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NONINTERCEPTIVE TRANSVERSE BEAM DIAGNOSTICS*

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Summary

The transverse emittance properties of a high-current linear accelerator may be measured by using TV cameras sensitive to the visible radiation emitted following beam interactions with residual gas. This paper describes the TV system being used to measure emittances for the Fusion Materials Irradiation Test (FMIT) project.

Introduction

To provide a neutron source for research on steel alloys suitable for a fusion reactor environment, the Hanford Engineering Development Laboratory and Los Alamos National Laboratory are developing a 100-mA, CW, 35-MeV deuteron linac. The combination of high beam power and deuteron beam requires accurate characterization and precise control of the beam to minimize beam spill and the resultant irradiation of the facility. Also implicit in such a machine is the use of noninterceptive beam diagnostic sensors. Obtaining the transverse spatial and phase-space distributions of the beam without interception poses a challenge. Cross sections for ionization of residual gas atoms by beam interactions were reported by DeLuca[1], as well as a technique for collecting the ions or liberated electrons. However, for a high-current CW machine, these interactions provide a photon intensity sufficient for detection by low-light level TV cameras.

Digitizing a line of the composite video signal from a TV camera that is viewing the beam region transversely provides a projection of the beam density distribution. Four of these profiles at that position, spaced at 45° angles serve as input to a computer reconstruction[2] of the transverse spatial distribution, an x-y plot of beam intensity.

Further, a set of three or more such 4-view measurements suffices to characterize the transverse emittance of that beam if the transport properties of the intervening beamline are known.[3] The reconstruction coding for x-x' is based on the MENT algorithm for x-y reconstructions[4].

The following sections describe the implementation of these transverse beam-diagnostic measurements for the FMIT linac.

Feasibility

To determine the requisite sensitivity (both absolute and spectral) for the TV cameras, preliminary measurements were made of the light emissions from an FMIT prototypic ion source, with nitrogen gas (assumed to be the strongest emitter) bled into the beamline. Figure 1 shows the typical[5] N_2 spectra obtained. Attempted calibration to a National Bureau of Standards source left large uncertainties but the light levels expected under FMIT conditions appeared adequate. Corresponding to the decrease of light intensity with increasing beam energy, the camera sensitivity must increase from vidicon style through intensified stages of TV tubes.

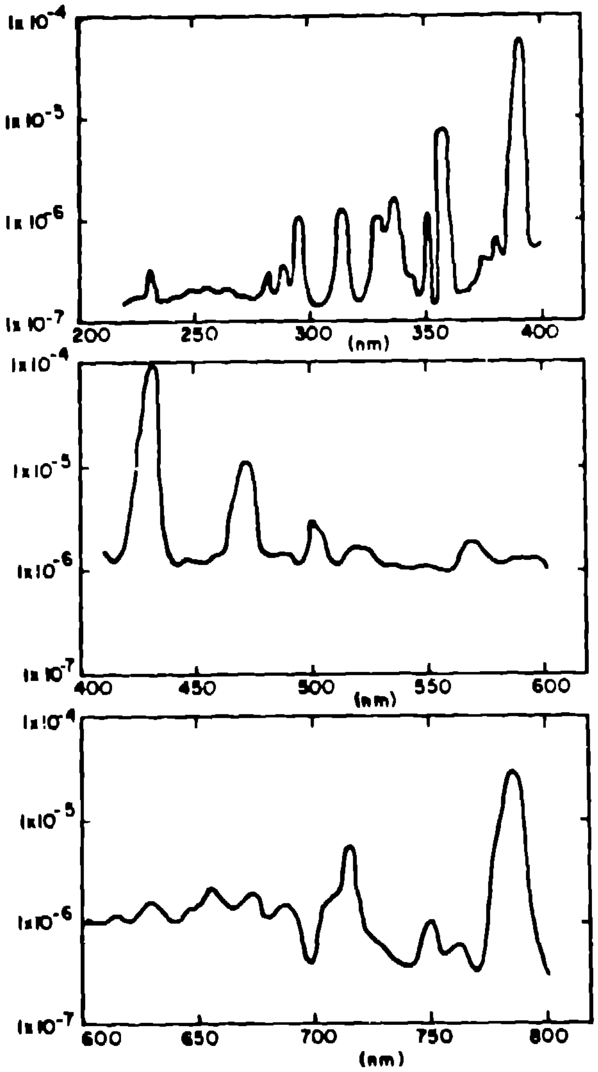

Fig. 1. Spectrum of 80-KeV protons on nitrogen.

TV views of this prototype beam were digitized and passed on to the spatial and phase-space codes. The resultant distributions compared quite well with interceptive technique measures such as a pepper pot and with measured values of current, divergence and neutralization.

Set-Up

The four transverse views of any one longitudinal station are presented to a single camera by an array of mirrors such as that shown in Fig. 2. The dominant design criteria were equal path length, large field of view, maximum resolution, and minimum overall packaged size. Other locations of the FMIT machine have space limitations that call for an even more compact optical system, such as a coherent fiber optic bundle to relay the image to a camera several feet away.

In compliance with the FMIT goals of high maintainability and use of commercially available modules,

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Fig. 2. Four-view mirror array.

the electronic signal processing fits the CAMAC standard. Figure 3 presents the data acquisition system. A 20-MHz ADC with associated fast memory digitizes the entire frame, which is transferred, either directly or following some data compression in a local minicomputer, to a PDP 11/60 control computer. This process is being optimized for speed to present the final display within a few seconds, corresponding to human operator response times. Switching of input among the various cameras will be under computer control with fiber optic links for both the control lines and the composite video.

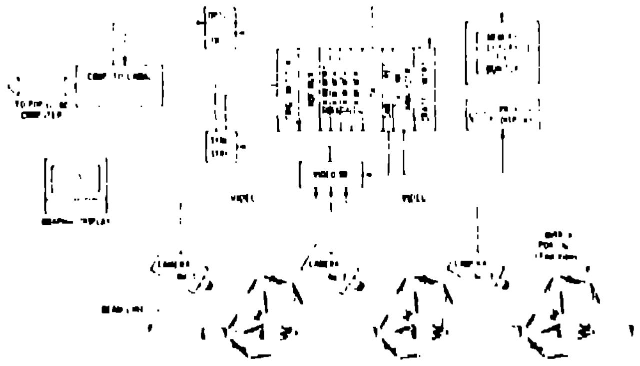

Fig. 3. FMIT T.V. data diagnostic system.

Software coding is designed to standardize the incoming profiles and present them to a reconstruction code using a maximum entropy algorithm. The resultant distributions are stored for subsequent display, usually as contour plots or isometric displays.

By initially extracting rms parameters from the TV profiles, a linear algorithm may be used for more rapid calculation of rms envelope parameters. All these phase-space codes must account for the influence of space charge on the beam transport. An iterative loop of these emittance calculations with a beam transport code that will converge on both beam parameters and neutralization level is planned.

With the full-frame information available, averaging over several lines may improve signal-to-noise ratios, and image-enhancement processing may be used to provide information on the low-level tails of the beam distribution.

Measurements

Raw profiles, obtained as one line of composite video, appear in Fig. 4. The data is averaged over several lines, background is subtracted then the resulting profiles are normalized.

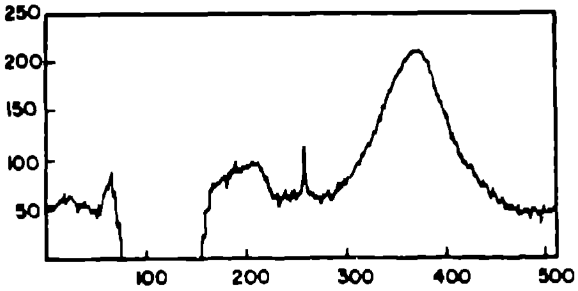

Fig. 4. Digitized TV line showing beam profile.

The 2-D MENT reconstruction codes described in Refs. 2 and 4 have been adapted to run on a minicomputer. We have developed ANSI FORTRAN versions with low memory requirements and semi-interactive graphics package. The graphics package allows the user to select a small number of options for displaying 1-D input profiles or 2-D reconstructions. The minicomputer versions have been adapted[6] for installation on the PDP-11/60 support computer of the FMIT prototype. A 4-D reconstruction code[7] has been developed to process profiles obtained at several different angles at three or more stations to reconstruct the 4-D transverse emittance distribution of the beam. The TV-camera imaging chain will be able to yield views at four angles, 0°, 45°, 90°, and 135° from the horizontal, at three or four different stations. We believe that this information, used as input in the 4-D MENT reconstruction code, will give a good determination of the 4-D emittance distribution.

Output displays are available in formats as shown in Fig. 5. Four iterations show convergence of the algorithm with roughly 3/4 s per iteration.

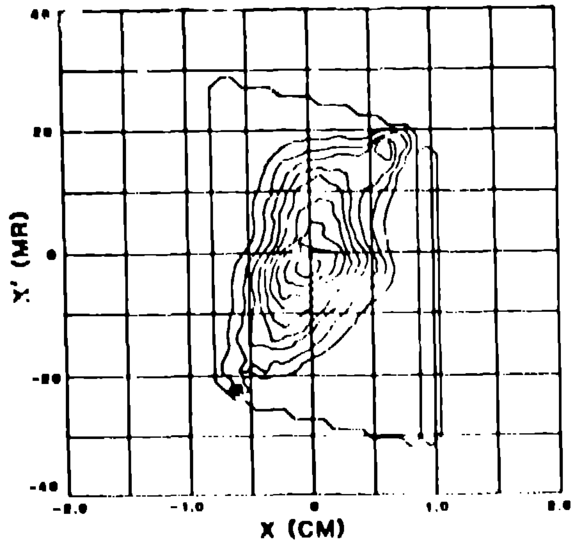

Fig. 5. Reconstructed transverse emittance plot.

The uncertainties in the data collection and handling processes have not been well explored. Preliminary indications are that spatial positions are known to ± 0.1 mm, and intensity levels are accurate to better than 20%

At present, the time span from collection to display is artificially long, several minutes. Automatization and optimization of the various steps involved is anticipated to reduce this time to less than 1 minute. This same optimization may reduce the linear rms calculation time so as to provide emittance displays updated every 10 s or less, in the range of operator response times.

Status and Plans

Portions of the system described are presently in use on the Low-Energy Beam Transport (LEBT) of the FMIT prototype at Los Alamos. Solenoidal magnets soon will be installed in this beamline to focus the beam for presentation to the next beamline element, an RFQ. Accordingly, the emittance reconstruction coding will be augmented to calculate 4-D transverse emittances, as done for the LAMPF accelerator[7].

Future work is directed toward optimizing station placements for both viewports in the linac tanks and in the High-Energy Beam Transport (HEBT), and to use fiber optic "Imagescopes" in the limited spaces between RF tanks. Work is in progress to assign a figure of merit to station placements that are far from the optimum, as defined by Metzger[3]. As experience with the system grows, a major effort will be directed toward optimizing both speed and display formats for maximum ease of operator/beam interaction.

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