Electron Beam Size Measurements in the Fermilab Electron Cooling System

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Abstract. The Fermilab Electron Cooling Project requires a straight trajectory and constant beam size to provide maximum cooling of the antiprotons in the Recycler. A measurement system was developed using movable apertures and steering bumps to measure the beam size in a 20m long, nearly continuous, solenoid. This paper will focus on results of these measurements of the beam size and the difficulties in making those measurements

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INTRODUCTION

This paper reports on experimental results of measurements of the size of the electron beam in Fermilab's electron cooling system. The general understanding of the system and results of preliminary measurements performed in a prototype system have recently been reported[1]. Since then measurements have been made in the final production configuration.

The Fermilab electron cooling system [2] has recently provided cooling of the complex's antiproton beam in the Recycler. Typical electron currents have ranged between 50 - 200 mA although the system is capable of supplying 500 – 600 mA as antiproton intensities increase. This beam of cold electrons moves along a trajectory coincident with the trajectory of the beam of antiprotons. When the velocities of the two beams are matched, Coulomb interactions transfer energy ("temperature") from the antiprotons to the electrons.

For electron cooling to be effective, the electrons need to have a total transverse motion of no more than 200 μrads[3]. Of this, a maximum of 100 μrads is allocated for variations of the beam envelope. The beam's effective temperature due to trajectory perturbations and remnant variations of its envelope due to the optics of the beam line can be measured by the technique described here.

The cooling section consists of 10 two meter long solenoids [4]. Before and after the cooling section and between each solenoid is a movable circular aperture, a "scraper", which consists of a copper bar, .125" thick with a 15 mm hole through which the beam can pass. There are a total of 11 scrapers.

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The scrapers are inserted so that the DC beam passes through the aperture and then the beam is moved within the scraper to determine the shape of the beam at that location. Doing this at all 11 locations throughout the cooling section determines the evolution of the beam envelope as a function of the longitudinal position. The beam has very distinct edges which are used for determining its size.

TECHNIQUE

The procedure involves creating an offset trajectory through the cooling section using “4-bumps”. A scraper is inserted so that the hole is centered on the central trajectory. Then the beam is moved until it touches the aperture of the scraper. The same 4-bump is used with each of the 11 scrapers.

The 4-bumps are created using combinations of corrector coils with multiplicative coefficients so that they can be varied in unison to create the offset trajectory. The transfer function of the correctors, measured using the response of the beam in downstream Beam Position Monitors (BPMs), is used to compute these coefficients.

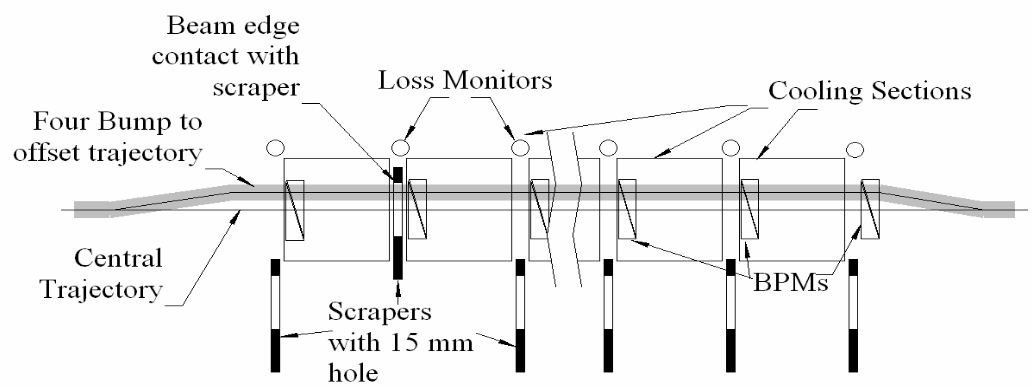

FIGURE 1. Schematic of the beam size measurement system in the cooling section.

The scrapers are inserted individually so that the aperture of the scraper is centered on the beam trajectory (Figure 1) and the beam is turned on. The beam is then moved up/down, left/right, and in 45º diagonals until it touches the aperture of the scraper. The touch is determined by: the response of a nearby loss monitor, a reduction in intensity in a BPM immediately downstream of the scraper, or loss of electron current.

The eight points of contact provide the information for determining the parameters of the beam envelope. These parameters include: the axes of the ellipse, its eccentricity, and tilt. The eleven ellipses along the length of the cooling section show the evolution of the beam envelope. This information about the variations of the envelope along the length of the solenoid can then be used to adjust the focusing (and trajectory if necessary) into the cooling section to reduce these variations below the allowed tolerances using a procedure described in reference [5].

RESULTS

Figure 2 shows the calculated ellipse for a recent measurement, displaced to the eight positions where a touch was indicated. The solid line shows the limit of motion in the X direction and the solid ellipses show its position at the edge. The dotted line indicates Y motion. The dot-dash shows the –XY motion and dot-dot-dash +XY motion. While the mults that produce the motion are not at 45º to each other, they are sufficiently distinct to allow the calculation of the ellipse.

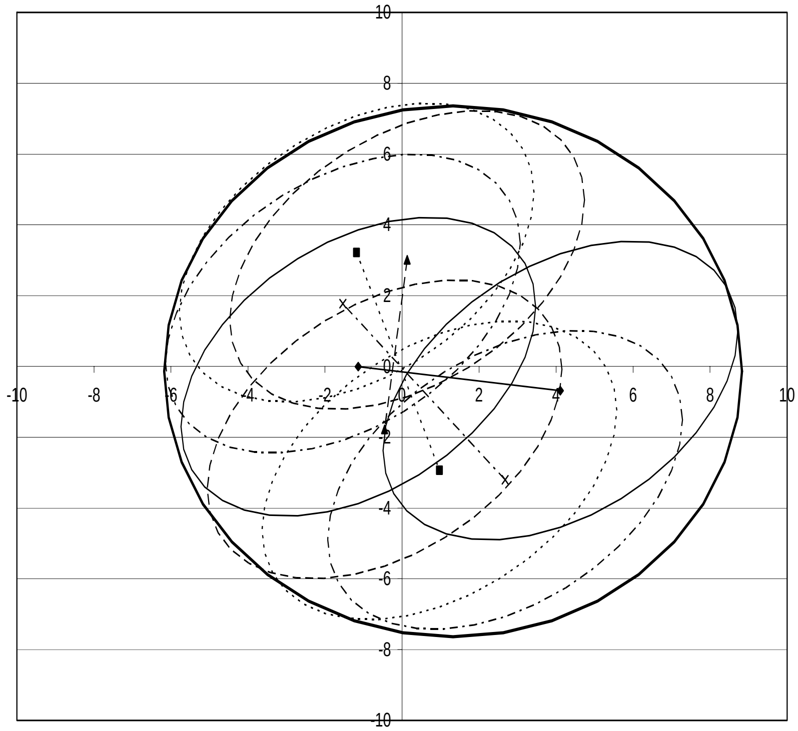

FIGURE 2. The positions of the beam ellipse in scraper SCQ01 at the point of interaction with the scraper aperture at each of the eight points of contact.

Table 1 shows the resulting ellipse parameters for five of the scrapers measured during a recent study period. The calculated ellipse parameters correspond to the following equation:

$$x = A_x \cos\Psi + x_0$$
$$y = A_y \cos(\Psi - \upsilon) + y_0 \qquad (1)$$

TABLE 1. Ellipse Parameters at Measured Scrapers

	SCQ01	SCC90	SCC80	SCC60	SCC00
A_x	4.60 ± .22	4.56 ± 1.09	4.35 ± .50	4.11 ± .29	4.91 ± .34
A_y	4.22 ± .19	4.17 ± .91	4.20 ± .18	4.45 ± .19	3.73 ± .44
Angle ν	1.16 ± .14	1.38 ± .43	1.34 ± .16	1.29 ± .12	1.17 ± .19
Major Half-axis	5.24	4.81	4.75	4.85	5.27
Minor Half-axis	3.39	3.87	3.74	3.62	3.20
Area (mm^2)	55.9	58.5	55.8	55.2	53.0
Average Area			55.7 ± 2.0		

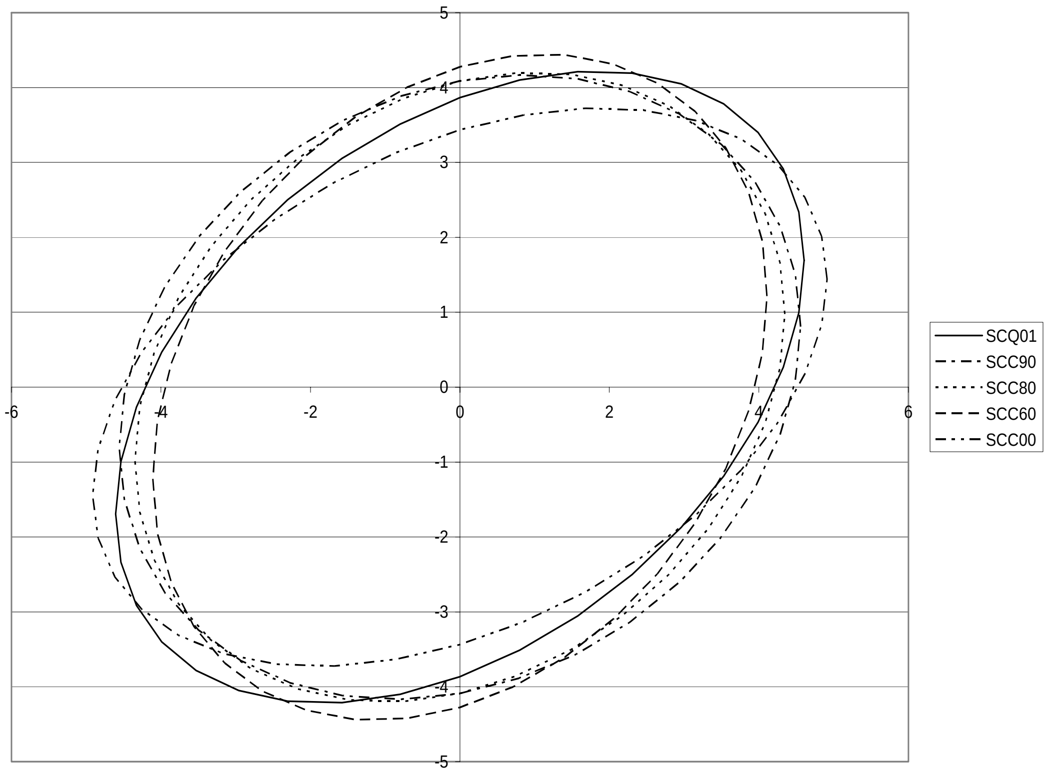

FIGURE 3. Ellipses for 5 scraper positions plotted together to show variation of measured ellipse.

Figure 3 shows all of these ellipses plotted together. As noted in the table, the physical area of the ellipse is 55.7 mm^2 with a statistical error of 2 mm^2. The position of the centroid of each ellipse is determined to about .4 mm. The error of the tilt angle ν is about 16% and the A_x and A_y are determined to within about 10%. These results indicate that the envelope oscillations are ~220 μrads[6]. The beam shape appears to be fairly uniform through the cooling section although it is somewhat elliptical. As stated in the introduction, the quality of the beam is sufficient to provide cooling for the present high energy physics program. Further analysis of the measurements is continuing.

USER INTERFACE

As operational experience has been accumulated, it has become apparent that a single automated process may not be possible. As noted above, three different signals can be use to determine the beam edge. The response of these signals is not necessarily consistent. Therefore, the judgment of the user is needed to best determine the beam edges. A new program interface has been developed, an image of which is shown in figure 4. It incorporates an X-Y plot of the limits of beam motion, which gives the user an indication of the beam shape as the measurement is being made. Surrounding this plot are 4 smaller plot (one for each of the four motion directions) showing the response of the signals as the beam is moved. Using this, the user can analyze the measurement just taken and determine if the thresholds are appropriate and if a measurement should be repeated.

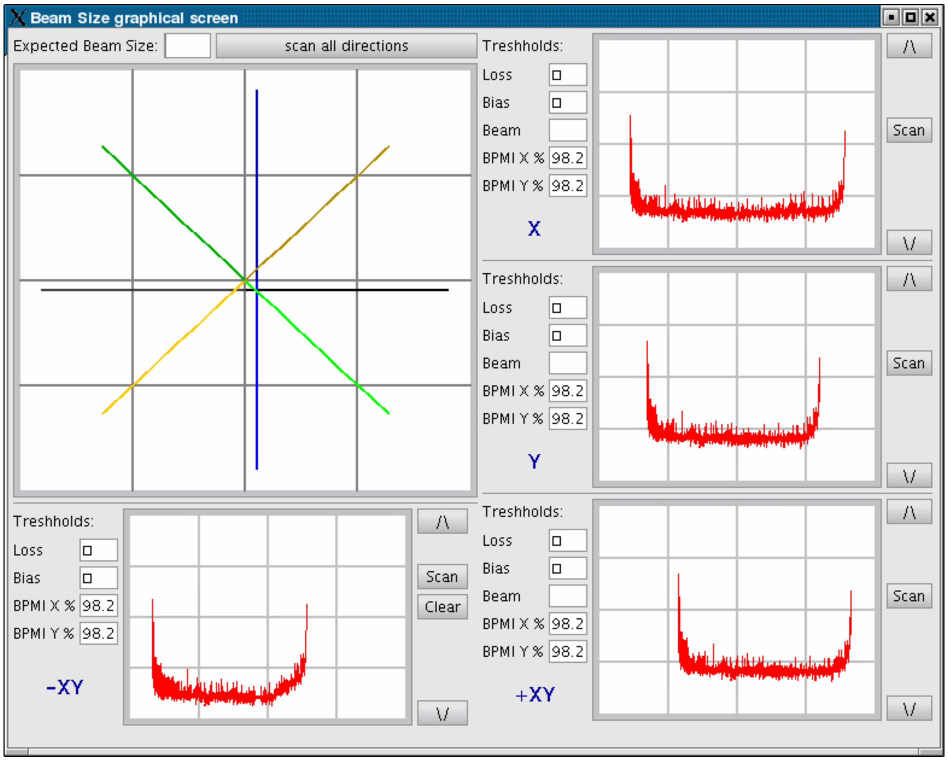

FIGURE 4. An image of the new user interface for beam size measurements. Only one signal for each of the four signal response plots is shown.

CONCLUSIONS

A technique has been developed for measuring the size, shape, and uniformity of a DC electron beam through the Fermilab Electron Cooling cooling section. Measurements indicate that the technique provides the data necessary to tune the optics of the line and that the present transverse velocity parameters of the beam are on the order of our tolerances. Initial results show r.m.s. angles of 220 μrads. Cooling has been observed and is now part of the regular operational program of the laboratory.

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