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NONINTERCEPTIVE TRANSVERSE BEAM MEASUREMENTS*

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Summary

Totally noninterceptive techniques for accurate measurement of transverse beam distributions are required for high-current continuous wave (cw) linacs, such as the Fusion Materials Irradiation Test (FMIT) accelerator.[1] Sensors responding to visible radiation from beam interactions with residual gas and computer algorithms reconstructing spatial and phase space distributions have been implemented. This paper reports on early measurements of the beam from the injector of the prototype FMIT facility at Los Alamos. The first section indicates hardware setup and performance whereas the second section describes the data-processing software. The third section outlines the resultant measurements and further developments are discussed in the fourth section.

Hardware/Setup

The basic data-acquisition system has been reported previously.[2,3] Silicon intensified target (SIT) television cameras are provided with four transverse beam profiles by a compact set of mirrors. These profiles correspond to transverse projections of the beam light intensity at the horizontal, vertical, and two nonopposing 45° angles. The cameras were specially set up with externally adjustable gain settings. Cameras from three longitudinal stations are multiplexed into a video digitizer with a present resolution of 0.57 mm per digitized point. Camera gain and bias level of the digitizer are adjusted for maximum peak to background ratio, presently about 245 (for an 8-bit ADC) to 70 (camera signal-to-noise ratio of ∿37 dB). Stability of camera, mirror, and electronics has been excellent, leading to better than anticipated reproducibility of emittance parameters. Data are quite high quality, owing at least partially to premium SIT tubes in the cameras and to light-tight enclosures. Some effort has gone into getting all the cameras onto a common ac circuit for identical phasing and into eliminating ground loops. Mirrors are front surface and were prepared with a quarter-wavelength antireflective coating. All surfaces were black anodized to reduce reflections. With these preparations, setup, adjustment, and stability of the mirror mounts have been easy and straightforward.

Software/Acquisition

After the initial gain adjustment, the remainder of a measurement sequence is automatic. A single command sequences the multiplexer through the cameras with synch-registered TV frames passed onto the computer's magnetic disk. The TV line and column windows select the region of interest; backgrounds are well fit by a linear subtraction with the resultant line-averaged profiles being presented to the computational algorithm.

The maximum entropy criterion used to compute a density distribution (either spatial or phase space) has been reported previously.[4-6] The maximum entropy (MENT) technique agrees well with traditional measurement techniques.[5,6] The version reported here differs only in having been modified to run interactively in a minicomputer (DEC PDP-11/60) and has been verified to produce results identical to those from the original main-frame (CDC 7600) version. The computed density distribution is put into a 51 by 51 array for further calculation or output plots specific to an application.

Various checks of the automatic process are available. The raw frames may be plotted either as intensity contours or in an isometric projection. Individual lines or columns from these frames may be plotted. Matrices connecting the associated profiles may be checked and adjusted. These are rotation matrices for an x-y spatial reconstruction at one station, or transport matrices for a given axis for an emittance reconstruction from several stations. Other parameters are adjustable, although no detailed exploration of the available options has yet been carried out. Backgrounds may be fit by higher order polynomials, although this has not been necessary with the present quality of the data.

Outputs may be plots of either equal intensity contours, projections, or isometric views. Numerical information concerning total contained intensity, area covered, or rms parameters describing the distribution may be readily calculated. Projections from the solution distribution may be compared with the input data profiles.

Measurements

The system described above has been used for a preliminary characterization of the beams emerging from the injector of the FMIT prototype. Capable of up to 75 kV and greater than 100 mA cw operation, the injector is being optimized for FMIT requirements. Data sets may be taken with less than 1-min separation with 1% repeatability. Figure 1 shows a typical beam profile as a single line of composite video. The first step in that characterization is to establish the level of space-charge neutralization of the beam. An rms emittance is calculated for the beam, assuming drift-only transport. This emittance value encloses about 47% of the very nearly bi-Gaussian distribution. Courant-Snyder shape parameters are extracted corresponding to 87% of the beam. Using

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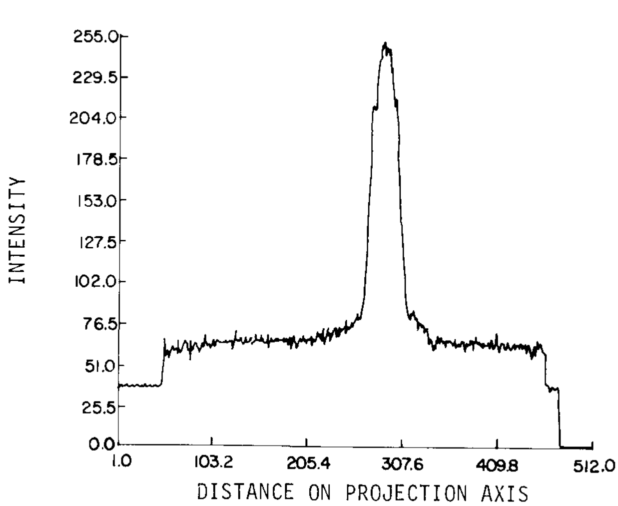

Fig. 1. A single line of composite video after digitizing to 512 points by an 8-bit ADC. The projection of beam light intensity is clearly defined with minimal noise contribution.

these shape parameters, and four times the rms emittance, a TRACE[7] run is performed for a uniform distribution (that is, with an rms emittance equal to that of the measured distribution). The transport matrices from the TRACE dynamics calculation for an assumed beam current are input to the MENT algorithm for a corrected solution. By the third iteration, all parameters have settled to better than 1%. Thus, various levels of space-charge effects may be tested for a best fit.

Contour plots of the calculated emittance are available in various formats, such as shown in Fig. 2. Density distributions at a location are conveniently displayed in an isometric view as in Fig. 3.

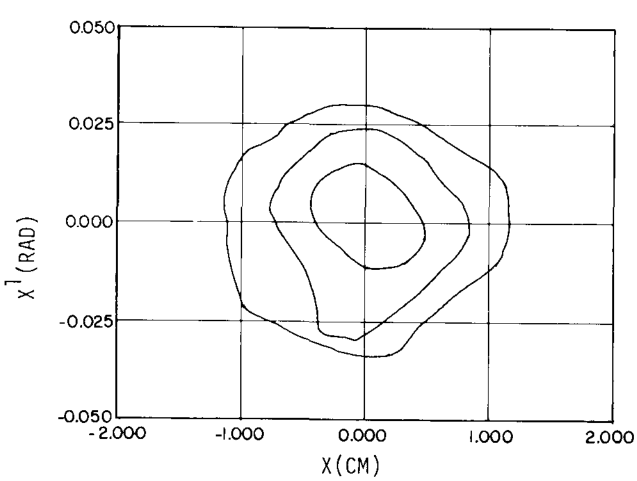

Fig. 2. Emittance distribution equal intensity contours as reconstructed by the MENT algorithm from projections of beam light intensity. The contours shown enclose approximately 99%, 87%, and 47% of the total intensity.

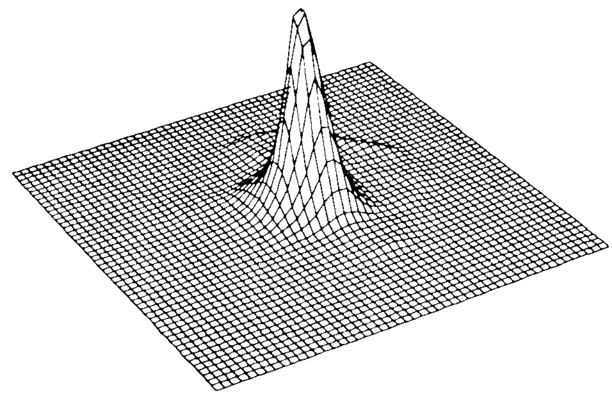

Fig. 3. Isometric plot of the spatial density distribution as reconstructed by the MENT algorithm from four projections of beam light intensity at a single location.

Future Improvements

The TV scheme has proven to be an accurate repeatable measurement system for transverse distributions and emittances of the beam in a totally noninterceptive fashion. Long-term reliability and stability are expected but not yet confirmed. Ease of use is comparable to traditional methods.

There are several possible techniques for improving the spatial resolution from the present 0.57 mm to 0.1 or 0.2 mm per point. We hope soon to have automatic gain-setting capability for the cameras and to have permanently installed fiducial markings in the view box. The MENT algorithm soon will run in a local LSI-11/23 with an attendant reduction in data-transfer times. A 4D version of MENT will be reworked to operate in the minicomputer environment as a means of following x-y correlations through a solenoidal magnet focusing system. The fit to space-charge neutralization level will be initiated by a linear algorithm that will be much faster and that may be used as a fast feedback readout for real-time operator tuning.

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