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OPERATION OF COLD-CATHODE GAUGES IN HIGH MAGNETIC FIELDS

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Abstract

The Mirror Fusion Test Facility (MFTF-B), under construction at LLNL, requires measurement of the neutral gas density in high magnetic fields near the plasma at several axial regions. This Background Gas Pressure (BGP) diagnostic will help us understand the role of background neutrals in particle and power balance, particularly in the maintenance of the cold halo plasma that shields the hot core plasma from the returning neutrals [1]. It consists of several cold-cathode, magnetron-type gauges stripped of their permanent magnets, and utilizes the MFTF-B ambient B-field in strengths of 5 to 25 kG. Similar gauges have operated in TMX-U in B-fields up to 3 kG [2]. To determine how well the gauges will perform, we assembled a test stand which operated magnetron gauges in an external, uniform magnetic field of up to 30 kG, over a pressure range of 1E-8 T to 1E-5 T, at several cathode voltages. This paper describes the test stand and presents the results of the tests.

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Introduction

Past experience and recent results on TMX-U have showed the importance of dynamic pressure measurements close to the plasma. Originally, these measurements were made with shielded Bayard-Alpert gauges located at the vacuum vessel wall and connected to the warm wall plasma region by conductance "chimneys" [1-2]. Recently, pressure measurements with magnetron and unshielded Bayard-Alpert gauges aligned with the ambient magnetic field of TMX-U nearer the plasma were successfully used and showed the local pressures to be more than an order of magnitude higher than those previously measured by the shielded gauges.

Because of the large size of the MFTF vacuum vessel relative to the plasma and higher magnetic fields, neither shielded Bayard-Alpert ion gauges at the vessel wall nor unshielded Bayard-Alpert ion gauges near the plasma are very practical. However, the rugged construction and simpler electronics of the magnetron and the reliability requirements of MFTF-B make the magnetron an attractive alternative for pressure measurements near the plasma. Also, Pickles has shown on TMX-U that a properly aligned magnetron will operate in a uniform 3 kG magnetic field with approximately 0.5 A/Torr sensitivity over the 1E-8 to 1E-5 Torr range.

To quantitatively assess the performance of the magnetron throughout the MFTF-B operating conditions, a test stand was set up. The goals of the test program were to: 1) confirm the gauge operation in pressures of 1E-8 Torr to 1E-4 Torr in uniform magnetic fields up to 30 kG, 2) check gauge current linearity, sensitivity, and repeatability as a function of pressure for external uniform magnetic field strengths of up to 30 kG and cathode voltages of up to -5 kV, and 3) evaluate gauge-to-gauge consistency.

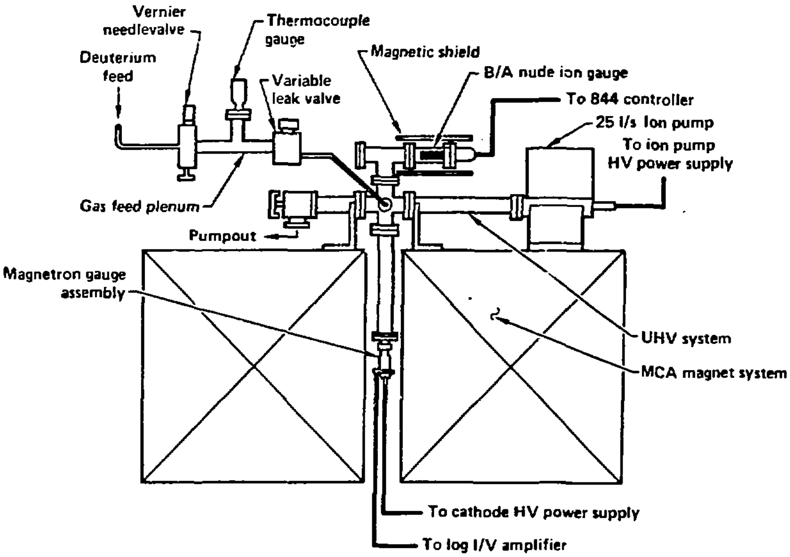

Figure 1. Magnetron test stand arrangement.

Description of the Magnetron Test Stand

Figure 1 shows the test stand arrangement. The gauges we tested are Varian 524, cold-cathode magnetron gauges, like those used in TMX-U. It is mounted to a ceramic insulator and 2-3/4-inch conflat-type flange assembly to accommodate attachment to a small ultra-high vacuum (UHV) system and maintain electrical isolation. The UHV system is an approximately 1-liter, electro-polished, tainless steel assembly connecting the magnetron to a gas feed plenum, 25 l/s ion pump, a shielded Bayard-Alpert ion gauge, and external pump-out port. Care was taken to make the conductance from the gas feed and ion pump to both gauges approximately equal. The entire UHV system, including ion pump, is bakeable to 250°C, and typically has a rate-of-rise of 6.55E-10 T/s after bakeout. The system's ultimate pressure with ion pump on is 1.5E-9 Torr. The ion gauge is a Varian UHV-24 dual-filament, Bayard-Alpert configuration, nude ion gauge with 844 controller.

The magnet system is a MCA model VYW8060L superconducting magnet system loaned from the MFTF-B ECRH system. It is a 5-coil array with individually controlled and regulated power supplies, and has a 4.25-inch diameter, room temperature, vertical bore centered on its axis. There is an approximately 5-inch long region within the bore, where the magnetic field is flat, that the magnetron is positioned. Because the Bayard-Alpert gauge is in the fringe field of the MCA magnet system, it is shielded and in a magnetic field measured to be less than 10 gauss.

The gas plenum is isolated from the UHV system by a manually-operated variable leak valve to regulate the rate of pressure rise to the UHV system during a test. Though nitrogen was used in earlier tests, deuterium was used in all the data reported in this paper. Typically, we found that maintaining the plenum pressure in the few 100's of millitorr range allowed us fine enough control to maintain the UHV system at a constant pressure as low as 5E-9 Torr against the ion pump.

To accommodate the large range of current corresponding to the expected pressure range in MFTF-B, a LLNL designed [3] LOG current-to-voltage amplifier based upon the Analog Devices 757 chip was prototyped and utilized on the test stand. This gives a usable 2 volt/decade output. Its 1 nA to 1 mA range proved more than adequate for the testing.

Test Procedures

The testing procedure was to: 1) set the MCA system magnetic field and magnetron cathode voltage, 2) bleed deuterium through the variable leak valve, increasing the pressure from the UHV system base pressure up to a maximum of 1E-4 T, 3) close the variable leak valve, letting the ion pump reduce the pressure back to the base pressure. Data were collected as plots of Bayard-Alpert pressure as a function of magnetron current. To study gauge striking characteristics, we could also set the UHV system to an arbitrary pressure, balancing the variable leak valve throughput with the ion pump, and varying the cathode voltage as the independent variable from -500 V to -5 kV. Though the magnet system could be controlled to within 50 G, its inductance limited its ability to be varied during a test.

The LOG I/V amplifier linearity and response time were checked independently several times during the test period to assure it had no effect on the data. Its time response over a 5 decade input is 1.5 ms in rise time and 4 ms in fall time. The LOG I/V also has protection circuitry. Several tests were run with and without the circuitry to assure there was no effect on the data.

Test Results

In general, a magnetron can be ignited and kept lit in uniform magnetic fields up to 30 kG from pressures of approximately 1E-8 T up to approximately 1E-5 T. However, it requires increasing cathode voltages to ignite a gauge, and keep it lit, with increasing magnetic field strength (i.e., ~1 kV at 1 kG and -5 kV at 30 kG). Though the magnetron will stay lit down to 3E-9 T under certain conditions, it could not be done so reliably. Operating at pressures higher than 1E-5 T was done, but periodically we would experience a radical increase in current. This is believed to correspond to the high pressure impedance change in the gauge referred to by Jepsen [4]. This current change occurred at all cathode voltages and B-field strengths at pressures of 5E-5 T to 5E-4 T at currents of 6E-6 A to 6E-5 A before the installation of a grounded screen between the ion pump and the UHV system and the reinstallation of the magnetron baffles. It was not seen, however, in any of the later tests, even when we were above the current range (though the corresponding pressures were an order of magnitude lower).

The magnetron sensitivity (i.e., Amperes/Torr) increases with increasing cathode voltage regardless of pressure or magnetic field strength. Figure 2 is an example of this at 11 kG. Also, the magnetron sensitivity decreases with increasing magnetic field strength. Figure 3 exemplifies this for several B-field strengths at -5 kV. Sensitivity ranged from 0.02 A/T to 10.0 A/T throughout the testing.

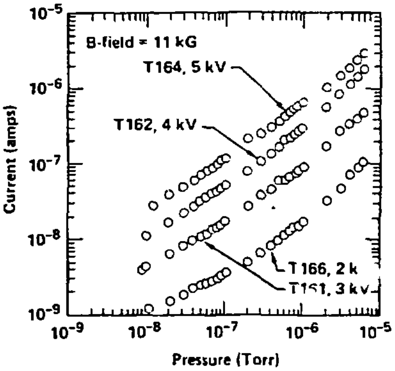

Figure 2. Anode current vs pressure as a function of cathode voltage at a uniform B-field of 11 kG.

Note that though the current/pressure relationship does not appear quite linear as predicted in the literature [5], it is repeatable. Figure 4 compares several pairs of tests at the same conditions. Note that the 25 kG/5 kV calibration curve has higher sensitivity than the 18 kG/3 kV calibration curve.

Jepsen [4] predicts a current/pressure hysteresis at low pressures and currents near the magnetron striking voltage, which we experienced. The location of this hysteresis was found to vary with B-field strength, and for 10 kG, is evident at about 1E-8 T or below.

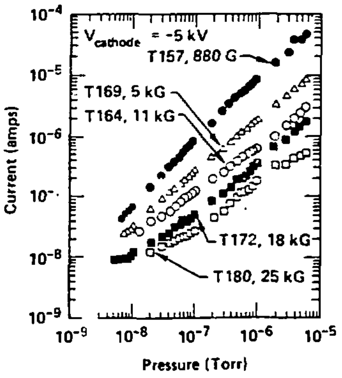

Figure 3. Anode current vs pressure as a function of B-field for a cathode voltage of -5 kV.

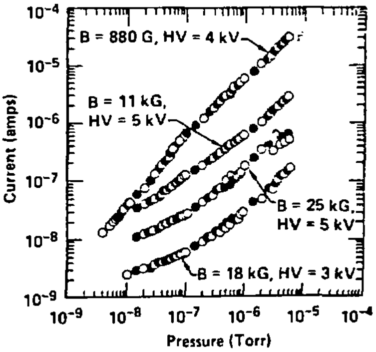

Figure 4. Test-to-test repeatability for several sets of operating conditions.

Above the striking region, current/pressure hysteresis is also seen, generally less than 10 percent (though has been seen as great as 70 percent) of the lower current value for that pressure. This higher pressure hysteresis is test-to-test reproducible and not understood. Figure 5 is an example of test data where the hysteresis is evident.

A second magnetron gauge was tested for evaluating gauge-to-gauge repeatability. Figure 6 shows that though the current vs pressure curves for the gauges with their own magnet differ by more than a decade, going to higher, uniform magnetic field strengths reduces this difference considerably. Still, it appears that individual gauge calibrations will be unavoidable. Note a significant difference in slope between the current/pressure curves for a given magnetron when it is run with its own permanent magnet (i.e., with a symmetric, but nonuniform B-field) rather than a symmetric, uniform B-field. This apparent "rotation" of calibration curves seems to occur for all uniform magnetic fields, independent of field strength. This has the effect on the magnetron sensitivity of changing it from decreasing with decreasing pressure to being constant or slightly increasing with decreasing pressure. The axial B-field for the permanent magnets ranged from about 800 G to 900 G.

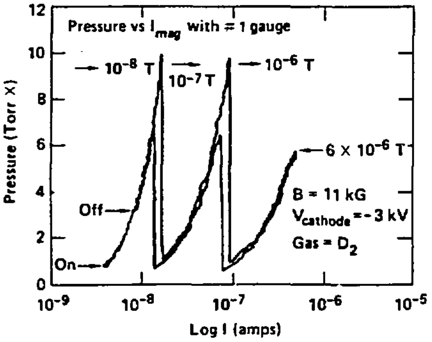

Figure 5. An example of test data showing pressure/current hysteresis. Note horizontal offsets are caused by controller auto-scaling.

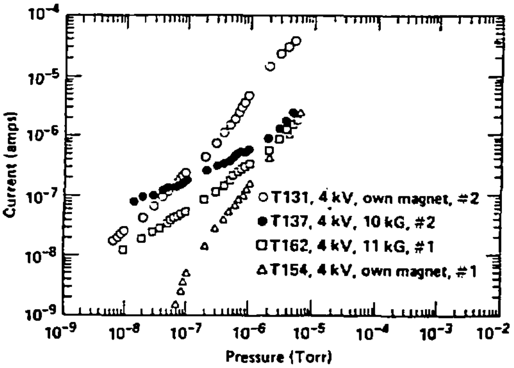

Figure 6. A comparison of gauge-to-gauge repeatability between the magnetron with its own magnet and higher, external, uniform magnetic fields.

Because the gauge is calibrated on a test stand and then installed into the MFTF-B at air, a change in calibration with cleanliness is of concern. Figure 7 shows the difference in calibration of a magnetron which has been baked-out and subsequently exposed to air. Note that the calibration curves increasingly diverge below 1E-6 T, where bakeout reduces the sensitivity of the magnetron. From other tests, it appears that the effect of bake-out on gauge sensitivity is mitigated with increasing cathode voltage and increasing magnetic field strengths.

As noted earlier, a grounded screen was placed between the ion pump and the UHV system, and the magnetron baffles were reinstalled. Besides eliminating the high pressure anode current change noted earlier, it also reduced the level of "spiking" seen in the anode

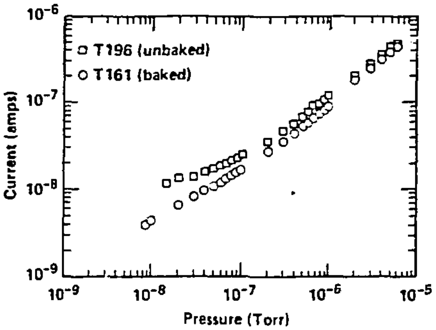

Figure 7. Calibration curves for a magnetron in a uniform B-field of 11 kG at -3 kV cathode voltage, comparing bake-out (T161) with exposure to air (T196).

current by three orders of magnitude. This spiking appears as a rapid reduction (50-200 Hz) of the gauge current, increasing in frequency and amplitude and decreasing in pulse length, with increasing pressure and cathode voltage. The "spiking" required a 5 Hz low pass filter on the chart recorder input throughout all of the testing. Care was taken to keep the time rate-of-change sufficiently slow to not have the RC circuit affect the data. Though not understood, the effect of this "spiking" on gauge calibration is most pronounced below 1E-8 T at high cathode voltages and above 1E-6 T above 25 kG and at high cathode voltages.

Conclusions

It appears that the cold-cathode magnetron can be made to operate reliably over a broad band of pressures, magnetic field strengths, and cathode voltages with adequate sensitivity and repeatability to be useful as the BGP diagnostic in MFTF-B. Current/pressure hysteresis and current "spiking" have been seen, and their presence will limit the accuracy and time response of the measurement. The cause of these phenomena is not yet understood. The magnetron will be field tested in MFTF-B during its engineering acceptance testing this fall.

Acknowledgment

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