflux has been observed to be primarily HD and H_2 as opposed to D_2 . This observation supports the model that all of the neutral D_2 gas enters the plasma region, strikes the plasma first, and is dissociated. The part of the D_2 gas, which is not absorbed as ions, strikes a wall, where it is converted to HD. Electron induced wall desorption measured by a mass spectrograph and actual analysis of the Ti indicates predominately H_2 instead of D_2 wall loading in TMX-U.

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1. INTRODUCTION

The long thin and partially elliptical Tandem Mirror Experiment-Upgrade (TMX-U) plasma threads through a Ti gettered Al first wall. This first or warm wall is relatively complex. The D_2 gas injection, other than from the neutral beams, is performed at four different locations in the central cell. We have successfully measured neutral-gas pressures near the TMX-U plasma at a radius of $R = 60$ cm and the axial location (z) near the D_2 gas-fueling sources. The resulting pressure measurements are more than an order of magnitude higher than those measured (Refs. 1,2) previously with shielded ion gauges. The shielded gauges are located on the outer wall of the TMX-U vessel and connected by a chimney to the plasma warm-wall region. For these new pressure measurements, we used unshielded Bayrd-Alpert gauges and magnetron gauges aligned to the TMX-U B field (Ref. 3).

We have also measured the neutral pressure near the plasma ($R = 60$ cm) in the TMX-U plugs. This pressure measurement was an order of magnitude lower than previously measured with the magnetically shielded gauges at $R = 220$ cm. We have used the mass spectrometer diagnostic located at the outer wall of TMX-U and connected to the plug-plasma region by a chimney to determine the time history of H_2 , HD, and D_2 pressures at $R = 220$ cm. Throughout the first few weeks of plasma operation after an air exposure, the prompt neutral species outside the plasma during plasma operation is almost entirely HD and H_2 with D_2 becoming significant only after the plasma is gone. These data suggest a gas dynamics model during plasma operation where the D_2 gas input from the neutral beams enters the plasma region then strikes the plasma before striking a wall. These

molecules are then dissociated primarily as Franck-Condon neutrals, which then strike the H_2 -loaded Ti-gettered warm wall producing HD. Subsequently, the HD, or H produced from HD, may strike a wall producing H_2 .

Because the pressure in the plug plasma region is lower near the plasma than near the outer warm-wall chimney, the integral amount of gas liberated from the first wall in the plug can be estimated using these pressures and by assuming that the wall is a source and that the plasma is a pump. The integrated plug wall reflux is approximately 0.2 t/s during plasma operation.

II. PRESSURE MEASUREMENT NEAR THE PLASMA

The TMX-U plasma is long (20 m) and highly elliptical at four locations on either side of the plugs. The plasma in the center of TMX-U is approximately circular with a radius of 20 cm defined by a limiter on the gas-injection box on the west side of the central cell near the middle ($z = +218$ cm). Calderon in Ref. 8 reports on the geometry details of the TMX-U vessel and gas source locations. The first or warm wall is a Ti-gettered Al sheet that forms an envelope, which closely follows the contours of the plasma. The plasma and wall separation are about 40 cm in the center of the machine and are as small as 10 cm in the elliptical parts between the plugs and central cell. Figure 1 shows the complete warm wall of TMX-U. Figure 2 shows the relationship of the plasma edge to the warm wall from a vertical- and horizontal-plane view. The new diagnostic (Ref. 1)

system of Bayrd-Alpert gauges and magnetron gauges, which are located on the warm wall and are aligned to the TMX-U B field, are shown in each of the drawings.

Figures 1 and 2 also show the locations of the shielded Bayrd-Alpert gauges and mass spectrometers outside the vessel. These devices communicate with the plasma region via large chimneys. The operation of the magnetically shielded Bayrd-Alpert gauges and mass spectrometers is discussed in Refs. 4 and 5. The use of Bayrd-Alpert gauges in high-B fields by aligning the collector and filament coplanar with the magnetic field is discussed in Ref. 6.

III. MAGNETRON GAUGES

The magnetron gauges are a cold-cathode type gauge with the E and B fields parallel. Redhead in Ref. 7 presents a complete summary of all these gauge types with their operating characteristics. We chose magnetron gauges for TMX-U, as opposed to the Penning gauges chosen by Dylla⁵ for the Tokamak Fusion Test Reactor (TFTR), because magnetron gauges operate well at lower pressures (10^{-9} to 10^{-5} Torr) and will ignite reliably. The TMX-U magnetron gauge design is described in detail in Ref. 1. The magnetron gauges ignite when the TMX-U B field is turned on two seconds before the plasma operation starts. Figure 3 compares the pressure measured by a shielded Bayrd-Alpert gauge and a magnetron gauge. The magnetron gauges have operated successfully in 3-kG ambient B field. The calibration of these gauges is approximately 0.5 A per Torr. Specially designed controllers are required that synchronize the operation of the magnetron

gauges with the TMX-U B field. The pressure data presented in the remainder of this paper was taken with the unshielded Bayrd-Alpert gauges located on the warm wall; each gauge has a separate filament and collector aligned to the local TMX-U B field.

IV. PRESSURE NEAR THE FUELING SOURCES

The gauge labeled WCP in Figs. 1 and 2 is located at $z = 180$ cm, which is about 40 cm from the west gas box at $z = 220$ cm in TMX-U. Figure 4 shows the pressure measured by WCP and five other fast-ion gauges during typical plasma operation. Note that the pressure measured by WCP is 20 times that measured by FCCS1 (the shielded ion gauge at $z = 0$, $R = 220$ cm). The pressure reduction, which occurs at 20 ms and 55 ms, is due to the expansion of the plasma radius to reach the gas-box limiters. This expansion reduces the leakage of neutral D_2 from the gas box. The plasma radius is apparently affected by the plug electron-cyclotron resonant heating (ECRH). When the second harmonic ECRH-plug-electron heating was turned off at 40 ms, the radius decreased. When the fundamental ECRH-plug-electron heating was turned off at 50 ms, the effective radius increased again. In this case, the plasma was sustained by beams alone from 50 to 70 ms and was of a large enough radius to "seal" the gas box. Figure 5 shows an order of magnitude pressure reduction in the TMX-U central cell when the plasma fully fills the gas box. In these shots (9/6/84, 8, 9, 28), the plasma filled the gas box for the entire shot.

V. PLUG PRESSURE NEAR THE PLASMA

We found large variations in pressure measurements, when comparing the results of two Bayrd-Alpert gauges located near the east-plug plasma and at the top of the east-plug warm-wall chimney. We used the unshielded Bayrd-Alpert gauge EPPE, which is located at $R = 60$ cm on the warm wall in the east plug and the shielded Bayrd-Alpert gauge at $R = 220$ at the top of the east-plug warm wall.

Figure 6 shows that the pressure near the plasma is initially higher than the chimney pressure. We expected this result because the gas sources are the beam inlets near the plasma and because the walls are freshly gettered with Ti, which pumps. However, as soon as the plasma is established (at 15 ms) the pressure at the top of the chimney, which has no gas sources, exceeds the pressure near the plasma by about 10^{-6} Torr. This pressure reversal is maintained until the plasma decays at 65 ms. The Ti-gettered wall in the chimney crosses over from being a net pump to being a net source of gas, which maintains the pressure difference of 6×10^{-7} Torr against the 1.5×10^5 l/s plasma-pumping speed. This pressure difference corresponds to 0.2 tℓ/s net wall desorption if the conductance to the plasma region from the chimney is 2×10^5 l/s; the wall desorption is about one-third of the total gas input to the plug as estimated by the plug plasma-pump exhaust fluence Q of

$$Q = SP = 1.5 \times 10^6 \times 4.5 \times 10^{-7} \approx 0.6 \text{ tℓ/s} ,$$

where

S = plasma pumping speed $\approx 30 \times$ (plasma surface area) (cm^2)

P = pressure (Torr).

VI. PLUG GAS DYNAMICS

Figure 7 shows the partial pressures of HD, H_2 , and D_2 during plasma operation in the east plug. These data were taken with the mass spectrometer located at the top of the east plug chimney as shown in Figs. 1 and 2. The prompt species is HD and is about two-thirds of the total pressure. The remainder is primarily H_2 . These data are from a shot taken within two weeks of an air exposure. Later in the experimental cycle the HD, H_2 , and D_2 become essentially equal components. However, the D_2 pressure is never greater than one-half of the total plug pressure. Figure 8 shows the partial pressures of HD, H_2 , and D_2 from 0.5 s before to 3.5 s after the plasma operation at 0. When the magnets in the plug are turned off at 0.6, 0.9, and 1.0 s the ECRH-driven energetic-electron population crashes into the wall. The resulting pressure rise is almost entirely H_2 , which coupled with the analysis of TMX-U Ti samples⁹ by Malinowski using thermal desorption analysis, results in the finding that TMX-U Ti-gettered walls contain more H_2 than D_2 (probably from rediffusion from the substrata of Ti). Each time the machine is open to the air, the substrata of Ti is probably loaded with H_2 by pumping H_2O from the initial pumpdown and clean up operation.

The model of the gas dynamics for the plug plasma region of TMX-U suggested by the HD predominance and H_2 wall loading is shown in Fig. 9. Streaming and diffuse D_2 gas from the beams strikes the plasma and is

dissociated into energetic neutrals or ionized. The neutrals are either absorbed by the plasma or strike a wall. Because the wall is predominately H_2 added, HD is preferentially desorbed. This HD may then be dissociated by striking the plasma or may strike another wall. If it is dissociated, then the H may strike a wall creating H_2 . If the HD strikes the wall, H_2 may also be released. The gauges and mass spectrometer are baffled from the plasma region such that at least two wall bounces are required for a molecule to enter the gauge. Hence, the gauges see only the resulting desorbed molecules of HD and H_2 with some D_2 at approximately the temperature of the wall.

VI. SUMMARY

We are gaining new insights into the detailed gas dynamics of tandem mirror machines by measuring neutral gas pressures near (within 60 cm) the plasma. To make these measurements, we are successfully using Bayrd-Alpert gauges and magnetron gauges aligned to the internal magnetic field. We have found gas pressures near fueling sources to be high. Pressures in the plugs are low, even in the presence of substantial HD and H_2 wall reflux.

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FIGURE CAPTIONS

- Figure 1. Isometric drawing of the TMX-U first or warm wall showing the location of all the gauges used for fast-pressure measurements.
- Figure 2. Cross-sections of the TMX-U warm wall show the relationship of the TMX-U plasma to the warm first wall and the location of all the gauges.
- Figure 3. Overlay of the pressure measured by a magnetron gauge and a nearby Bayrd-Alpert gauge during plasma operation of TMX-U.
- Figure 4. Pressure during TMX-U plasma operation in six plasma regions. The gauge labeled WCP is 40 cm from the plasma near the gas box in the central cell. Pressure drop variations result from sealing and unsealing at the plasma to gas box limiter.
- Figure 5. Pressure near the central cell gas box is an order of magnitude greater without plasma (8) than with plasma (28).
- Figure 6. Pressure near the top of the warm-wall chimney exceeds the pressure near the plug plasma at 15 ms when the walls become a net gas source.
- Figure 7. A mass spectrometer shows the prompt HD and H_2 partial pressure in the east plug and the late D_2 partial pressure after the plasma decays.
- Figure 8. The H_2 desorption from the Ti-gettered warm wall, when the magnet turn off allows energetic electrons to strike the wall at 1 s after plasma operation.
- Figure 9. Gas dynamics model of the TMX-U plug suggested by our pressure measurements shows D_2 gas interacting with the plasma before striking Ti wall and desorbing HD and H_2 .

W. Pickles - Figure 1

Magnetically

- 1 Shielded
- 2 Unshielded
- 3 Self field
- 4 External field

- Bayrd-Alpert
- Filament and collector colinear with B field
- Fast magnetron gauge aligned to TMXU B field
- Cold cathode Penning Gauge
- Mass Spectrometer
- Inside

W. Pickles - Figure 2

W. Pickles - Figure 3

W. Pickles - Figure 4

W. Pickles - Figure 5

W. Pickles - Figure 6

W. Pickles - Figure 7

W. Pickles - Figure 8

W. Pickles - Figure 9