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A FLUOR AND WIRE-SHADOW DIAGNOSTIC FOR LOW-ENERGY ION BEAMS*

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Abstract

A video diagnostic technique utilizing a fluorescent screen and a video camera has been developed to monitor the two-dimensional beam-intensity profile and angular divergence of low-energy (25-35 keV) ion beams. Detailed off-line analysis is used to compare and augment standard beam emittance data. Experimental results on 2-D beam profiles will be presented.

Introduction

A fluor screen is placed in the low-energy beam transport (LEBT) line between two solenoid magnets, where the observed beam is nearly parallel and of maximum diameter. Fluor material is Aluminum-Oxide that is plasma-jet sprayed onto the surface of an aluminum or a water-cooled copper substrate. When the beam hits the surface of the fluor, it fluoresces in the visible with a bluish-white color. Over a wide range, the light intensity is directly proportional to the beam intensity at that location. Use of an optional, upstream shadowing wire allows the determination of local beam divergence. The digitized image from a CCD camera is stored and subjected to off-line data analysis. This diagnostic is capable of providing:

1. A measure of real-time beam size and shape on a pulse-to-pulse basis
2. Beam profiles in both transverse directions
3. A measure of the convergence (or divergence) of the beam
4. Beam local divergence (emittance)

Beam Profile Measurements

Figure 1 shows the digitized image of a single 30-keV beam pulse when the LEBT's first solenoid current was set for converging beam. An unexpected beam structure is immediately apparent. The following real-time observations can be made:

1. The beam is nearly circular (the oval shape is caused by the camera angle distortion and can be corrected) with a diameter of 3.5 cm.
2. There is a hot spot at the center of the beam.
3. There is a bright halo on the outside of the beam.

Figure 2 is a 3-D reconstruction of this beam pulse which reveals an enhanced view of the beam structure. This real-time diagnostic capability enabled us to perform a series of experiments to determine if the beam structure is preserved under varying extractor voltages and LEBT focus conditions.

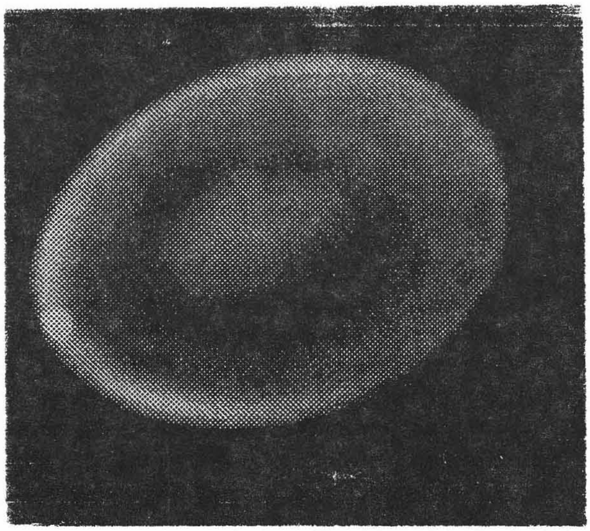

Fig. 1. 30 keV beam intensity profile.

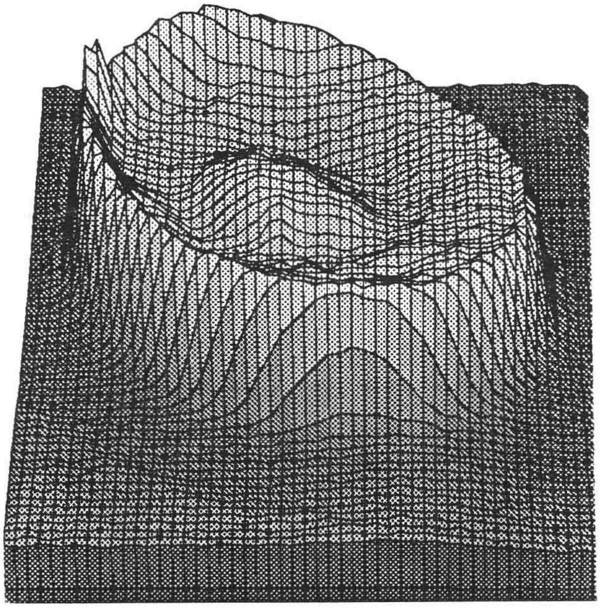

Fig. 2. 3-D reconstruction of the beam intensity profile shown in Fig. 1.

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This beam structure was not readily apparent from the standard emittance profiles. The beam structure was present only for the under-focused beams with energies lower than the design energy of 35 keV, for which the beam perveance is not properly matched in the injector. For comparison, Fig. 3 shows the digitized beam image when the beam perveance is properly matched (2 cm diameter, Vext = 35 keV, solenoid current was set for converging beam) .

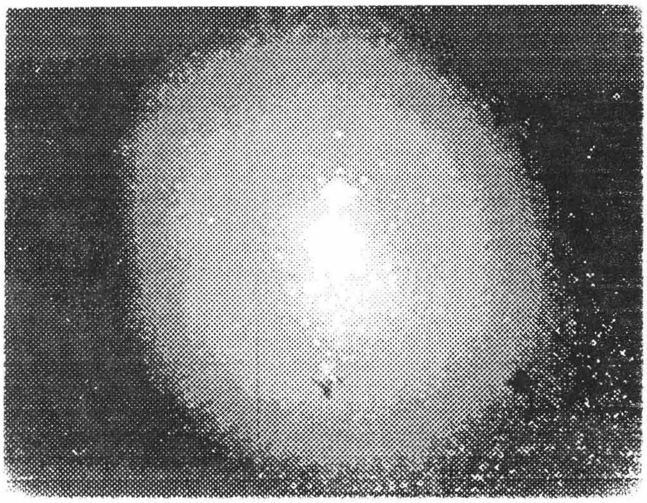

Fig. 3. 35 keV beam intensity profile.

Beam Divergence Measurements

A wire placed in the beam path (upstream of the fluor) will cast a shadow on the fluor. Analysis of the shadow profile leads to the determine of beam divergence. For a beam with a flat spatial distribution and Gaussian transverse velocity (angular) distribution

$$f(\theta) = K \exp\left[-\frac{\theta^2}{2\sigma^2}\right] ,$$

one can show that the ratio of the downstream current density to the initial on axis current density is given by[1]

$$J(x,z)/J(0) = 1 - 1/2\left[\mathrm{Erf}\left[\frac{x+a}{\sqrt{2}\,Z\,\sigma}\right] - \mathrm{Erf}\left[\frac{x-a}{\sqrt{2}\,Z\,\sigma}\right]\right]$$

where

$a \equiv$ wire radius

$z \equiv$ distance between the wire and the fluor

$\sigma \equiv$ beam divergence

$x \equiv$ transverse distance along the fluor

In the case of the beam with a small divergence, it is easily shown that the depth of the shadow given by

$$\mathrm{Depth} = \mathrm{Erf}\left[\frac{a}{\sqrt{2}\,Z\,\sigma}\right]$$

can be used to determine the divergence of the beam.

Experiment

A wire grid consisting of three Nichrome wires (0.13-cm wire diameter) in each direction, was placed 10 cm upstream of the fluor. Grid wires were positioned 1.27 cm apart. Figure 4 shows the shadow depth as a function of beam divergence for this setup.

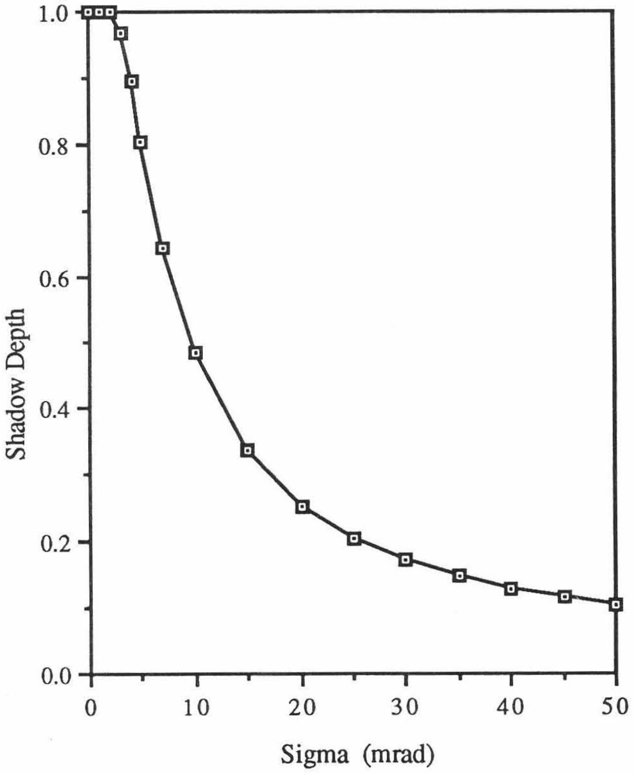

Fig. 4. Shadow depth as a function of beam divergence.

Figure 5 is the digitized image of a 25 keV beam pulse (first solenoid current was set for converging beam). The beam is 3.5 cm in diameter and the distance between the markers on the fluor screen is 1 cm. Beam envelope divergence can be calculated by measuring the shadow spacing on the fluor and comparing it with the grid spacing upstream. This will give the tilt of the phase space ellipse. This beam is converging and the measured portion of the phase space ellipse of the horizontal plane is shown in Fig. 6.

Using figure 4, the local beam divergence can be estimated by measuring the depth of the wire shadows in the various regions of the beam. Figure 7 is a horizontal cut of the beam pulse of Fig. 5. This beam has a localized one sigma divergence angle of 3-5 mrad throughout (Fig. 6). This value of local divergence is similar to values measured for the similar beam using the emittance-scanner diagnostic.

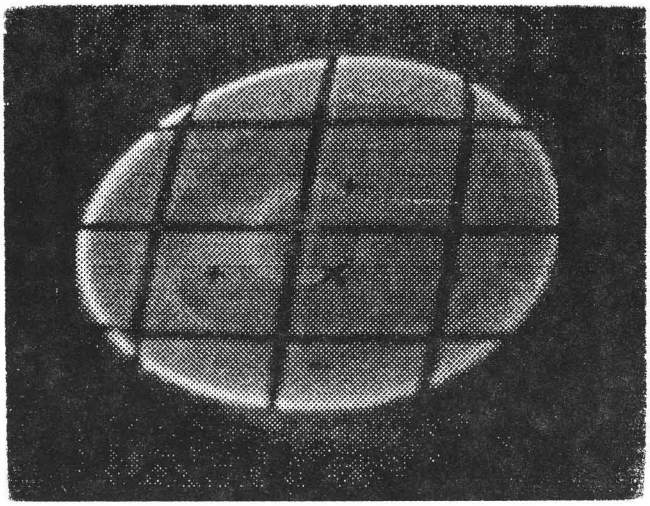

Fig. 5. 25 keV beam intensity profile. Shadows shown are cast by the wire grid upstream.

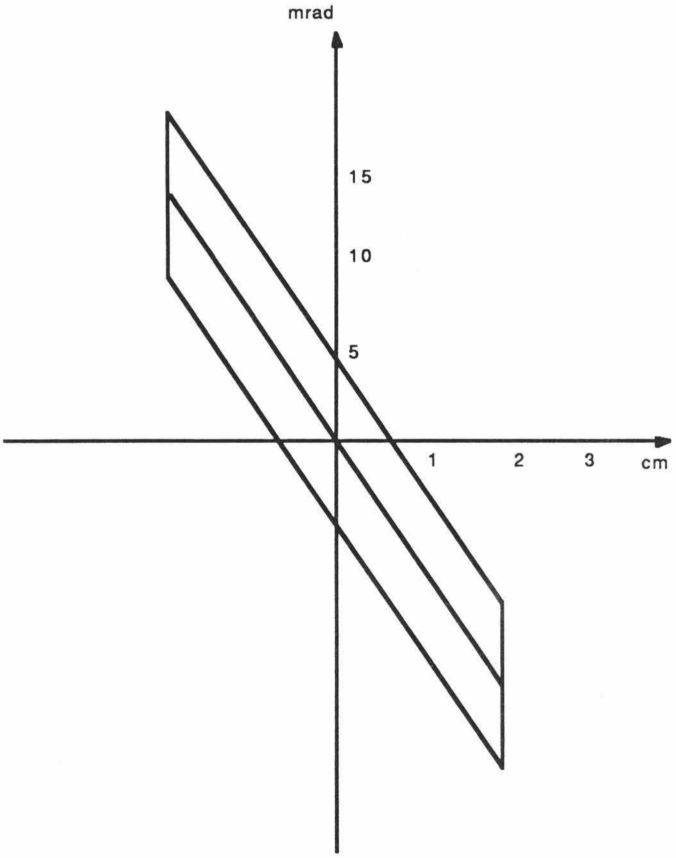

Fig. 6. Phase space distribution of the beam shown in Fig. 5.

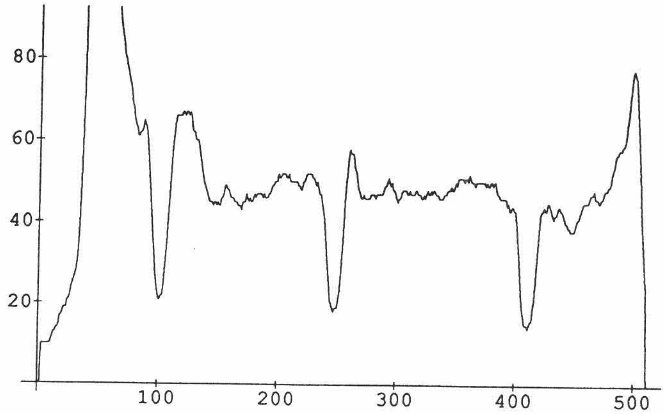

Fig. 7. A horizontal cut near the center of the beam shown in Fig. 5.

Conclusion

The real-time visual knowledge of the beam structure, shape and size, alone, emphasizes the importance and effectiveness of this diagnostic. Prior to this experiment, only emittance scanner beam profile information (which is averaged over hundreds of beam pulses) was available. This technique can be a very useful aid to the experimentalists in providing the desired beam by real-time observation of the beam response to parameter changes. Quantitative information, such as beam local divergence, make this diagnostic a primary candidate for any particle beam system.

Acknowledgements

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References

1. J. H. Head, 'private communication.'