# UNIFORM BEAM DISTRIBUTIONS USING OCTUPOLES*

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*Abstract*

The Gaussian beam profile of the BNL 200 MeV $H^-$ Linac beam at the Radiation Effects Facility target location was transformed into a rectangular profile with almost uniform distribution by placing two octupole magnetic elements at particular locations along the beam line. Experimental results of the beam profile projection in the horizontal and vertical planes, with and without octupoles, are presented and compared with third order calculations.

## I. INTRODUCTION

The purpose of the present study was to demonstrate experimentally that a particle beam which is transported to a given target location using first order quadrupole focusing, can have its Gaussian profile distribution transformed into a rectangular profile with almost uniform distribution. This can be accomplished by using third order focusing which is provided by octupole magnetic elements placed at particular locations along the beam line. The concept of introducing third order focusing using octupoles to modify the distribution of the beam profile, was first proposed by P.F. Meades.[1] Other authors[2,3,4,5,6] have also discussed the concept and published theoretical results on the subject. The octupole focusing method to achieving uniform beam profiles was employed in the present study in which the first experimentally demonstrated uniform beam distributions were obtained at the Radiation Effects Facility (REF) using the 200 MeV $H^-$ beam delivered by the BNL LINAC. Beam profiles with uniform distributions are very useful in applications such as isotope production, radiation effects studies of materials and Nuclear Medicine where it is desirable that the area under irradiation receive a uniform dose. The experimental results obtained were compared to the theoretical third order optics calculations applied to the REF beam transport line.

## II. EXPERIMENTAL RESULTS OF UNIFORM BEAM PROFILING

The TRANSPORT computer code[7] was used for the first order calculations in order to position the octupoles. Figure 1 shows the horizontal and vertical beam envelopes of the first order focussing and the preferred location of the octupoles for the REF beam line. The REF beam line is part of the REF/NBTF (Neutral Beam Test Facility) facility of BNL. The beam emittance used in the calculations was experimentally measured.

The horizontal beam profile, at the location of the octupole that affects the distribution of the vertical profile (Figure 1), has the minimum possible profile that the first order focussing allows. Such a small profile keeps the horizontal beam size close to the octupole axis, therefore limiting the contribution from the aberration coefficients which mix the horizontal and vertical coordinates through the octupole field. Similar beam conditions hold at the location of the octupole that affects the horizontal beam profile, but with the horizontal and vertical focussing beam conditions reversed.

When both octupoles are off, first order focussing dominates and the beam distribution is Gaussian at any point along the beam line. When the octupoles are turned on, third order aberrations are included in the beam focussing which partly cancel out the effect of the first order terms resulting in the uniform beam profile distribution at the target location. The theoretical calculations were performed using the TRANSPORT code which calculates the third order aberration coefficients of the beam line. Subsequently, a Monte Carlo program was used which randomly selects rays from the experimentally measured beam ellipse and then calculates the horizontal and vertical beam profiles at the target location. The profiles were correct to third order in aberration coefficients. Figure 2 shows the theoretical calculations (top graph) of the horizontal

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beam profiles at the REF target location, with octupoles on and off. The bottom set of points shows the corresponding experimental horizontal profiles as taken by the harps. The harps are tungsten multiwire (1 mm spacing) monitors in both vertical and horizontal planes. The wire current is directly proportional to the $H^-$ beam intensity. Similarly, Figure 3 shows the theoretical calculations and the experimental results of the vertical beam profiles for both cases, octupoles on and off.

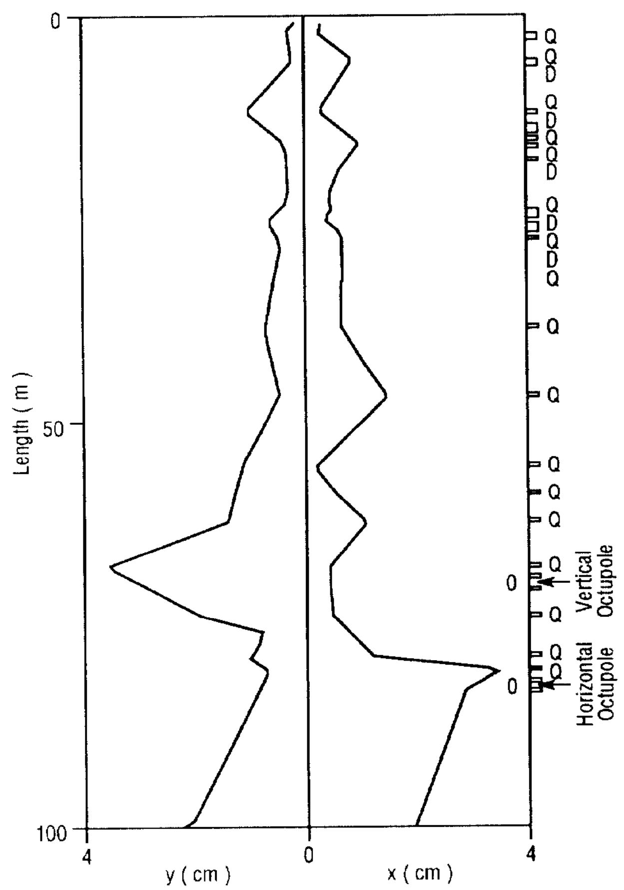


Figure 1. Horizontal and vertical beam envelopes ($1\sigma$) for the REF beam line as calculated by the first order optics TRANSPORT code. Definite first order focussing conditions are imposed at the location of the octupoles which introduce the third order focussing.

The theoretical and experimental data shown in Figures 2 and 3 were analyzed with regard to flatness and the "folding" efficiency of the beam in the wings of the Gaussian. The beam tune was not optimized to give the most uniform beam. It was simply our first trial. The octupoles were loaned to us by the acclerator group from the BNL National Synchrotron Light Source, and, although adequate for our purposes to demonstrate the principle, they were not a high enough field to produce optimum beams for both horizontal and vertical beams. The vertical profile (theory and experiment in Figure 3) has "ears" caused by overcorrecting with the octupole field; yet the theory and experiment are in good agreement on this account. Analysis of the horizontal profile in Figure 2 shows good

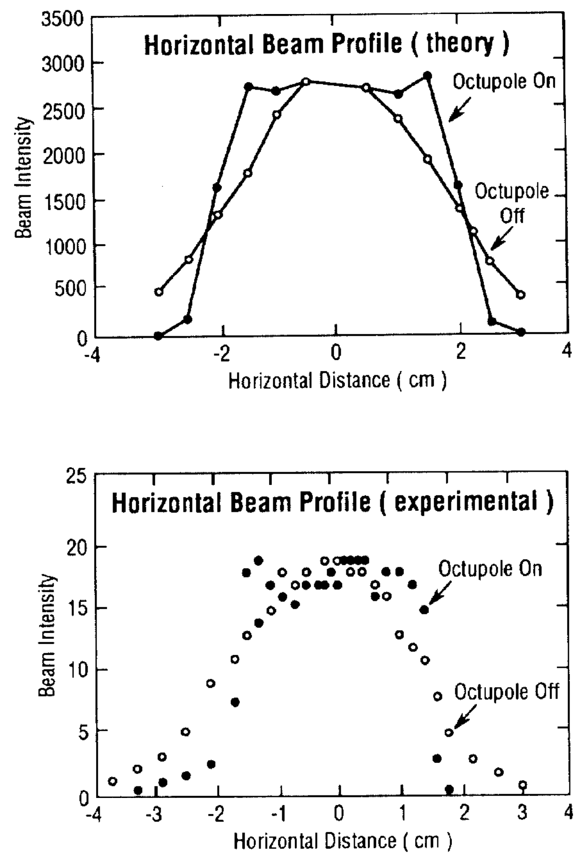


Figure 2. Theoretical calculations (top graph) and the experimental results (bottom graph) of the horizontal beam profiles at the target location in the REF facility, with octupoles on and off.

agreement between theory and experiment with an experimental uniformity of $\pm 7.5\%$ and more than 97% of the beam folded into the central distribution. Theoretically, more than 99.7% of the distribution was predicted to fall within the FWHM of the initial Gaussian profile. This discrepancy is not too surprising as the tune is not our best and the borrowed octupoles were really designed for correcting small third order aberrations, not to purposely introduce them.

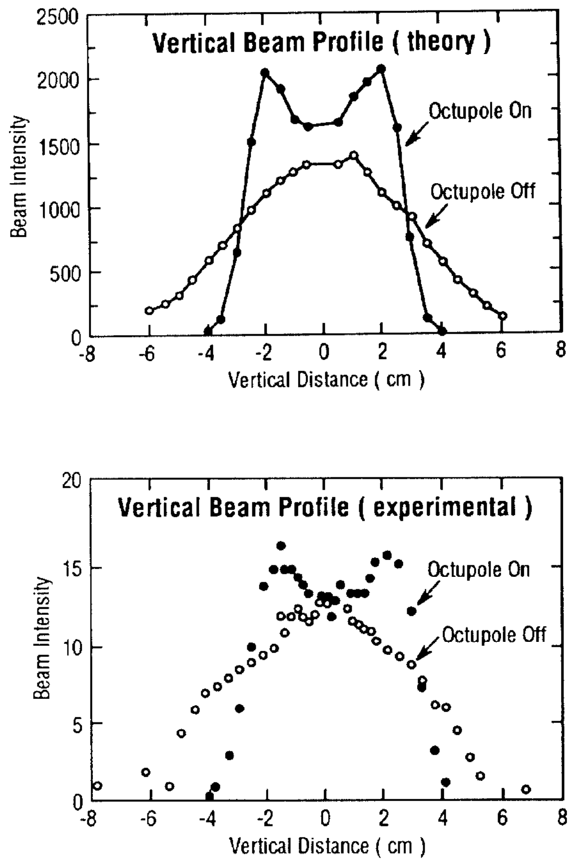


Figure 3. Theoretical calculations (top graph) and the experimental results (bottom graph) of the vertical beam profiles at the target location of the REF facility, with octupoles on and off.

## III. REFERENCES

[1] P.F. Meads, IEEE Transactions on Nuclear Science, Vol. NS-30, No. 4, p. 2838, 1983.

[2] H. Wollnick, Optics of Charged Particles, Academic Press, 1987, p. 218.

[3]E. Kashy B. Sherrill, NIM B26 p. 610, 1987.

[4] E. Kashy and B. Sherril, U.S. Patent No. 4736106.

[5]A.J. Jason, B. Blind, and E.M. Svaton, Linear Accelerator Conference Proceedings, CEBAF Report-89-001, October 1988, p. 192.

[6] B. Sherrill, J. Bailey, E. Kashy, and C. Leakeas, NIM B40/41, p. 1004, 1989.

[7] K.L. Brown, D.C. Carey, Ch. Iselin and F. Rothacker, CERN Report No. 80-4 (1980).