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D-DOT AND B-DOT MONITORS FOR Z-VACUUM-SECTION POWER-FLOW MEASUREMENTS

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ABSTRACT

New differential D-dot and B-dot monitors were developed for the Z vacuum section. The D-dots measure voltage at the insulator stack. The B-dots measure current at the stack and in the outer magnetically-insulated transmission lines. Each monitor has two outputs that allow common-mode noise to be cancelled to first order. The differential D-dot has one signal and one noise channel; the differential B-dot has two signal channels with opposite polarities. Each of the two B-dot sensors in the differential B-dot monitor has four 3-mm-diameter loops and is encased in copper to reduce flux penetration. For both types of probes, two 2.2-mm-diameter coaxial-cables connect the outputs to a Prodyn balun for common-mode-noise rejection. The cables provide reasonable bandwidth and generate acceptable levels of Compton drive in Z's bremsstrahlung field. A new cavity B-dot is being developed to measure the total Z current 4.3 cm from the axis of the z-pinch load. All of the sensors are calibrated with 2-4% accuracy. The monitor signals are reduced with Barth or Weinschel attenuators, recorded on Tektronix 0.5-ns/sample digitizing oscilloscopes, and software cable compensated and integrated.

I. INTRODUCTION

The 36-module Z accelerator[1] - designed to drive z-pinch loads at currents up to 20 MA - is contained in a 33-m-diameter tank with oil, water,[2,3] and vacuum[4-10] sections. The peak total forward-going power in the 36 water-section bi-plate transmission lines is approximately 63 TW.[2,11] Nine transmission lines deliver power to each of the four vacuum-section levels (referred to as levels A (the uppermost), B, C, and D).[4-6]

To monitor the vacuum-section performance, new differential D-dot and B-dot probes were developed. Six of the D-dots and three B-dots are fielded in each of the four Z-insulator-stack modules; in addition, six B-dots measure the current in each of the four outer magnetically-insulated transmission lines (MITLs).[4,6] A new cavity B-dot design is being tested to measure the total Z current 4.3 cm from the axis of the z-pinch load.

The differential D-dot and B-dot probes are described in Sec.'s II and III, respectively. The status of the cavity B-dot development is reported in Sec. IV. Results of Z-vacuum-section power-flow measurements are presented in Sec. V.

II. DIFFERENTIAL D-DOT DESIGN AND CALIBRATION

The differential D-dots are mounted in the insulator-stack anode rings as shown in Figure 1. Each of the 24 monitors is located at the same radius, between an anode triple junction and an O-ring groove. Two-dimensional electrostatic ELECTRO[12] simulations show that the perturbation of the electric field at the vacuum-insulator interface by the monitors is negligible.

DISCLAIMER

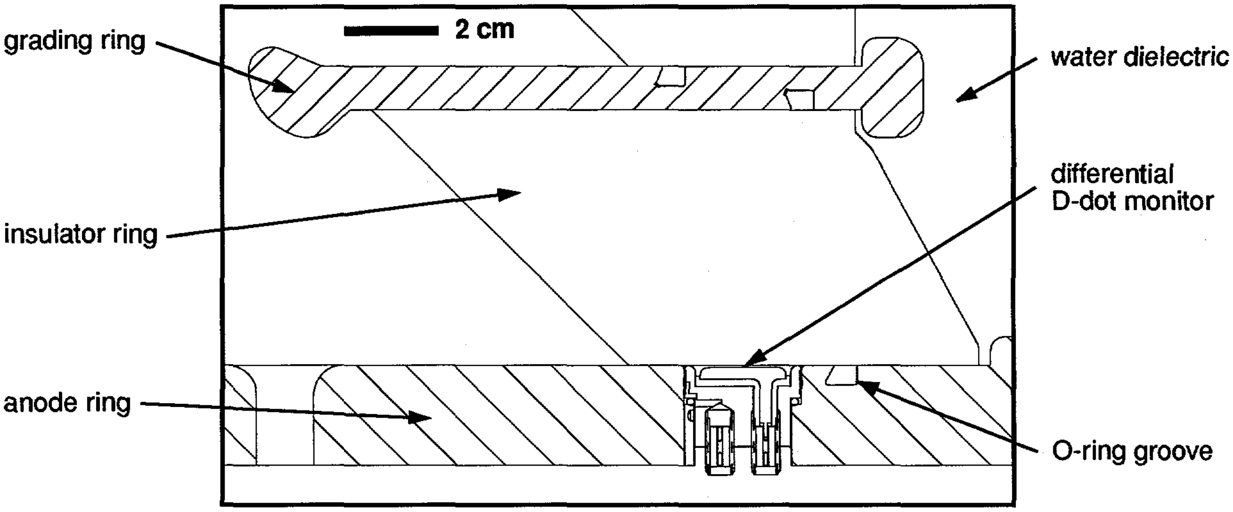

Figure 1. Detail of the Z insulator stack.

The design is detailed in Figure 2. One of the monitor's two outputs is connected to the displacement-current sensor; the other provides only a noise measurement. Two 2.2-mm-diameter Belden[13] RG-405 conformable coaxial cables connect the two outputs to a Prodyn[14] balun (model BIB-100B(mod)) for common-mode-noise rejection.[15] The cables provide reasonable bandwidth (power attenuation: 0.49 dB/m at 0.5 GHz) and generate acceptable levels of Compton drive.[16]

The D-dots are calibrated in situ with nine-module Z-accelerator shots that deliver power to a single MITL terminated with a short-circuit load. Faraday's law of induction is used to provide the reference voltage: the B-field is obtained from calibrated MITL B-dot monitors, and the geometry from the MITL and stack dimensions. A typical calibration result is presented in Figure 3. The nominal D-dot sensitivity is 6.6×10^{12} V/(m*s*V).

For a typical Z shot, the peak voltage at the balun output is 50-100 V during the main power pulse. Each of the 24 balun-output signals is reduced with a Weinschel[18] attenuator (model WA 1-20), recorded on a Tektronix[19] TDS-640 or TLS-216 0.5 ns/sample digitizing oscilloscope, and software cable compensated and integrated. The signals are recorded with long baselines to permit accurate baseline-offset calculations for the software integration.

III. DIFFERENTIAL B-DOT DESIGN AND CALIBRATION

The differential B-dot design is outlined in Fig. 4. The 0.005-mm-thick nichrome film allows the B-field to penetrate but shields the epoxy and B-dot loops from the electric field. The two outputs have opposite polarities for common-

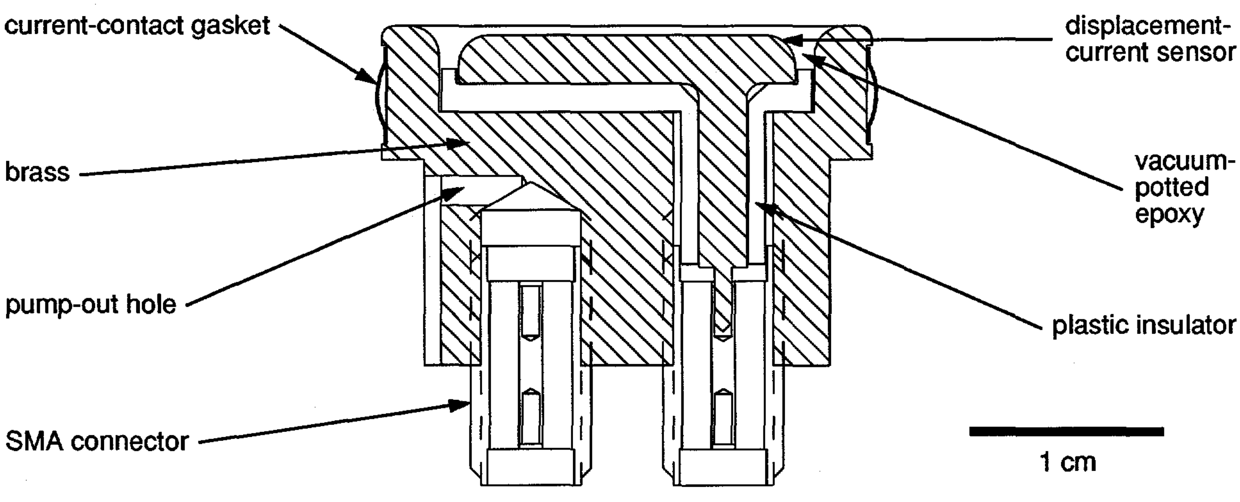

Figure 2. Detail of the differential D-dot monitor.

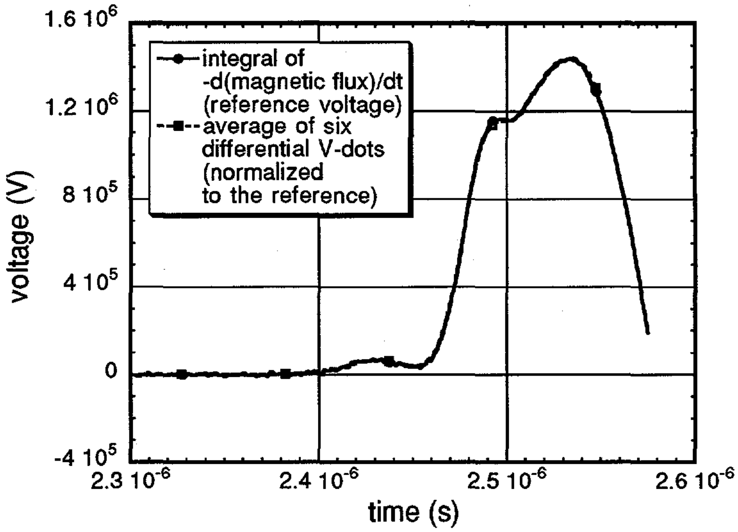

Figure 3. Result of in situ calibration of the six differential D-dots in the D-level stack module. The normalized standard deviation of the difference in the two wave shapes[17] is less than 1%.

mode-noise rejection. The output signals are processed as described for the differential D-dots (Sec. II).

The B-dots are calibrated with a 75-cm-diameter radial transmission line powered by a 5-kA pulse generator. The current wave shape of the system duplicates that of the Z accelerator. A precision 5-milliohm T&M Research[20] current-viewing resistor (model SSMA-2-005) mounted at the center of the transmission line measures the current. A typical calibration result is presented in Figure 5. The nominal B-dot sensitivity is determined to be 1.5 x 10^{11} A/(m*s*V). For a typical Z shot, the stack and MITL B-dot peak-output voltages (during the main power pulse) are approximately 50 and 100 V, respectively.

IV. CAVITY B-DOT DESIGN AND CALIBRATION

A new monitor is being developed to measure the total machine current 4.3 cm from the axis of the z-pinch load. The monitor, outlined in Fig. 6, measures the B-field that couples through a 2.4 x 4.8 mm aperture into a 2.7-mm-tall 12.7-mm-diameter cavity. The design reduces the electron and z-pinch x-ray flux at the B-dot sensor and may prolong its lifetime in the high-energy-density environment. A differential measurement is obtained by fielding two monitors with opposite polarities at different azimuthal locations: the signals are recorded separately and common-mode-noise is subtracted in software. The signals (which peak at ~500 V) are reduced with Barth[21] (model 142-NMFP-26) attenuators before being recorded.

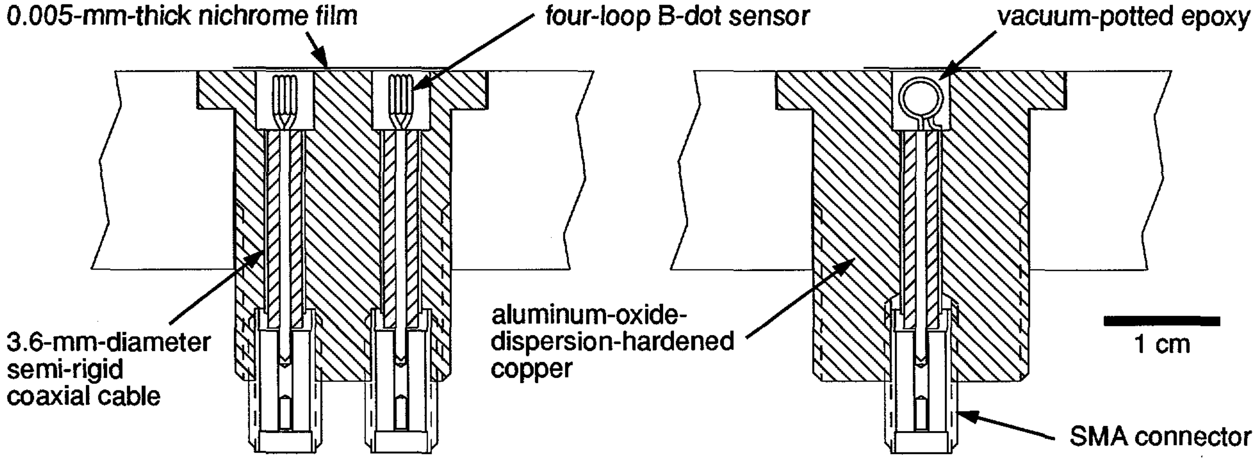

Figure 4. Two views of the differential B-dot monitor.

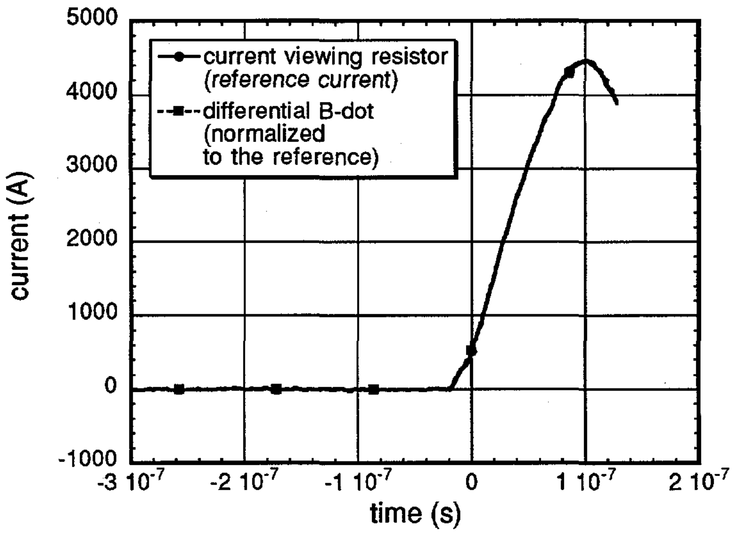

Figure 5. Differential B-dot calibration result. The normalized standard deviation of the difference in the two wave shapes[17] is less than 1%.

The monitor is calibrated with the same system used to calibrate the differential MITL and stack B-dots. Recent calibration results are presented in Figure 7. The B-dot sensitivity is typically 1.6×10^{12} A/(s*V).

V. Z-VACUUM-SECTION POWER-FLOW MEASUREMENTS

Measurements of the A-level stack voltage and MITL current (for Z-shot 66) are presented in Fig.'s 8 and 9. The effectiveness of the common-mode-noise rejection was determined with null measurements performed with monitors VSA260 and IMA300. Results, included in the Figures, indicate the residual noise can be neglected.

Measurements of the total Z current (for Z-shot 66) are presented in Fig. 10. The dip after peak current is due to the rapidly changing z-pinch inductance and is coincident with the emission of x-rays from the pinch. The principle limitation of this measurement appears to be closure of the aperture due to plasma formation by electron bombard-

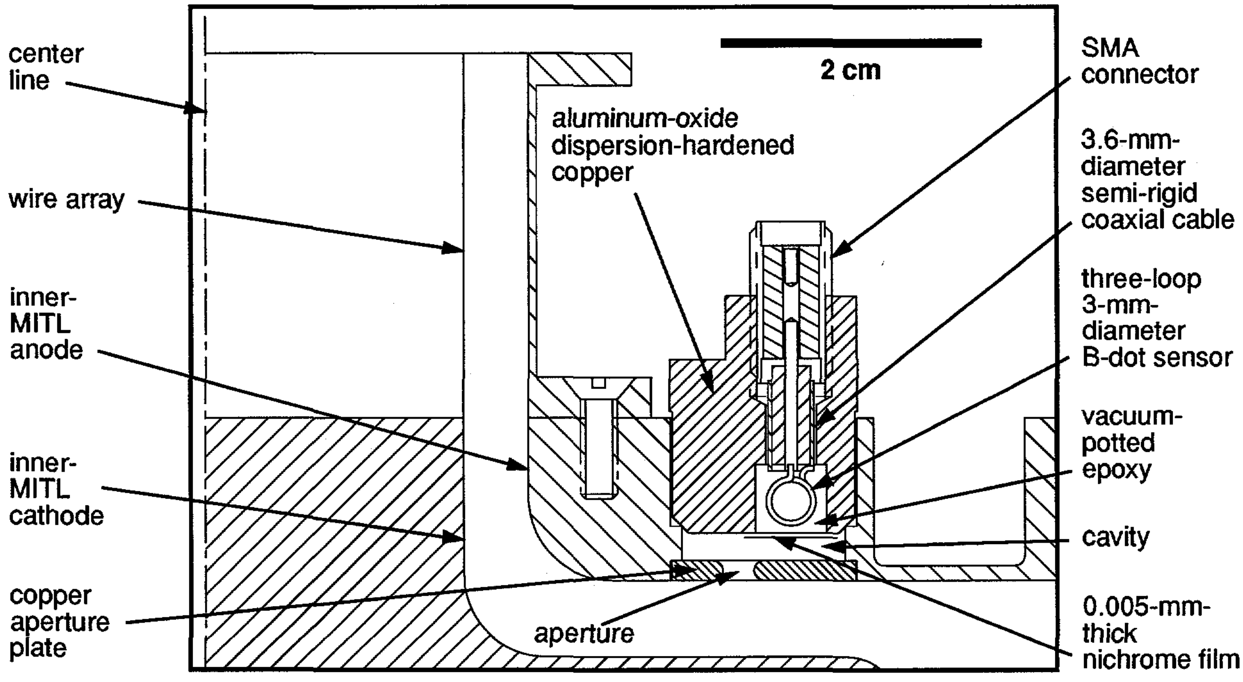

Figure 6. Detail of the inner MITL and developmental cavity B-dot monitor.

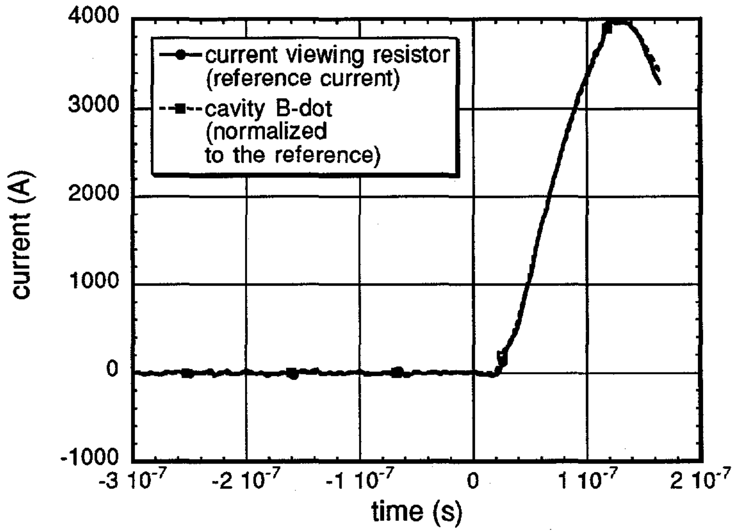

Figure 7. Cavity B-dot calibration result. The normalized standard deviation of the difference in the two wave shapes[17] is less than 1%.

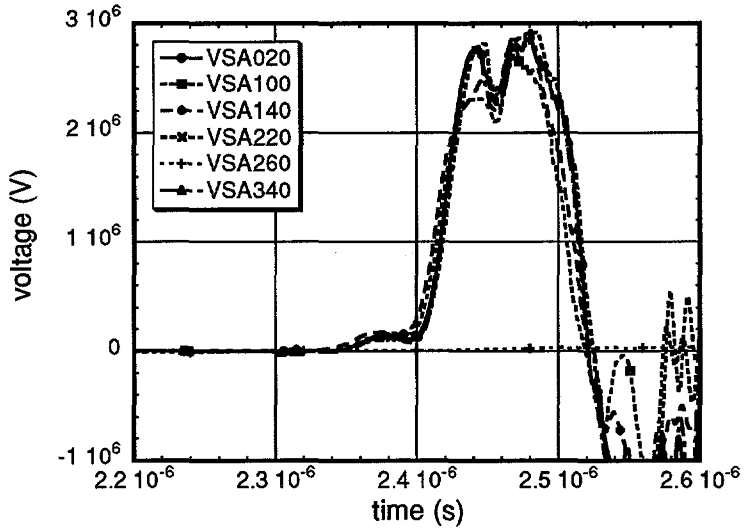

Figure 8. Measured A-level stack voltage at five azimuthal locations (Z-shot 66). Also plotted is a null measurement.

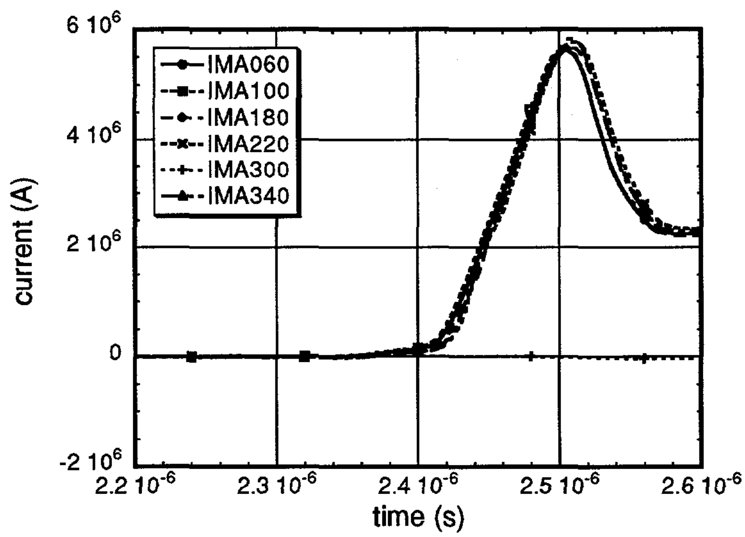

Figure 9. Measured A-level MITL current at five azimuthal locations (Z-shot 66). Also plotted is a null measurement.

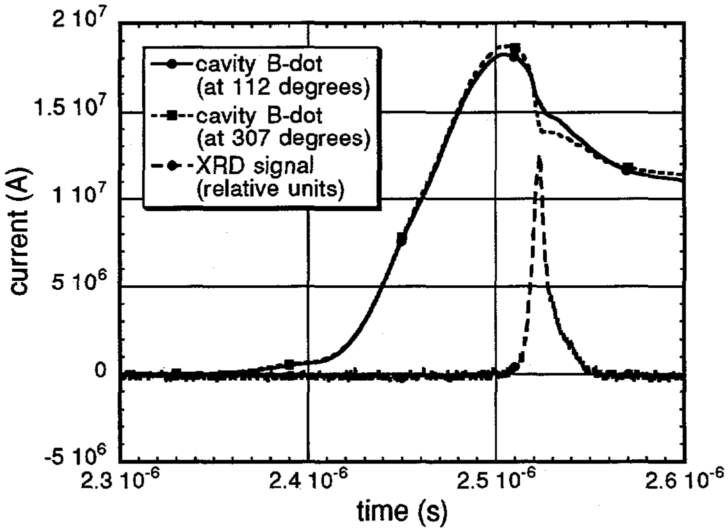

Figure 10. Measured total current 4.3 cm from the z-pinch load for Z-shot 66. The x-ray detector monitors radiation from the pinch.

ment and conduction-current heating.

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