ESTIMATION AND DISPLAY OF BEAM DENSITY PROFILES

S. DASGUPTA, T. MUKHOPADHYAY, A. ROY and C. MALLIK

Variable Energy Cyclotron Centre, BARC, Calcutta-700064, India

A setup in which wire-scanner-type beam-profile monitor data are collected on-line in a nuclear data-acquisition system has been used and a simple algorithm for estimation and display of the current density distribution in a particle beam is described.

1. Introduction

Wire-scanner-type beam profile monitors are cheap and are abundantly used at various points down the transport line of accelerated charged particles. They give indications about the placement of the particle beam with respect to the transverse axes of the beam tube. Estimations about the size of the particle beam can also be obtained from the output of the profile monitor although no estimate about the shape of the beam is available. Neither is current density distribution over the transverse plane of the beam observable. The requirement in such a case is a wire-mesh-type profile monitor, necessitating a higher precision-worked transducer and more elaborate electronics. The machine operator gets an immediate and better understanding of the transport characteristics of the beam-line system, which contributes towards lessening of overall beam tuning time.

The three beam lines of our laboratory are each equipped with one NEC-made wire scanner model BPM6 and a FP3 controller capable of giving an oscilloscope display of the beam profile. The inherent difficulty of interpreting these waveforms, especially in case of positional instabilities of the beam, works as a dis-incentive to operators to use this equipment. The operators, during transporting, feel more at home with the alumina-plate beam viewer, which obviously stops the beam and deters a simultaneous view of the beam profile further downstream. Also finer details of the profile are not recoverable from such a view. Here is an approach to process the data from a wire-scanner-type profile monitor for generating a graphic display of the cross section of the particle beam. The on-line graphic monitoring of the shape, size and current density distribution in the particle beam gives very effective help towards optimising the transport efficiency of the beam through the beam pipes. Also certain irradiation experiments benefit from such an on-line display of the beam cross section near the target point.

2. Setup

Presently the profile data logging system has been implemented by utilising the CAMAC based nuclear data acquisition system [1] (fig. 1). However, the software has been tailored to perform a specific purpose although the real time program and the hardware scheme remains the same. Since the CAMAC compatibility of the higher version of the wire scanner was not available to us, the wire scanner was run continuously and the profile data and the time markers were sampled asynchronously and acquired by two ADCs in list mode. The event count per ADC channel was kept limited to 1024.

Considering the worst case conversion time of 100 μs for the nuclear ADCs, a sampling rate of about 10 kHz was selected to record beam-profile data and time markers. The list buffer size was chosen so that the data were sampled for about 2 cycles of scanner wire rotation. This allows for about 256 samples for each of the X and Y scans over the entire scanning cross section. Since the wire scanning diameter is 57 mm, even a fine beam of 2 mm diameter will allow about 10 samples within just the beam cross-sectional area. Obviously in
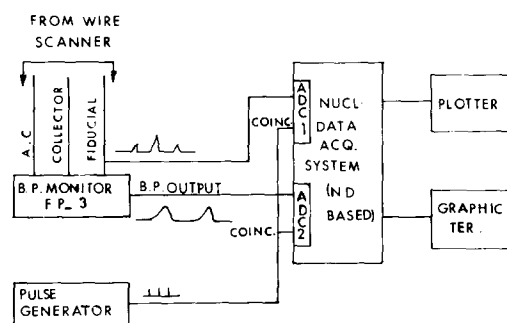

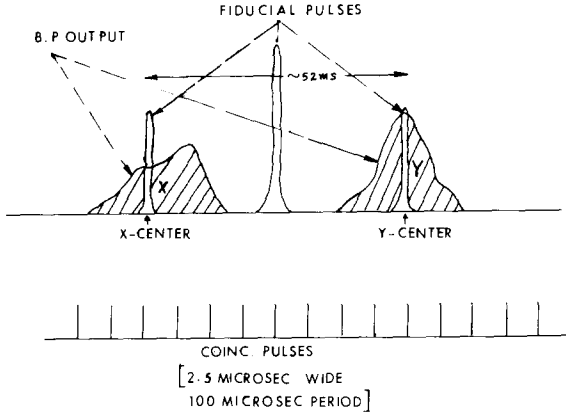Fig. 1. Beam profile data collection setup.

Fig. 2. Profile sampling timing.

cases of beams with larger cross-sectional area, the setup allows for a larger number of samples over the beam area (fig. 2).

3. Program

Beam profiles and time marker contours were generated from the list data and displayed on a graphic terminal with the horizontal axis calibrated in distance units.

This gives a steady display of the beam widths and also the positioning of the beam with respect to the X and Y axes passing through the centre of the beam tube. The facility has also created an opportunity of measuring the emittance of the beam with reasonable speed, by the method of varying quadrupole currents. The "cross section" mode generates a display of current densities in multiple colour over the sampled cross-sectional area of the particle beam where each colour signifies a particular range of current density.

A simple algorithm has been developed to compute the current density at the cross points of lines over which integrated current values are known (fig. 3). Assuming the fields in X and Y directions to be independent of each other to a first approximation, the current density function $P(x, y)$ at cross position (x, y) can be assumed as a product of two independent functions

$$P(x, y) = W(x)S(y),$$

where $W(x)$ and $S(y)$ are current density functions along X and Y directions. Hence for any vertical position of the scanner wire the measured data (integrated current on the vertical line) can be represented as

$$X(x) = \int_0^d P(x, y) \, dy,$$

where d is the side of the square scanned. Similarly for the case when the wire is horizontal

$$Y(y) = \int_0^d P(x, y) \, dx,$$

$$X(x) = \int_0^d W(x)S(y) \, dy$$

$$= W(x)\int_0^d S(y) \, dy = W(x)K,$$

where

$$K = \int_0^d S(y) \, dy.$$

Similarly

$$Y(y) = \int_0^d W(X)S(y) \, dx$$

$$= S(y)\int_0^d W(x) \, dx = S(y)M,$$

where

$$M = \int_0^d W(x) \, dx.$$

Hence

$$X(x)Y(y) = W(x)S(y)KM,$$

and

$$P(x, y) = W(x)S(y) = X(x)Y(y)/KM.$$

The product KM is the sum of all the integrated currents along X or Y directions or, in other words, the sum of all the current densities over the cross section, as is evident from the following:

$$\int X(x) \, dx = \int Y(y) \, dy = \int \int P(x, y) \, dx \, dy$$

$$= \int^d W(x) \, dx \int S(y) \, dy = KM.$$

Simplifying the notations, at the (i, j)th cross point the current density can be computed from
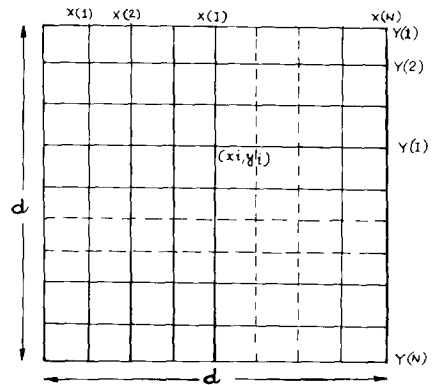
$$P(i, j) = X(i)Y(j)/KM,$$

Fig. 3. Scanned square of the beam area.

Fig. 4. PC display.

of 4×4 pixels, filled up with the colour corresponding to the intensity group of that point with the help of Turbo-PASCAL graphic procedures on a PC. The fiducial marks, which correspond to the centre-crossing of the scanning wires, are used to generate a cross-hair on the display screen representing the beam tube centre (fig. 4). Overlaid is the picture of the cross section generated as described above.

5. Discussion

The setup is particularly suitable in a situation where dedicated and expensive computer-compatible hardware, e.g. motor drives and data loggers for profile monitors, are not available but a general nuclear data-acquisition system is working [3].

The underlying assumption of separability of the density function into two independent functions is realistic, to a first approximation, as the beam shape is primarily governed by two independent fields of the preceding quadrupole [4].

Such an on-line display is an aid to the operators and experimenters, as regard optimisation of the beam conditions. Further work towards determination and display of the centroid of the beam cross section with the computed density data can be taken up.

where $X(i)$ and $Y(j)$ are measured known data and KM is the sum of either the X data or the Y data. No explicit assumption about the nature of the beam density distribution function is made in this approach unlike in the common approaches [2].

4. Display generation

The computed intensity values (fig. 5) are grouped into four equal ranges and represented by four colours ranging from 0 to 3 on a graphic display device. This gives a view of the beam cross section with density distribution contours in four colours.

For a blown-up image of the beam cross section, each cross point of the beam is represented by a square

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	69	73	83	87	97	93	104	104	111	107	104	90	83	73	62	0
0	76	80	91	95	106	102	114	114	121	118	114	99	91	80	68	0
0	82	87	99	103	115	111	124	124	132	128	124	107	99	87	74	0
0	89	93	107	111	125	120	134	134	142	138	134	116	107	93	80	0
0	99	104	119	124	139	134	148	148	158	153	148	129	119	104	89	0
0	107	114	131	136	152	147	163	163	174	169	163	141	131	114	98	0
0	106	111	127	132	148	142	158	158	169	164	158	137	127	111	95	0
0	107	114	131	136	152	147	163	163	174	169	163	141	131	114	98	0
0	107	114	131	136	152	147	163	163	174	169	163	141	131	114	98	0
0	112	118	135	140	157	151	168	168	179	174	168	146	135	118	101	0
0	106	111	127	132	148	142	158	158	169	164	158	137	127	111	95	0
0	106	111	127	132	148	142	158	158	169	164	158	137	127	111	95	0
0	69	73	83	87	97	93	104	104	111	107	104	90	83	73	62	0
0	86	90	103	107	120	116	129	129	137	133	129	111	103	90	77	0
0	59	62	71	74	83	80	89	89	95	92	89	77	71	62	53	0
0	69	73	83	87	97	93	104	104	111	107	104	90	83	73	62	0
0	69	73	83	87	97	93	104	104	111	107	104	90	83	73	62	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 5. Computed current densities.

References

[1] A. Bandyopadhyay et al., Nucl. Instr. and Meth. A257 (1987) 309.

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[3] M. Kase et al., Proc. 11th. Int. Conf. on Cyclotrons (1987) p. 443.
[4] F. Bloemhard and Z. Gelbart, ibid., p. 465.