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FMIT DIAGNOSTIC INSTRUMENTATION*

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Summary

The Fusion Materials Irradiation Test facility (FMIT) cw prototype accelerator has noninterceptive beamline instrumentation to measure beam parameters. The transverse emittances and beam profiles are measured with an array of photodiode sensors viewing light emitted from the beam region. Tomographic reconstructions of both spatial-density distributions and of transverse-emittance distributions are performed throughout a quadrupole focusing section. Beam bunches passing through capacitive probes produce bipolar waveforms whose zero crossing corresponds to the bunch's longitudinal centroid. By measuring the time required for a bunch to travel the known distance between two probes, velocity and energy are determined. A toroidal transformer measures the average ac beam current. Beam spill is measured by a set of movable jaws that intercept the beam edges. Each jaw contains a water flow channel whose flow rate and differential temperature are measured to derive a transverse power distribution. Beam centroid position is measured by a four-lobe, magnetic-loop pickup.

Introduction

A prototype accelerator[1] of high-current, cw D or H_2^+, 2-MeV ions for the FMIT facility has been designed and built at the Los Alamos National Laboratory. The accelerator consists of an injector and low-energy beam transport (LEBT) whose 75-keV dc beam is matched into a radio frequency quadrupole (RFQ). The 80-MHz RFQ output beam is tightly bunched and is transported through the high-energy beam transport (HEBT) to a beamstop. When operating in the cw mode, even at currents lower than 100 mA, the beam can quickly damage any beamline component in the beam path. Therefore, noninterceptive instrumentation was used to measure most of the characteristics of the 2-MeV beam. Figure 1 shows the HEBT and its associated components and diagnostic probes. Only the halo-feeler probes intercept a portion of the 2-MeV beam. The capacitive pickups, beam-position monitors (BPMs), and the Pearson toroidal transformer respond to changes in the electromagnetic fields of the beam bunches. Transverse beam profiles are reconstructed from measurements of the visible radiation emitted when the beam interacts with residual gas. Beam-loss and halo are determined by calorimetric probes that "feel" the outer fringes of the beam.

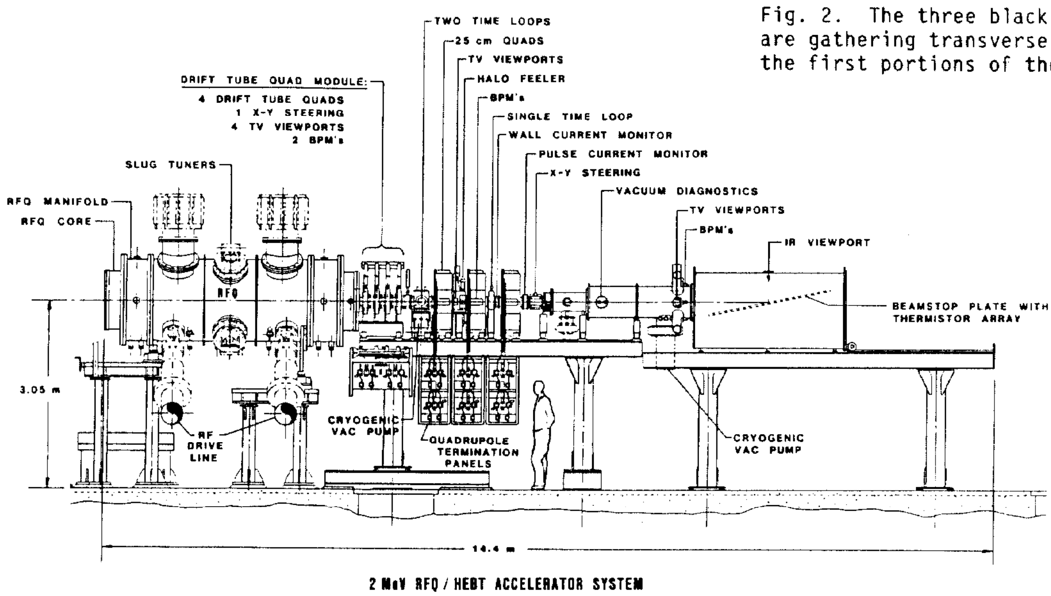

Fig. 1. HEBT sketch showing the relative placement of the diagnostic probes with respect to the other beamline components.

Measurement-System Descriptions

A new version of the photodiode array, reported previously,[2] is now operational and has been used to measure transverse emittances and beam profiles. Figure 2 shows the beam-imaging systems (or camera-head units) installed in the magnetic quadrupole array. Digitized profile data and computer control commands are transmitted to and from the these camera-head units over fiber-optic links. A communications network receives these data and, under control of a microprocessor master-communications controller, a dual-port CAMAC memory accepts and temporarily stores the profile information. An LSI 11/23 is used to store the raw profiles on a Winchester-style disk and to reconstruct transverse density and emittance distributions of the beam.

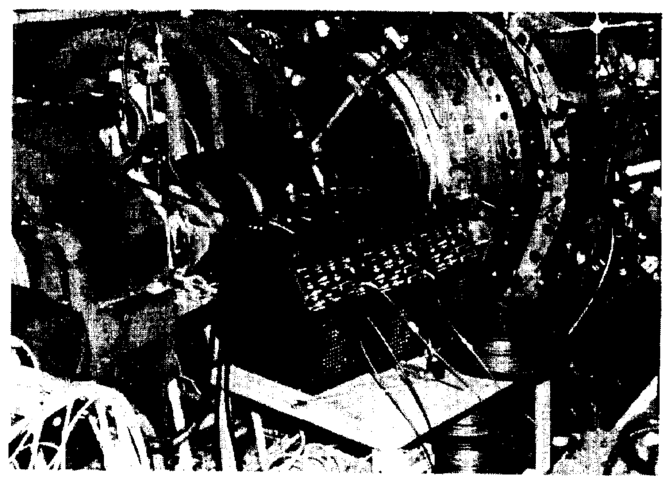

Fig. 2. The three black instrument enclosures are gathering transverse profiles of the beam in the first portions of the HEBT.

Figure 3 describes the time-of-flight system used to determine the energy of the particles in the

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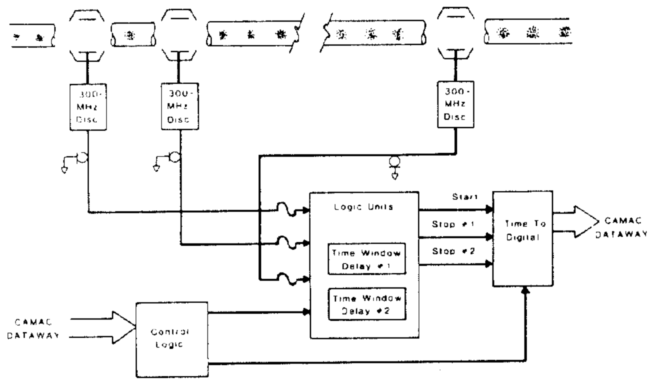

Fig. 3. Time-of-flight diagram showing the overall logic of the energy measurement.

peak of the bunch distribution. The system's probes shown in Figure 4 are the capacitive pickups (or time loops) whose two concentric rings respond to the change in the electric fields as a beam bunch passes to produce a bipolar signal. Three time loops[3] are placed on the beamline so that the distance between the first two is less than one βλ and the distance between the first and third is 1.2 m (6.94 βλ). As a bunch passes through the time loops, 300-MHz discriminators and logic units produce fast pulses. A pulse from the first discriminator starts the time-to-digital converter (TDC) and produces a timing window for two "stop pulses." Within these time windows, the converter is turned off as the bunch passes the second and third time loops. The timing window corresponding to Time Loop 3 references the timing interval of Time Loops 1 and 2 so that only a specific bunch starts and stops the TDC. At 80 MHz, bunches are separated by 12.5 ns and the 2-MeV ions travel from the first to third time loops in 86.7 ns. With all of the timing

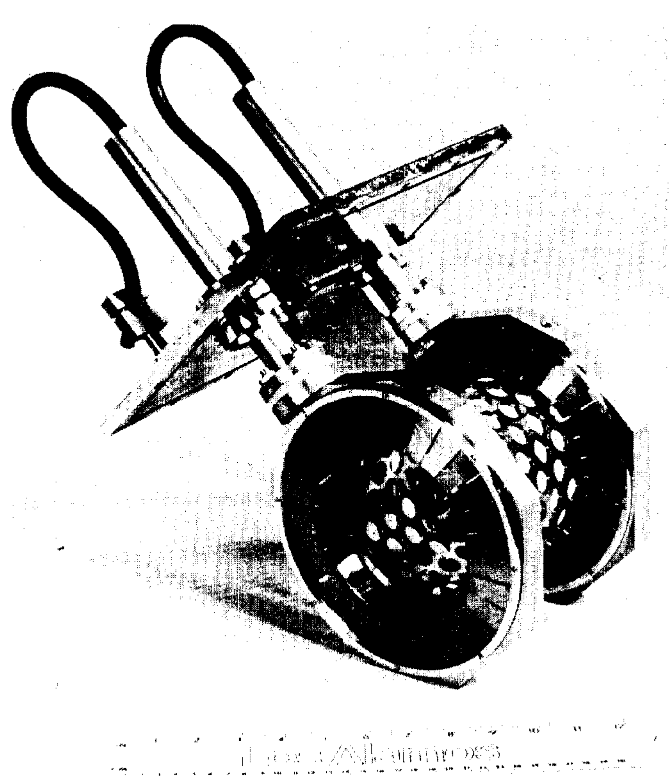

Fig. 4. The two capacitive pickups (including their flexible coaxial cables) pictured are less than one βλ apart.

inaccuracies (that is, cable delays, discriminator trigger jitter, etc.,) accounted for, the energy calculated from the bunch drift time is within ±10 keV.

The cw beam current is measured with a specially designed Pearson[4] toroidal transformer tuned to match the 80-MHz characteristics of the FMIT beam. A system block diagram is shown in Fig. 5. The transformer (including a 43.1-dB preamplifier) is carefully shielded from external rf noise. The preamplified signal is detected and filtered (with a crystal detector) and amplified to produce a dc voltage proportional to the peak, time-varying beam current passing through the toroid. There are two precautions to be considered when designing this measurement system. First, care should be taken to stay within the linear portion of the diode detector's operating range; and secondly, the toroid and its initial amplifier should be carefully shielded against all external noise (especially if the detected frequency and the likely rf noise frequency are one and the same).

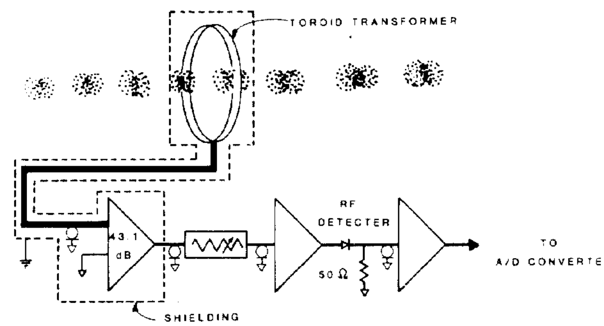

Fig. 5. The electronic detection circuitry for the toriod transformer.

Beam loss or spill is monitored with the only interceptive measurement system installed on FMIT. Four copper jaws intercept the outer transverse fringes of the beam. Each jaw has a meandering water-flow channel whose water temperature and flow rate are measured. Calorimetric measurements are made as a function of movement of these rectangular jaws from outside the beampipe radius to within two standard deviations of the assumed beam transverse profile. Each jaw is driven by a geared stepper-motor assembly that is controlled by a CAMAC stepper-motor controller. Flow rates are measured with precise "paddle-wheel" style flowmeters whose repeatability is within ±0.15% from 1.5 to 0.05 gpm. Differential temperature is measured with a thermister bridge calibrated to within 0.1°C. A hardware-safety interlock system prevents beam operation if water temperature is too high or if water flow is too low. Under the interlock condition, the jaws automatically retract, temporarily disabling the beam. A multichannel strip-chart recorder has been invaluable for both calibration and data recording. Two minor flaws with this system are its slow response time and its present lack of reliability. Synchronous or dc motor drives, resistive temperature devices, and linear variable differential transformers position indicators (rather than stepper motors, thermisters, and potentiometers) would be the preferred system-design choices.

Each BPM probe (Figure 6) consists of four lobes placed along the beamtube's x- and y-axes. Within each lobe, a wire loop senses the change in magnetic field as the beam bunches pass. Each of these lobe signals is presented to a centroid detection circuit with four phase-matched, coaxial cables. The circuitry converts the amplitude of the BPM signals into two phase angles that vary as a function of x- and y-centroid beam position. The two position-dependent

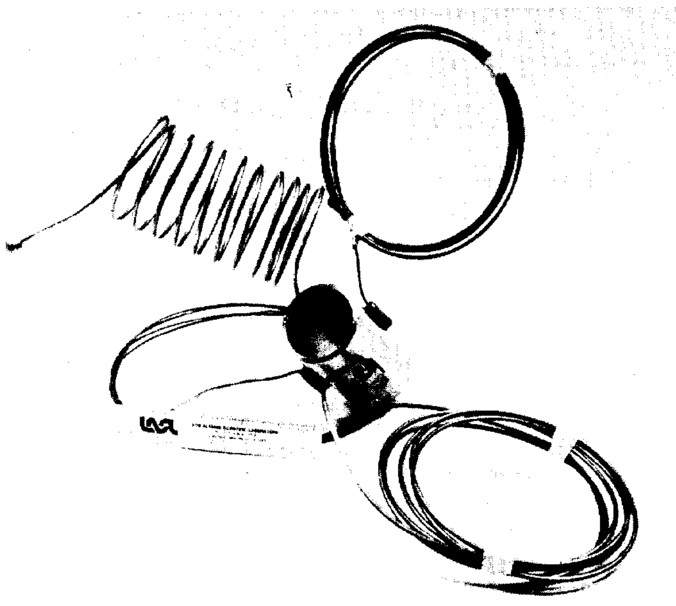

Fig. 6. The beam position monitor picture shows the four lobes with four semirigid coaxial cables.

phases are then detected and filtered to produce x- and y-signals. Tested successfully for the Proton Storage Ring[5] at Los Alamos, this circuitry offers a large dynamic range, wide bandwidth, and amplifier-drift insensitivity. Unlike other probes on the FMIT beamline, the BPMs do not have a separate signal ground; therefore, care must be taken to include high common-mode rejection devices in the input circuitry. In this case, a phase-stablized, rf amplifier was used.

Conclusion

The noninterceptive diagnostic instrumentation provides measurements of beam parameters unattainable with older interceptive techniques. This measurement instrumentation also supplies the accelerator operator and control system with accurate and timely beam-parameter information.

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References

1. W. D. Cornelius "CW Operation of the FMIT RFQ Accelerator," these proceedings.
2. D. D. Chamberlin, J. S. Hollabaugh and C. J. Stump, Jr., "Imagescope to Photodiode Beam-Profile Imaging System," IEEE Trans. Nucl. Sci. 30 (4) (August 1983), 2201.
3. J. D. Gilpatrick, B. A. Sherwood, J. Hahn, and D. D. Chamberlin, "Wide-Bandwidth Test Fixture for Electromagnetic Beam Sensors," IEEE Trans. Nucl. Sci. 30 (4) (August 1983), 2256.
4. Pearson Electronics Inc., 1860 Embarcadero Road, Palo Alto, CA 94303.
5. E. F. Higgins and F. D. Wells, "A Beam Position Monitor for the Proton Storage Ring at LAMPF," IEEE Trans. Nucl. Sci. 30 (4) (August 1983), 2308.