BEAMDYN - A PROGRAM FOR CALCULATION OF PARTICLES DYNAMICS IN THE STRONG-FOCUSING IHEP ACCELERATOR.*

M.Yu. Gorin,
Institute for High Energy Physics,
142284, Protvino, Moscow region, Russia.

ABSTRACT

The circulating beam particle parameters need to be controlled during many turns when particles dynamics is being modelled in the accelerator at their interaction with internal targets, elements for extraction the beam or forming beam emittance. Calculations need significant time. The programs used before (see, for example, [1]) did not allow to control reasonable number of parameters during calculation since the computers were too slow.

1 INTRODUCTION

The program BEAMDYN written on Turbo C for IBM PC 486DX2 allows to provide, for example, modeling the task of interaction of accelerated beam with internal targets (during secondary particles generation) at a speed by two orders of magnitude higher than it was earlier. BEAMDYN allows one to solve the following tasks:

a) obtaining phase ellipses of an unperturbed beam for any azimuth of accelerator;
b) calculation of the trajectories of the circulating and/or extracted beam centre of gravity as well as the local distortions of the closed orbit;
c) calculation of a many turns beam dynamics during interaction with internal targets;
d) calculation of particles distribution in the aperture of a first deflector of the slow extraction system at non-resonant slow extraction [2];
e) modeling a beam extraction from the accelerator by bent crystals.

Particle losses on the vacuum chamber wall, aperture boundaries of septum-magnets as well as on other “narrow” points of the accelerator perimeter are under control during calculatins.

2 DESCRIPTION OF THE PROGRAM

2.1 Structure of the accelerator and matrix coefficients

For modeling the motion of particles in the accelerator the matrixes 3×3 for horisontal plane and 2×2 for vertical vertical one are used. The structure of the accelerator used in program is shown in fig.1. Two ways were used to fix the control points of magnetic blocks along the closed orbit. In the first case all five points along any block (point are 1 to 5) and one point (point 0) in the middle of any straight section are controlled; in the second case only one point in the middle of a block (the point 3) is used and point 0 in the middle of a straight section. The points number 0,1,3,5 are the same as it was given in [3] for which the Floquet functions were calculated.

The second way is less flexible and is used mainly to get preliminary results when many variants are calculated. The detailed calculations are made by the first method.

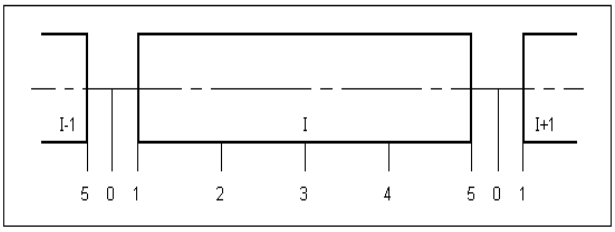

Figure 1: The accelerator structure used in the program. I, I±1 are numbers of the current accelerator blocks; 1-5 are points along a block; 0 marks the middle of a straight section.

For calculating a trajectory of the beam centre of gravity the trial particle, taken occasionally in the chosen point of the accelerator with some coordinates r,r',z,z',$\Delta p/p_0$ makes N turns (not less than 10). It allows one to get the beam phase ellipses at any of the chosen points of the accelerator asimuth.

Change of particle trajectories by the local distortion of a closed orbit (bump) is modeled also proportionally to the current in additional windings of corresponding magnetic blocks.

2.2 Submission of the origin beam and deriving the phase ellipses

The origin parameters of a beam are taken usually in the middle of the first straight section of the choosen part of the accelerator perimeter. In the horisontal plane the maximum amplitude of betatron oscillations equals 7 mm. It corresponds to emittance 2π mm·mrad. The angular distribution of beam particles is taken as

*This work was supported in part by the International Science Foundation and Russian Government (Grants RMK000 and RMK300).

monotonous while the amplitude distribution corresponds to the Relay law. The particle's coordinates in vertical plane are selected by Monte-Carlo according to gaussian distribution. Submission the beam in both planes may be changed according to the task.

Each particle moves certain number of turns while its coordinates on each turn are stored in the program memory. This mode is used for choosing internal target coordinates, optimization of bump strength at moving the beam towards septums of the septum-magnets under non-resonant slow extraction [2], etc.

2.3 Description of particles interaction with internal targets

The following proceses are considered when particles interact with internal targets: multiple Coulomb scattering, elastic nuclear scattering, nuclear absorption and ionization energy losses.

The multiple Coulomb scattering changes both the amplitudes and phases of betatron oscillations. The projected angle θ due to multiple Coulomb scattering is calculated according to [4]:

$$\sqrt{\langle\theta^{2}_{coul}\rangle} = \frac{E_s}{p\beta_v c}\sqrt{\frac{D_t}{L_{rad}}}\ , \qquad (1)$$

where E_s=15 MeV; p - particle's momentum; β_v and c are relativistic factor and the speed of a light, respectively; D_t is the target length; L_{rad} is the radiation length of target's material.

Sometimes some particle parameters connected to elastic nuclear scattering need to be determined. The angle of scattering, if the probability of an elastic scattering is high enough, may be derived as follows [5]:

$$\sqrt{\langle\theta^{2}_{el}\rangle} = \frac{2\hbar}{Rp}\ , \qquad (2)$$

where $\hbar$ is the Planck constant, R is the radius of a nucleus (fermi).

Absorption of protons is the main mechanism of decreasing the beam intensity. The probability to interact inelastically is determined for particles according to [6]:

$$W = 1 - exp\left(-\frac{D_t \cdot r}{L_{nucl}}\right), \qquad (3)$$

where ρ and L_{nucl} are the density and nuclear length of the target material, respectively.

Ionization energy losses which result in a radial displacement of the closed orbit may be evaluated as [6]:

$$\Delta E = -T \cdot D_t \cdot r\,, \qquad (4)$$

where $T(MeV/g/cm^2)$ - is the specific ionization energy loss value for the target material.

After hiting the target by a particle all the matrix elements are to be redefined and calculations continue till the next hitting the target or extraction the particle from the accelerator.

The bent crystal of Si may be used as target (see, for example,[7]). Particles are considered as captured in the channeling mode if:

$$|r' - \alpha_{cr}| \le |\psi_c|, \qquad (5)$$

where r' is the angle of a particle motion, α_{cr} is the set angle of the crystal, ψ_c is the critical angle of channeling. In this case the equation of a proton motion in the field of planar channel can be expressed as [8]:

$$\frac{d^2y}{dz^2_{cr}} = -\frac{1}{pv}\frac{d}{dy}\left(W(y) + \left(\frac{pv}{R_{cr}}\right)y\right), \qquad (6)$$

where $y(z)$ is the distance from the particle to the centre of a channel; p and v are the momentum and speed of a particle, respectively; z_{cr} is the distance along the channel axes; $W(y)$ is the planar potential; R_{cr} is a crystal bending radius. If the particle after hiting the crystal is not captured into channeling mode or undergo dechanneling, the interaction is considered to be with an amorphous target.

2.4 Simulation of particle jump into a septum-magnet aperture

Increase of betatron amplitudes at interaction with internal targets is used for jumping the particles into a septum-magnet aperture at non-resonant slow extraction [2]. After every turn a check of the next condition on the first deflector asimuth is made

$$|r| \ge |r_{gr}|, \qquad (7)$$

where r is a particle coordinate; r_{gr} is a coordinate of a septum of the deflector.

When this condition is satisfied, hiting the septum of the deflector or the wall of its vertical aperture by a particle is checked. In the case of a "clean" jumping into the magnet aperture, the particle is considered to be extracted and its parameters are kept in the memory. After calculations are finished for the given beam distribution of particles in the septum-magnet apertures, their life time in accelerator etc. are derived. Since the extracted beam trajectory is fare from the centre of the vacuum chamber, where non-linearities of the magnetic field are noticeable calculations of the following movement of extracted particles is made by program TRAEK [9]. It integrats the equations of particle motion in the real accelerator field corresponding to the magnetic measurments. The distribution of particles in the first deflector aperture is taken as original.

3 EXAMPLE OF A PROGRAM WORK

For illustration of program work the non-resonant slow extraction mode was taken when beam is scattered by two internal targets placed in magnetic blocks 24 and 27. The septum-magnet of straight section 18 as the first element of slow extraction scheme is used.

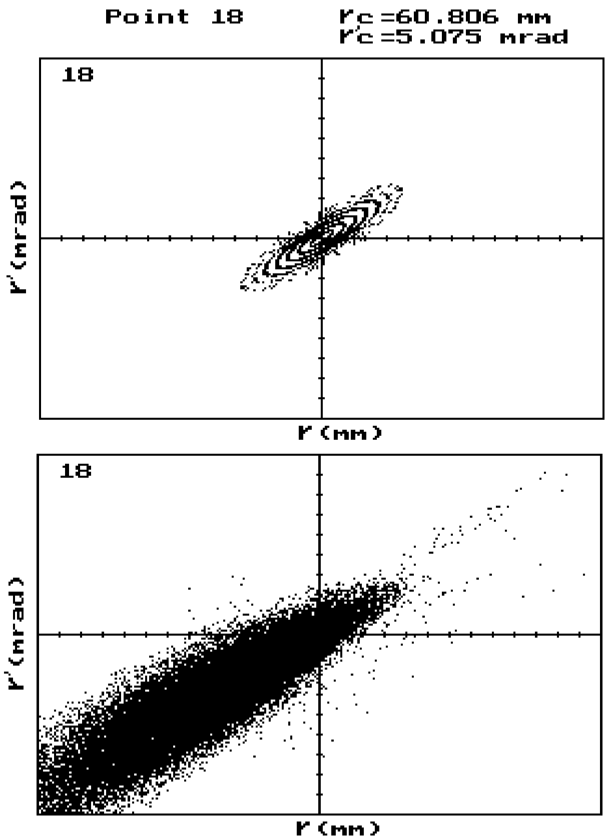

Figure 2: Illustration of scattering by internal targets. a) - unperturbed beam; b) - the beam after interaction with targets.

For beam displacement to the targets the local distortion of the closed orbit is formed by current of additional windings of blocks 20, 26 and 24, 30, respectively. Target of block 24 has positive coordinate while worcing coordinate of target of block 27 is negative. Beam is displaced towards the deflectors by the bumps 15-21 and 16-22 (see, for example, [2]). 1000 particles were taken to get reasonable statistics.

The phase portraits of the unperturbed (a) and scattered by targets (b) beams in the straight section 18 are shown in fig.2.

The phase pictures for particles which jumped into the septum-magnet aperture in planes r,r' and z,z' are shown in fig.3. The dependences of number of jumped particles versus the number of beam revolutions in the accelerator and the number of hits of the targets by particles are shown also here. The data of particle losses as well as the mean number of hits of targets by each particle are given in the bottom.

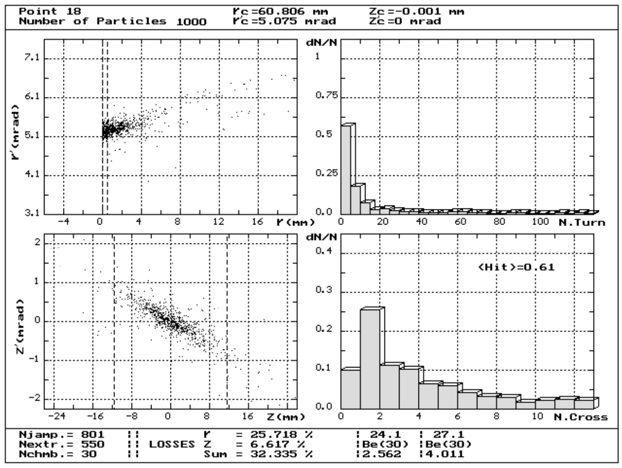

Figure 3: Illustration of particles distribution inside the first deflector aperture at non-resonant slow extraction; a) and b) are the phase portraits of the beam; c) and d) are particles distribution versus the time of life during extraction.

4 CONCLUSION

The program BEAMDYN simulating the dynamics of a proton beam in the strong-focusing IHEP is the sutable instrument for optimization of existing and developping the new modes of beam extraction. It uses internal amorphous targets, bent crystals and any other devices which can serve as targets. The program structure allows one to introduce any elements need for making particles extraction (bump-magnets, kicker- and septum-magnets) with non-lineary field including. The program can be accomodated easily for calculations of analogous tasks of beam extraction from the accelerators of higher energy.

REFERENCES

[1] K.P.Myznikov et al.., IHEP 70-51, Serpukhov, 1970.
[2] A.A.Asseev et al.., Journ. of Tech. Phys., 1990, v.60, N° 9, p.70, Leningrad.
[3] E.K.Tarasov et al., Preprint ITEP N° 232, Moscow, 1964.
[4] P.Söding et al., Phys. Lett. B39, 1(1972) 19.
[5] H.G.Belletini, G. Cocconi, A. Diddens et al., Nucl. Phys., 1996, v. 79, p. 609.
[6] H.G.Herevard, J. Ranft, W. Richter, CERN 65-1, Geneva, 1965.
[7] A.A.Asseev et al., Nucl. Instr. and Meth. A330(1993)39.
[8] H.Kudo, Nucl. Instr. and Meth. 189(1981) 609.
[9] Yu.Fedotov, J.Frounteau, R. Keyser, CERN-DD/CO/67/5, Geneva, 1967.