MULTIPOLE CHANNEL PARAMETERS FOR EQUALIZATION OF BEAM INTENSITY DISTRIBUTION

Y.K.Batygin
Electrophysics Department
Moscow Engineering Physics Institute, 115409, Moscow, Russia

Abstract

A method of beam intensity redistribution in a transport channel containing linear and nonlinear elements to provide uniformed irradiation area at the target is discussed. Linear elements (quadrupoles) are used to prepare a large beam spot at the target and nonlinear elements (octupoles, dodecapoles, etc.) are used to improve the beam uniformity. A kinematic relationship between the final beam distribution vs. initial beam distribution and optics channel parameters is given. The flattening of a Gaussian beam is discussed.

Introduction

A uniformed irradiation zone at the target is often required when particle beams are applied. A particle distribution of an accelerated beam is usually approximated by Gaussian distribution. A useful method employing nonlinear optics to improve the beam distribution uniformity was considered [1-6] . The method is based on nonlinear transverse velocity modulation of particles which force the peripheral particles to move faster to the axis than the inner beam particles. During the drift after modulation the beam halo is eliminated and the boundaries of the beam become more pronounced. The method is applied sequentially to both transverse planes. A superposition of independent density transformations in transverse x and y directions results in a rectangular beam spot at the target with high uniformity (see fig. 1).

Equalization of a Gaussian Beam

The one dimensional problem of beam intensity redistribution was considered in ref. [8]. Modulation of transverse velocity of the beam at z = 0

$$v_x = v_{x0} + a_2 x_0 + a_3 x_0^2 + a_4 x_0^3 + \dots + a_n x_0^{n-1} \qquad (1)$$

transforms the initial distribution of particles $\rho(x_0) = dN/dx_0$ to distribution $\rho(x)$ at any z as

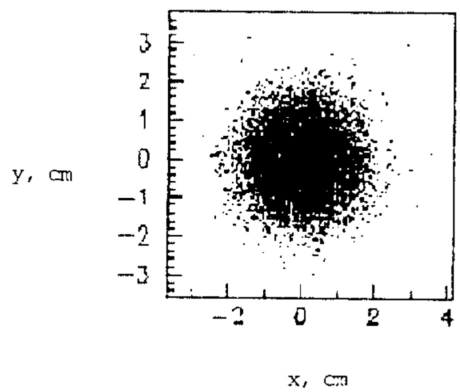
$$\rho(x) = \rho(x_0)\frac{1}{1 + \alpha_2 + 2\alpha_3 x_0 + \dots + (n-1)\alpha_n x_0^{n-2}} \qquad (2)$$

where $\alpha_n = a_n z/v_z$, v_z is a longitudinal beam velocity.

Particle distribution $\rho(x_0)$ of an accelerated beam is usually approximated by Gaussian function

$$\rho_0 \exp(-\frac{x_0^2}{2A^2}) = \rho_0(1 - \frac{x_0^2}{2A^2} + \frac{x_0^4}{8A^4} + \dots \frac{(-1)^k x_0^{2k}}{2^k k! A^{2k}}) \qquad (3)$$

where the value of 2A is usually assumed to equal a transverse size (radius) of the beam. From eqs. (2) and (3) the modulation coefficients [illegible] uniform distribution



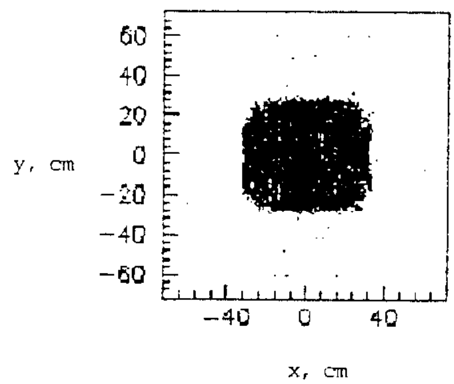


Fig. 1. Projections of computer simulation using code BEAMPATH [7] into real space (x-y) for an initial (upper) and final (lower) beam distribution in a nonlinear optics channel.

$$\rho(x) = P \qquad (4)$$

at the target are:

$$\alpha_2 = \frac{\rho_0}{P} - 1, \quad \alpha_4 = -\frac{1+\alpha_2}{6A^2}, \quad \alpha_6 = \frac{1+\alpha_2}{40A^4}, \quad \dots\dots, \quad \alpha_{2k+2} = \frac{(-1)^k(1+\alpha_2)}{2^k\, k!\, (2k+1)A^{2k}} . \qquad (5)$$

0-7803-1203-1/93$03.00 © 1993 IEEE

To provide rectangular distribution the numerator and denominator in eq. (2) have to be the same function of x_0 and can be distinguished by constant value only. The number of lenses in a transport channel is limited that means the truncation of series in denominator. Let us see how the flattening of initial Gaussian beam depends on truncation of the series in equations (2) and (3).

The expansion (3) consists of the terms with even power of x_0 which correspond to optical elements with 2k+2 (k=1,2,...) planes of symmetry or lenses with 4k+4 poles (8-pole, 12-pole, 16-pole, 20-pole, etc.). Actually the pure octupole field, being proportional to x_0^3, corrects the second term in expansion (3), which is proportional to x_0^2. Similarly the field of ideal 12-pole lens, being proportional to x_0^5, corrects the third term in expansion (3), which is proportional to x_0^4, etc.

Assuming that the transport channel consists of quadrupoles to extend the beam and octupole to improve the uniformity of the beam. The final distribution is

$$\rho(x) = \frac{\rho_0 \exp(-x_0^2/2A^2)}{(1+\alpha_2)(1-x_0^2/2A^2)} \qquad (6)$$

The denominator of eq. (6) equals zero if $x_0 = \pm 2^{1/2} A$. It results in peaks at the boundaries of the final distribution (see fig. 2b). Adding a dodecapole gives the function

$$\rho(x) = \frac{\rho_0 \exp(-x_0^2/2A^2)}{(1+\alpha_2)(1-x_0^2/2A^2-x_0^4/8A^4)} \qquad (7)$$

without any peculiarities because the denominator in eq. (7) is always positive (see fig. 2c). Expression (7) results in a more flattened distribution than eq. (6). Adding 16-pole lens results in peaks in the final distribution function as well because the denominator of the function

$$\rho(x) = \frac{\rho_0 \exp(-x_0^2/2A^2)}{(1+\alpha_2)(1-x_0^2/2A^2-x_0^4/8A^4-x_0^6/48A^6)} \qquad (8)$$

equals zero if $x_0 = \pm\, 1.78666$ A (see fig. 2d).

The analysis shows that the final distribution is characterized by the peaks corresponding to zero values of denominator in eq. (2) if the highest multipole consists of 8k poles (k=1,2,...). On the contrary the final distribution is more flattened if the multipole series is truncated by a 8k+4 pole element (k=1, 2,...). The portion of the flattened particles is increasing monotonously with the rise of the highest multipole number. In fig. 3 the number of flattened particles versus the highest multipole order is presented.

Parameters of multipole lenses

Eqs. (5) give the values of nonlinear optics coefficients to provide extended uniformed distribution. In ref. [8] the coefficients were determined via lenses parameters. It is convenient to use the definition of strength S_n of an n-th order multipole of length d_n for a beam with particle rigidity $(B\cdot\rho)$ [9]:

$$S_n = \frac{B_0\, d_n}{R\,(B\rho)}$$

where B_0 is the pole-tip field, R is the pole-tip radius.

A simple combination of two magnetic quadrupoles at L distance between them results in an extended beam with the coefficient of linear modulation

$$\alpha_2 = S_2^2\, L\, z \qquad (10)$$

The strength of higher order multipoles which provide for a uniformed particle distribution is the following:

$$S_n = \frac{\alpha_n}{z} \qquad (11)$$

The equivalent electric pole-tip field of 2n-pole lens is $E_0 = v_z B_0$.

The required number of ampere-turns MI at the pole of 2n-pole magnetic lens is obtained using Stokes theorem:

$$\frac{1}{\mu_0} \oint \vec{B}\, d\vec{l} = \int \vec{j}\, d\vec{S} \qquad (12)$$

Selecting an integration loop along the circle between neighbouring poles and neglecting the magnetic field inside the core the left hand integral for the azimuthal component of magnetic field $B_\theta = B_0 (r/R)^{n-1} \cdot \sin(n\theta)$ is

$$\frac{1}{\mu_0} \int_0^{\pi/n} B_\theta\, R\, d\theta = \frac{2}{\mu_0} \frac{B_0 R}{n} \qquad (13)$$

The right hand integral is equal to

$$\int \vec{j}\, d\vec{S} = 2\ \mathrm{MI} \qquad (14)$$

From eqs. (13) and (14) it follows that

$$\mathrm{MI} = \frac{B_0\, R}{\mu_0\, n} \qquad (15)$$

The power consumption of the lens is

$$W = \frac{2}{n} \left(\frac{B_0 R}{\mu_0}\right)^2 \frac{g\, h}{S} \qquad (16)$$

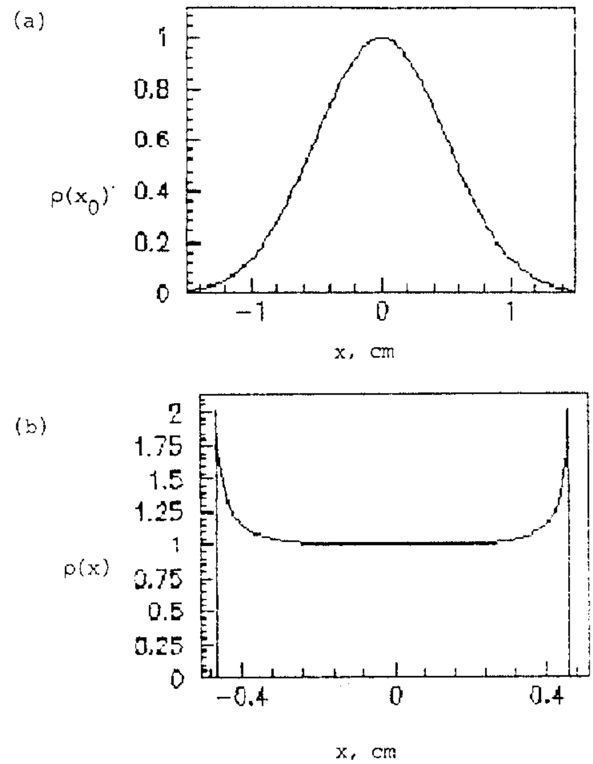
where g is a specific resistance, h is an average length of one turn, S is a cross section of the winding at one pole.

Conclusion

The nonlinear optics method for improving the beam intensity distribution was discussed. The kinematic relationship between the initial and the final distribution via lenses parameters was given. The features of the Gaussian beam transformation into rectangular distribution were considered. Major considerations relating to selection of lens parameters to provide for a required distribution at the target were discussed.

References

1. C.H.Johnson, Nucl. Instr. Meth., 127, 1975, p.163.
2. Ph.F.Meads, Jr., IEEE Trans. Nucl. Science, NS-30, No. 4, 1983, p.2838.
3. E.Kashy and B.Sherrill, Nucl. Instr. Meth., B26, 1987, p.610.
4. B.Sherrill, J.Bailey, E.Kashy, C.Leakeas, Nucl. Instr. Meth. B40/41, 1989, p.1004.
5. A.Jason, B.Blind, E.Swaton, Proc. 1988 Linear Accel. Conference, CEBAF Report 89- 001, p.192.
6. B.Blind, Nucl. Instr. Meth., B56/57, 1991, p.1099.
7. Y.Batygin, Proc.3rd Europ. Part. Accel. Conference, Berlin, 1992, p.822.
8. Y.Batygin, Beam Intensity Redistribution in a Non-linear Optics Channel, submitted at the 12th Int. Conf. on the Application of Accelerators in Research and Industry, Texas, 1992, to be published in Nucl. Instr. Meth.
9. K.L.Brown and R.V.Servranckx, AIP Conf. Proc. 127, p.52.



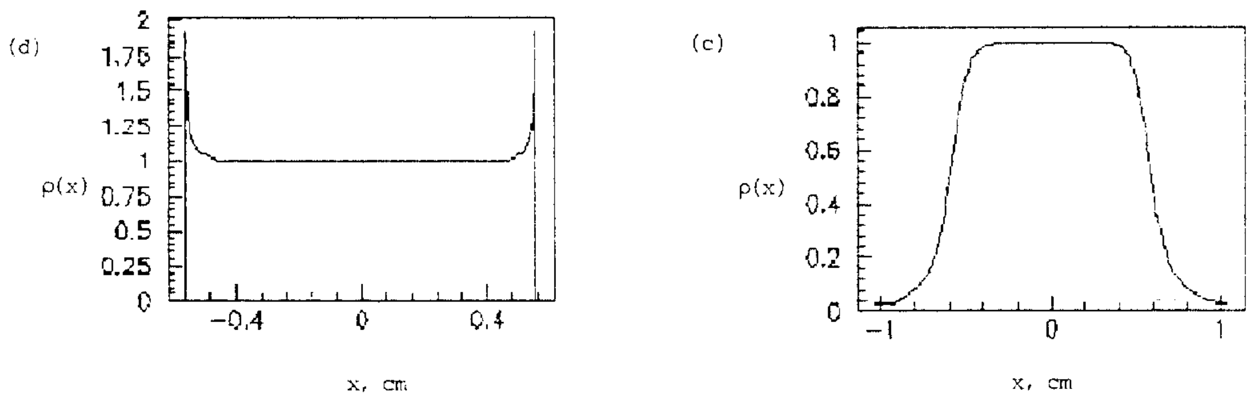


Fig. 2. Transformation of initial Gaussian distribution (a) into flattened distribution using different combinations of multipole lenses: (b) - octupole; (c) - octupole + dodecapole; (d) - octupole + dodecapole + 16-pole (see eqs. (6), (7), (8)).

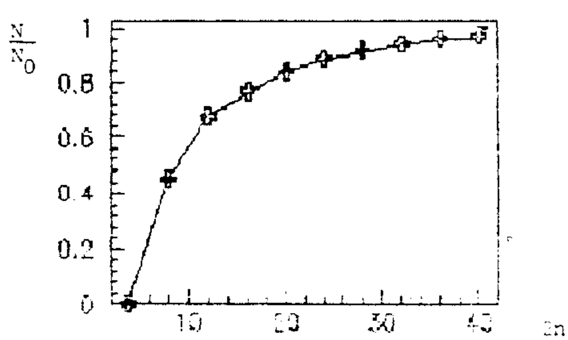


Fig. 3. Portion of flattened particles vs. number of poles of the highest multipole in transport channel.