VIDEO PROFILE MONITOR DIAGNOSTIC SYSTEM FOR GTA

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Abstract

This paper describes a video diagnostic system used to measure the beam profile and position of the Ground Test Accelerator 2.5-MeV H^- ion beam as it exits the intermediate matching section. Inelastic collisions between H^- ions and residual nitrogen in the vacuum chamber cause the nitrogen to fluoresce. The resulting light is captured through transport optics by an intensified CCD camera and is digitized. Real-time beam-profile images are displayed and stored for detailed analysis. Analyzed data showing resolutions for both position and profile measurements will also be presented.

Introduction

A diagnostic that measures the horizontal and vertical beam width and position of a high-current H^- particle beam is needed to monitor the output of the IMS. H^- ions collide with residual nitrogen in the vacuum chamber, causing the nitrogen to fluoresce, primarily at wavelengths of 394 and 427 μm [1] and [2]. The video approach was selected because of its nonintrusive nature and relatively small longitudinal dimension (2.0 cm). The system consists of a set of optics used to relay the beam image to an intensified CCD camera array, electronics to remotely control the camera and a piezoelectric valve (used to inject gas into the vacuum for increased light output) and a control system. The control system is used for data acquisition and analysis as well as to control the camera, intensifier and gas valve remotely.

Configuration

The video profile monitor (VPM) can be subdivided into three subsystems: optics, electronics, and controls.

Optics

Each optical system (x and y axis) consists of two lenses inside the vacuum vessel that relay the image to a third motorized lens which is attached to an intensified CCD camera. The camera is located outside the vacuum vessel in a light-tight box (Fig.1). The first lens is located 10.5 cm from the beam axis and captures the maximum amount of light, given our physical constraints. The second lens captures all the light transmitted through the first lens and forms an image of the beam between the second lens and the camera lens.

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All light is then captured by the camera lens and re-imaged on the CCD array. An extension tube is placed between the lens and the camera to properly focus the image on the array. All the lenses have broad band AR (anti-reflection) coatings for maximum transmission. The total transmission of the optical system is estimated to be approximately 85-90%. The scale factor of the system is 75 microns per digitized pixel and there are 512 digitized pixels per image line.

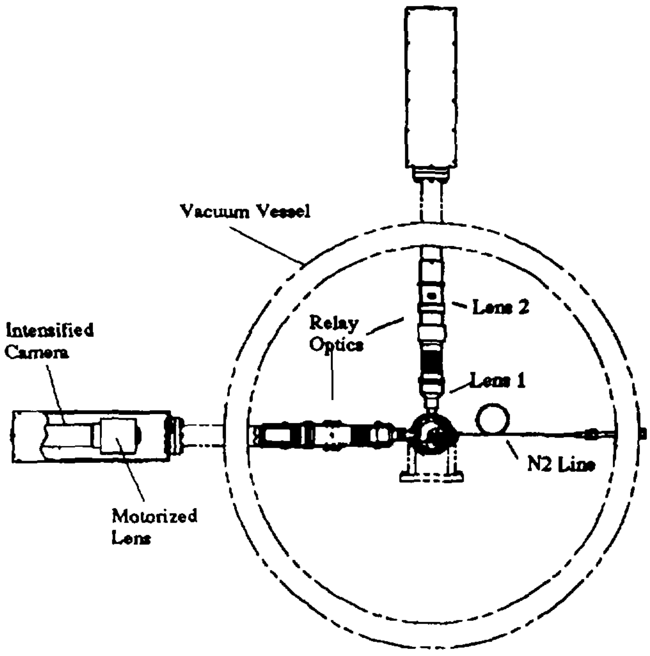

Fig. 1. VPM hardware configuration.

While the vacuum vessel is open, lenses 1 and 2 can be individually moved along the optic axis to optimize the image clarity. The zoom, focus, and iris settings for the motorized lens can be controlled remotely at any time. Once the vacuum vessel is closed, only the motorized lens can be adjusted.

The integration time (gate width) and the intensifier gain of the camera can also be controlled remotely. The optical gain of the camera is 20 k. The signal-to-noise ratio for a typical data set is approximately 60:1 with a gate width of 300 μs, 25 mA of beam current and an estimated gas pressure of 1 x 10^{-5} Torr in the VPM region during data acquisition.

Electronics

As shown in Fig. 2, the electronics consists of several subcircuits which handle separate functions.

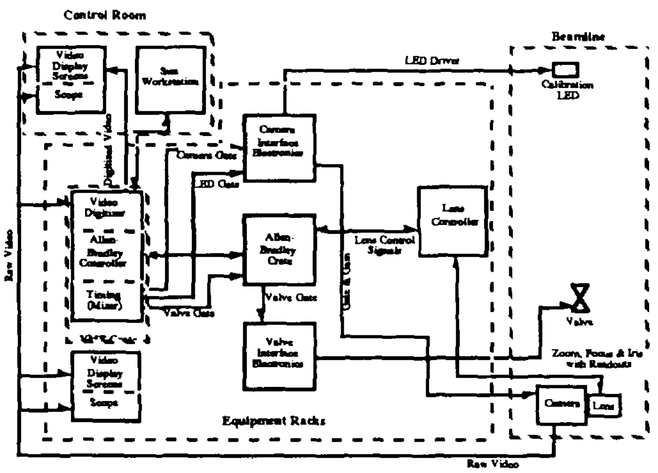

Fig. 2. Video profile diagnostic block diagram.

One subcircuit consist of a piezoelectric valve driver which opens the valve for a specified duration, usually 3 ms. As a precautionary measure, this subcircuit also includes electronics which limit the time the valve remains open. A second circuit allows the camera gate and gain to be controlled remotely, either manually or under computer control. The lens controllers allow the lens functions (i.e., zoom, focus, etc.) to be controlled remotely, either manually or under computer control. A timing module housed in the VME crate controls all timing functions. This timing card is also the driver for reference LEDs which are used to calibrate the system. All digitization is done in the video VME crate [3].

Controls

The VPM controls system incorporates the GTA control system to perform the basic hardware functions of setting the focus, zoom, and iris positions on the motorized lens. It also controls the intensifier gain and gate for the camera and the nitrogen flow through the piezoelectric valve.

Data is acquired and stored as an 8-bit image having dimensions of 512 by 240 pixels. Real-time plotting of a single row or column of data as well as its full-width half-maximum width is available at a rate of 10 Hz. Off-line data analysis is available as described in Ref. [3].

Data Acquisition and Analysis

Once the system was optimized, VPM data was taken at several settings of the field strength of the last two quads on the IMS. Emittance runs were taken in conjunction with the VPM data to characterize the validity of the VPM data.

The initial results of the on-line data analysis indicated a width much greater than expected. Subsequently the video profile images were transferred to a Macintosh in PICT format for analyses using Spyglass-Transform [4] and Sigma Plot [5]. The data was fitted to the following equation:

$$f = a_1 \frac{1}{s_1\sqrt{2\pi}} e^{-\frac{(x-m_1)^2}{2s_1^2}} + a_2 \frac{1}{s_2\sqrt{2\pi}} e^{-\frac{(x-m_2)^2}{2s_2^2}} + b \cdot \qquad (1)$$

Where a_n is the amplitude multiplier, m_n is the mean, s_n is the standard deviation and b is the dc offset. The dc offset is due to the system background, which includes dark current in the CCD array, luminous background, digitizer noise, etc. This same equation fits data taken from an image of the reference leds. This implies that the tails in the data are a systematic effect and is assumed to be photons in the intensifier leaking into adjacent pixels. One Gaussian represents the data; the other represents the leaking effect. Figure 3 shows the raw data with its fitted curve superimposed. Width and position information are then extracted from the data using Eq. (1).

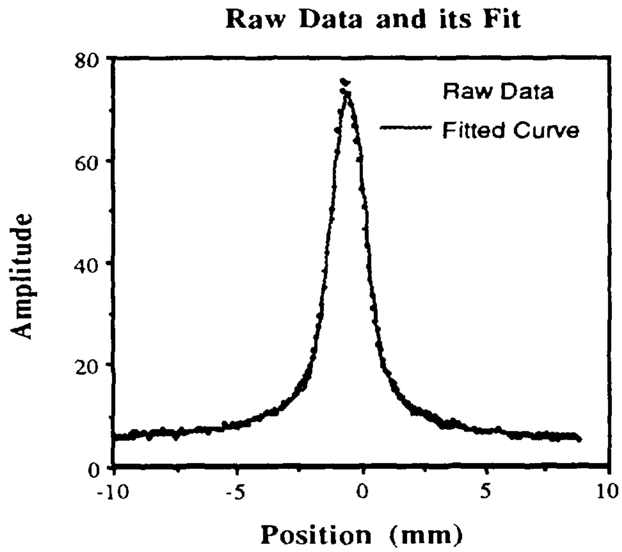

Fig. 3. Raw data plot with fitted curve superimposed.

This analysis worked well and was used to analyze all the data.

Results

The analyzed data was compared to width and position information obtained using a slit and collector. Because the slit is several centimeters from the VPM, the slit and collector data was traced back to the VPM location using TRACE 3D and REANE. TRACE 3D is an interactive beam-dynamics code that calculates the envelopes of a bunched beam through a user-defined transport system. REANE is an analysis code that can take a measured phase-space distribution and propagate it through a user-defined transport system. In both cases the resulting information gave beam widths at the VPM location. The VPM data and REANE processed data are given in Figs. 4 and 5.

The centroid information obtained from the slit and collector runs were also traced back using REANE to obtain the beam centroid position information. The beam locations using the slit and collector data are compared to the VPM data and shown in Figs. 6 and 7.

Conclusions

The above results show that both position and width information agree quite well with the slit and collector data. With the experience gained, we are now ready to modify the controls system so the VPM can be used as a turnkey diagnostic. The VPM diagnostic as implemented at Los Alamos has proven to be a reliable diagnostic which will benefit GTA.

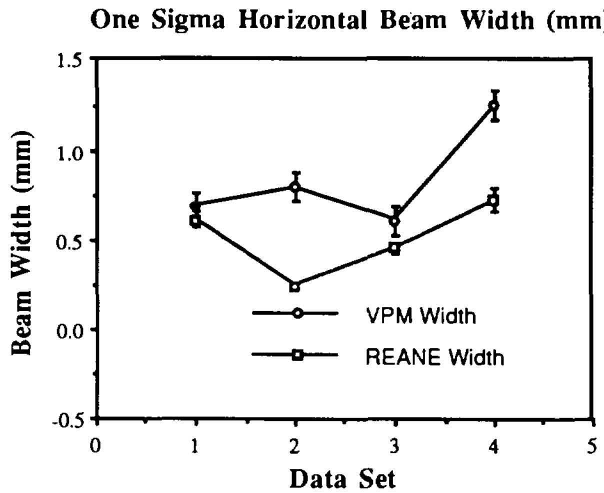

Fig. 4. Horizontal beam widths measured using the slit and collector gear and the VPM for several IMS output quad settings.

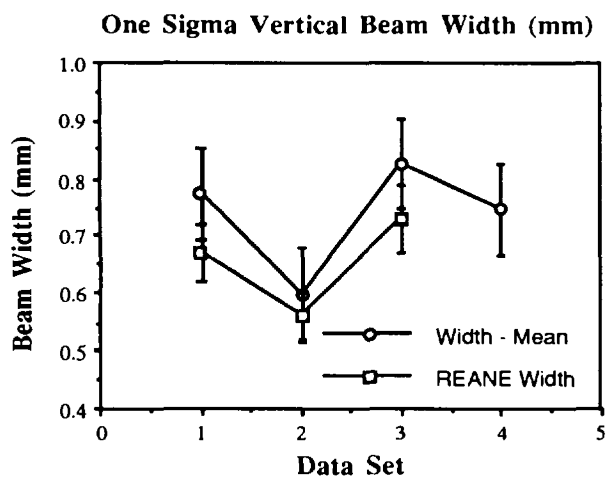

Fig. 5. Vertical beam widths measured using the slit and collector gear and the VPM for several IMS output quad settings.

Acknowledgments

We wish to thank Dan Rusthoi for doing the TRACE-3D runs.

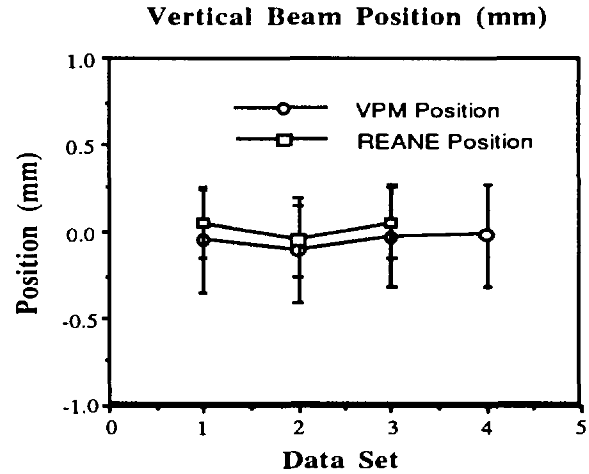

Fig. 6. Vertical beam centroid location as measured using the slit and collector gear and the VPM for several IMS output quad settings.

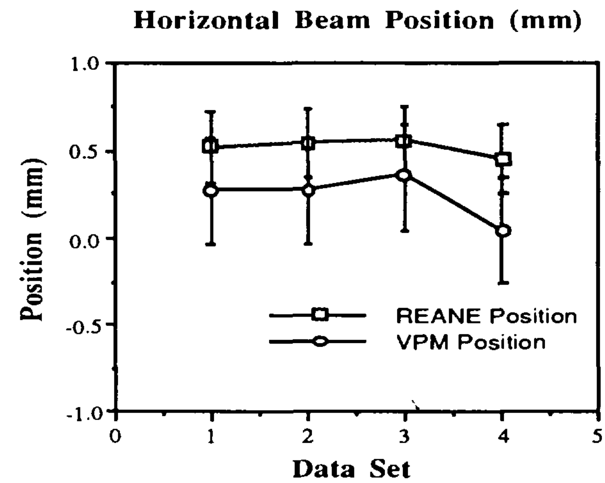

Fig. 7. Horizontal beam centroid location as measured using the slit and collector gear and the VPM for several IMS output quad settings.

References

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[5] Sigma Plot. Jandel Scientific. 65 Koch Road, Corte Madera, Ca 94925.