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BEAM EMITTANCE MEASUREMENT OF THE POSITRON GENERATOR AT KEK

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ABSTRACT

Beam transverse emittances have been measured in the Positron Generator by observing changes in beam sizes on a ceramic profile monitor as a function of the upstream quadrupole lens strength. Image signals from a TV camera viewing a ceramic screen monitor were recorded on a video cassette recorder and later they were processed and analyzed using a off-line personal computer. The beam emittances obtained are $5.0\times10^{-2}\pi$ and $5.3\times10^{-2}\pi$ (MeV/c.cm) in the horizontal and vertical directions respectively. These values are consistent with a result obtained in a beam transport calculation.

INTRODUCTION

Emittances are important values not only for transporting a beam in the linac but also for accumulating the beam in the PF Storage Ring or the Accumulation Ring of TRISTAN. Recently , there is a new plan for accumulating a positron beam in the PF Ring instead of an electron beam in order to decrease beam loss by trapped ions.[1] Positron beam current will be much less than electron current in a long pulse mode operation. Therefore ,it is necessary to estimate accurately the accumulating efficiency of the positron beam before injecting the beam into the PF Ring actually . For the purpose, the beam emittances are needed as well as energy distribution reported in elsewhere.[2]

As a model for the measurement , electron beam emittances have been measured in the Positron Generator at an energy point of 200 MeV; end of the third unit of the acceleration wave guide. Between a beam size on a screen and the strength of an upstream quadrupole lens, there is the relationship from which Beam emittance is derived . Consequently it is necessary to measure changes in beam sizes with various strength of the quadrupole lens ,namely with changing current in the lens.

The use of ceramic profile monitor is one of the popular and direct method to observe the beam profiles. In usual case,the image of the beam is directly observed on a TV monitor. In such a direct observation by eyes on the TV monitor,the spatial distribution of the beam density is not clear. The beam density distribution is obtained by means of a computer image processing of video signals from a TV monitor viewing the ceramic screen inserted in the beam line.[3] For efficient measurement ,video signals from the TV monitor were recorded at first in a video cassette recorder, and then they were analyzed by using a off-line personal computer.

This paper describes the method of beam emittance measurement and some results obtained.

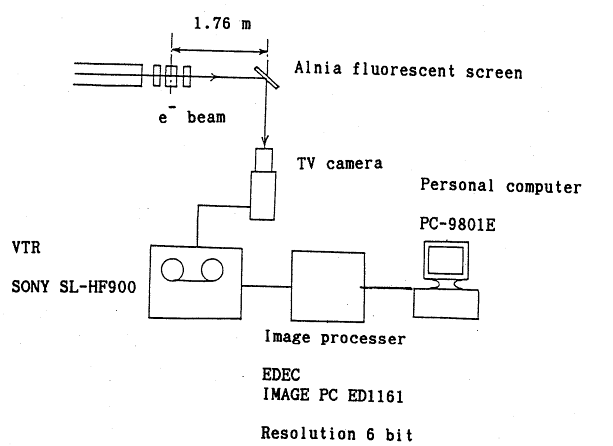

Fig. 1. Hardware configuration of the emittance measurement system

SYSTEM CONFIGURATION

Hardware

The entire hardware system is illustrated in Fig.1. It consists of a ceramic screen monitor, a black-and-white TV camera, a video cassette recorder,a image processor and a personal computer(NEC PC-9801E). The alumina screen monitor used was installed at the energy point of 200 MeV in the electron beam line. The TV camera viewing the screen was of the conventional vidicon type with a telescope lens. The aperture of the iris of the lens was selected to F8.0 by measurement in order that the video signals did not saturate at the beam spot. The horizontal scanning frequency of the camera was 15.75 kHz and vertical one was 50 Hz. In order to get linearity,the TV camera was used without automatic gain control and auto level control. The image processor and the personal computer were used before in the PF ring for the synchrotron radiation observation after a bending magnet.

The video signals from the camera were transmitted to the sub-control room of the Positron Generator and recorded by a video cassette recorder (SONY SL-HF900). Later they were image processed and analyzed to get the beam density distribution.

Software

The program for data analysis was written in BASIC and ran under the interpreter. The program can be divided into the following blocks

(a) Control of the image processor.
(b) Treatment of data smoothing ,background correction, etc..
(c) Peak search and full width at tenth maximum (FWTM) calculation.

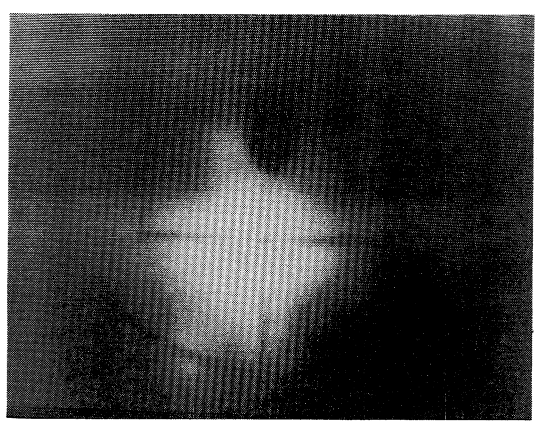

Fig. 2 A TV image of the beam on the screen with a hole at the center. There are vertical and horizontal reference lines at intervals of 5 mm on the screen. The beam was shifted from the center of the screen to avoid the hole .

DATA ANALYSIS

Scale calibration

Prior to the beam profile measurement, the visible area of the beam screen was set by adjusting the zoom lens of the camera so that a beam profile could be measured with a sufficient resolution. Figure 2 shows a TV image of the beam on the screen with a hole at the center. On the screen, there were vertical and horizontal thin reference lines at intervals of 5 mm. The brightness of these lines was less than the other parts. Therefore,with a broad beam profile these lines were easily identified on the beam intensity distribution curve as shown with arrows in Fig. 3. These points were used for scale calibration.

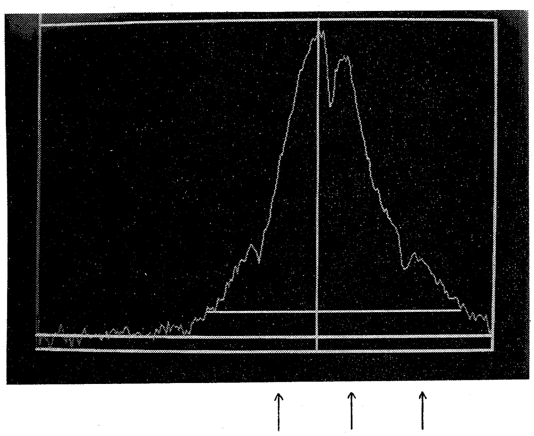

Fig. 3. An example of the beam density distribution. Arrows indicate positions of the reference lines. The beam profile was broaden for the scale calibration.

Beam density distribution and beam size

Figure 4 shows an example of the beam density distribution in the horizontal plane after integration of the beam current density with respect to the vertical direction. Integration was carried out between -5 digits to +5 digits of the video signal centered at the beam. A vertical line in the example indicates the position of the peak. A wide horizontal line is the base line obtained by averaging the level beside the bump. The short horizontal line in the bump indicates the beam size ; full width at the 10th maximum. The beam size is easily derived from this procedure.

Beam density distribution curves in Figs. 3 and 4 were gotten after subtraction of the background shown in Fig. 5 which is the level of image signal without the beam.

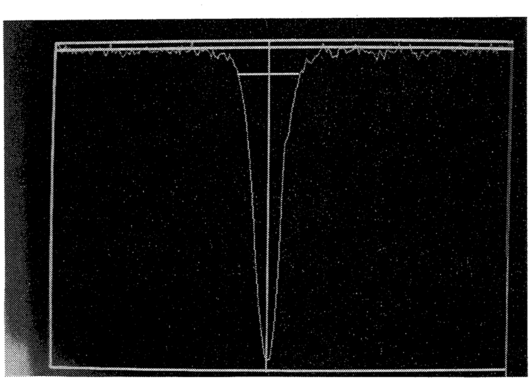

Fig.4. An example of the beam density distribution in the horizontal plane. The short/wide horizontal line indicates the beam size (FWTM) /the base line. The vertical line represents the position of the peak.

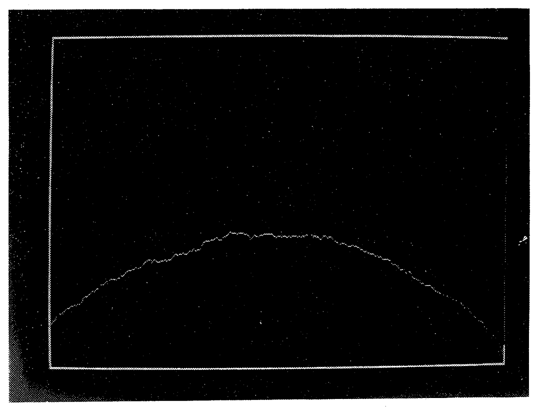

Fig. 5. Background obtained without the beam by processing image signals from the TV viewing the screen.

TRANSVERSE EMITTANCE

If the phase space distribution is assumed to be elliptical, the radius of the beam at a given z-location will vary hyperbolically with the strength of an upstream lens. In each plane the beam emittance can then be determined from the minimum of the hyperbola, which is proportional to the divergence of the beam at the lens, and from the asymptote of the hyperbola,the slope of which is proportional to the radius of the beam at the lens.

The profile screen monitor located at z = 35 m from the electron gun was used to estimate the beam radius,r. The quadrupole magnet located 1.76 m upstream of the monitor was chosen as the lens to be varied. By changing the strength of the quadrupole, the phase space ellipse could be rotated at the profile monitor. The results are shown in Fig.6a and Fig.6b where the data for the horizontal and vertical planes are plotted respectively. The solid curve is a hyperbola fitted to the data using a least squares program with three fitting parameters ; coordinates of the vertex of the hyperbola, Q_{min},r_{min},and the slope of the asymptote.

The beam radius at the lens, r_0, is transformed to r at the screen by the action of the lens and of the drift length L . The relationship between the beam radius ,r, and the strength of the lens, Q, is simply given in the thin lens approximation:[4]

$$\frac{r^2}{{r_{min}}^2} - \frac{(Q - Q_{min})^2}{(r_{min}/Lr_0)^2} = 1 .$$

The vertex of the hyperbola (Q_{min},r_{min}) and the slope of the asymptote ,Lr_0 ,are derived by the least squares fitting. Since the angular divergence ofthe beam at the lens, θ_0 , is given by $\theta_0 = r_{min}/L$, the emittance is written in the form

$$\varepsilon = r_0\theta_0 = r_0 r_{min} / L .$$

Using this relationship, the emittance areas, $A = \pi\varepsilon$, , determined from the data of Figs. 6a and 6b were $A_x = 5.0\times10^{-2}\pi$ and $A_y = 5.3 \times 10^{-2}\pi$ (MeV/c.cm) respectively. These values are about three times larger than the assumed values in the design of the beam transport system.

In the Positron Generator, it had not been simple to adjust parameters for transporting the electron beam as high intensity as 10 A to a conversion target.[5),6)] And the beam orbit had been sensitive to the parameters.These states have been improved by adding

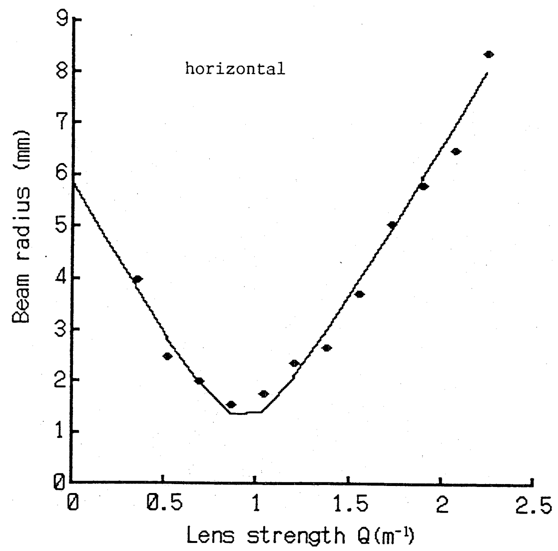

Fig. 6a.

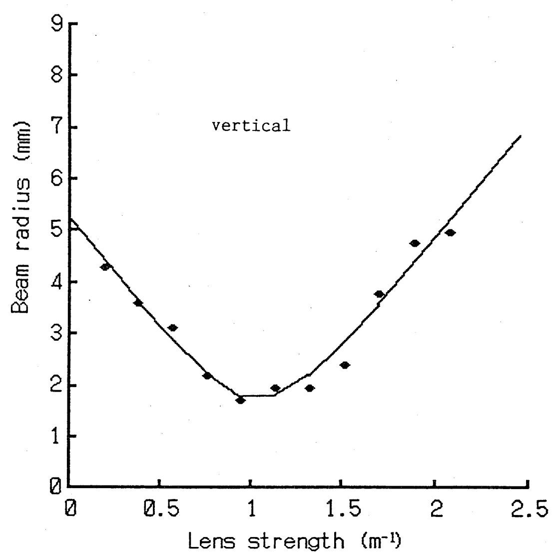

Fig. 6b.

Fig.6a/6b. Beam radius as a function of lens strength. The horizontal/vertical data are plotted in Fig. 6a/6b with the hyperbola fitted to the data using a least squares program.

quadrupole magnets in the second and third units of the acceleration wave guide in the Positron Generator.[7] This is consistent with the emittances obtained in this measurement.

This method of the emittance measurement is much simpler and more reliable compared with the method adopted before in the PF linac with a photo diode array instead of a TV camera.[8] This is expected to be a useful method for studying beam characteristics in the linac. With this method, the beam emittances will be measured at several points of energy along the linac not only in the electron line but also in the positron line.

ACKNOWLEDGMENTS

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