DESIGN AND EXPERIMENTAL INVESTIGATION OF THE 200-900 MEV PROTON BEAM OBTAINED BY THE MODERATION OF 1000 MEV PROTONS IN THE DEGRADER

N.K. Abrossimov, V.G. Vovchenko, V.A. Eliseev, E.M. Ivanov, Yu.T. Mironov, G.A. Riabov [#], M.G. Tverskoy, Petersburg Nuclear Physics Institute

Abstract

The application of the Monte-Carlo method for calculation of the proton beam lines with degraders is described. The calculation procedure consists of two parts. First of all parameters of the beam after degrader are calculated with the well-known GEANT3 code. Then the calculated coordinates and momentum vector for every proton after degrader are used as input data for codes “MEZON” and “OPTIMUM” developed for Monte-Carlo simulation of beam behavior in the beam line. Good agreement between experiment and calculations for the beam intensity, energy spread, magnetic fields in the dipoles and quadruples of beam line is achieved. Therefore the combination of the GEANT3 code and beam line simulation codes “MEZON” and “OPTIMUM” provides the reliable tool for the designing of the beam lines with degrader.

INTRODUCTION

The PNPI synchrocyclotron accelerates protons up to the fixed energy of 1000 MeV at beam intensity of 1 μA. However some problems of fundamental and applied physics require proton beams of variable energy. Such a beam has been created at 1 GeV synchrocyclotron in Gatchina within ISTC-1405 project. Beam energy variation from 200 MeV to 900 MeV is provided by the copper degrader.

DESCRIPTION OF THE VARIABLE ENERGY BEAM LINE

Schematic view of the PNPI synchrocyclotron and part of experimental hall with a system of beam lines [1] is shown on Fig.1. Intensity and diameter of extracted proton beam can be varied from 10^6 s^{-1} to $6{\cdot}10^{12}$ s^{-1} and from 5 mm to 500 mm respectively. In accordance to operation principles the synchrocyclotron generates pulsed beam with bunch duration of 300 μs and repetition rate of 40-60 Hz. By using the long burst operation system (so called Cee-electrode) the macro pulse can be increased up to 10 ms. At that the macro pulse is filled with micro bunches of 10 ns duration recurring with a period of 75.1 ns.

The variable energy beam is realized on the existing direction P3 (see Fig.1). The beam line consists of absorber, two collimators limiting dimensions and divergence of the beam, two doublets of quadruples and bending magnet.

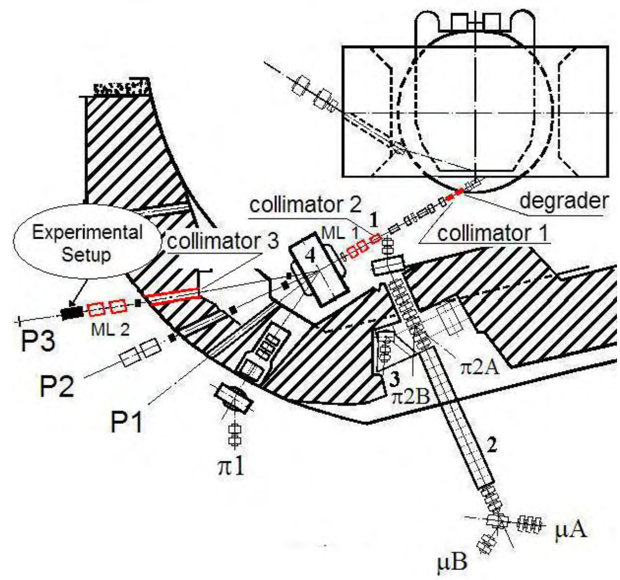

Figure1: The beam lines of the PNPI synchrocyclotron. 1 – meson-production target; 2 – muon channel; 3 – low energy π2-channel; 4 – bending magnet; π1 – high-energy pion beam; P1, P2, P3 – proton beam lines. Elements of the variable energy proton beam include: degrader, collimators 1,2, and 3, quadruple doublets ML1 and ML2.

Degrader is realized as a set of copper cylindrical blocks of different length placed in special guide. Density of copper is equal to 8.88 g/cm^2. Total width of absorber can be varied in a range between 65.19 g/cm^2 and 438.93 g/cm^2 that corresponds to the energy of protons after degrader equal to 900 MeV and 160 MeV respectively. The first collimator placed right after the absorber and intended to limit the beam size has a length of 50 cm along the beam line and aperture of 6x4 cm^2. The second collimator limits beam divergence on the input of the magneto-optical system. This collimator is a part of standard equipment of the accelerator complex. It consists of the set of four plates, which can be remotely moved in the vacuum thus limiting the horizontal and vertical beam dimensions in a range from 5 mm to 80 mm. The magnet bends the beam by 18^0 in the direction of collimator (3) installed in the wall between the main and experimental halls. The collimator has a length of 3 m along the beam line and diameter of 100 mm. The magnet provides beam momentum separation and eliminates undesired

riabov@mail.pnpi.spb.ru

background of neutral and charged particles. In beam optics the degrader presents a source. Doublet of quadruples 20K-50 (ML1) is used to reproduce an image of the source in the opening in the wall between the main and experimental halls where the momentum collimator is situated. The momentum dispersion of the beam after the bending magnet results in selection of momentum distribution of the beam. The second doublet of quadruples 20K-50 (ML2) located in the experimental hall is used to focus beam on the target in a spot with dimension of less then 30 mm. Only one quadruple doublet in experimental hall (ML2) is used for beams with reduced intensity.

Total length of the beam line is equal to 30 m. The channel is designed to provide proton beams of any energy in a range from 200 MeV to 1000 MeV without modification of the channel geometry. To change the beam energy one needs to change length of absorber and magnetic fields in dipoles and quadruples according to the relation: B/p = const.

CALCULATION OF THE BEAM LINE

It is common practice to decrease energy of the proton beam by using a degrader. However detailed calculation of such a beam leads to the problems of simulation of beam behavior in the degrader. We solved the problem by using Monte-Carlo method. The method consists in tracing and accumulation of large number of particle trajectories passing through the channel. Simulation algorithm consists of two major steps. On the first stage parameters of the beam particles after degrader are simulated with well-known GEANT3 code. On the second step the coordinates and components of the momentum vector for every proton after degrader are used as input data for "MEZON“ and “OPTIMUM” codes [2,3]. If deviation of particle trajectory from the channel axis is larger then some given amplitude then particle is considered to be lost. To get 300-500 particles on the output of the beam channel one has to simulate ~ 10^6 particles after degrader that looks quite acceptable. Application of GEANT3 code allows taking into account the following processes: ionization losses, δ - electrons, multiple scattering and inelastic nuclear interactions. Passage of particles through the degrader results in decrease of beam intensity due to nuclear interactions, decrease of beam energy, increase of divergence and cross section of the beam and increase of energy spread. Besides the absorber serves as a powerful source of background of charged and neutral particles. Therefore in beam lines with absorbers the magnetic analysis is essential. The average parameters of the beam after degrader are presented in Table 1.

When proton beam is decelerated from 1000 MeV to 900 MeV and 160 MeV it loses ~ 40% and ~ 96% of particles respectively. At the same time beam remittance increases to 0.11 cm·mrad and 2 cm·mrad and momentum spread increases to 1% and 11.6%, respectively. One can see that beam quality considerably deteriorates when energy of particles is changed from 900 MeV to 160 MeV. The degrader forms the secondary proton source whose brightness decreases by a factor of 1000. Brass collimator (1) with a length of 50 cm and aperture of 40x60 mm^2 is placed right after the degrader to unify parameters at different energies. The collimator absorbs 20% and 96.2% of the beam particles at 900 MeV and 160 MeV, respectively, but the beam emittances after the collimator differ not more then twice. So the geometrical parameters of 900 MeV and 160 MeV proton beams after collimator are very similar that is very convenient for calculation and adjustment of the channel.

EXPERIMENTAL AJUSTMENT OF THE BEAM AND RESULTS

Experimental study of parameters of the variable energy beam was carried out with use of additional set of experimental equipment shown on Fig.1. Composite degrader and collimator were installed close to output window of accelerator. Intensity of extracted proton beam was varied and measured with telescope of scintillating counters. Energy and energy distribution of the beam were measured by using a time of flight method. Analysis of time of flight spectra showed negligible admixture of background (mesons, neutral particles etc.).

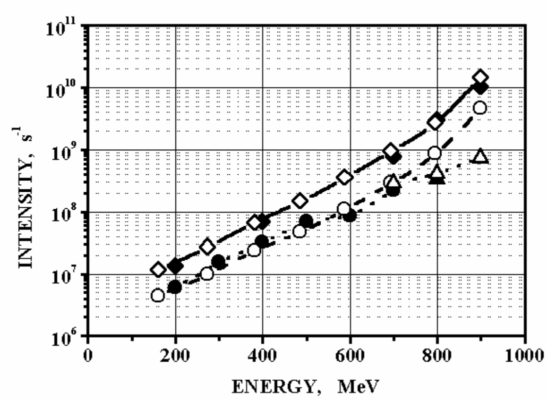

Figure 2: Experimentally measured and calculated beam intensities versus energy (intensity of the primary beam is 10^{12} s^{-1}). Solid marks – experiment, open – calculations. Circles represent variant with single doublet (ML2), triangles – single doublet with additional collimator (2), rhombs – the channel with two doublets.

Multiwire proportional chambers were used to measure spatial dimensions of the beam and to adjust magnetic fields in quadruples. Maximum intensity of the beam was measured by method of induced activity in Al foils.

Fig.2 shows comparison of calculated and experimentally measured intensities of the proton beams of variable energy in the point of experimental setup. Experimental studies showed very good agreement between calculated and experimentally measured parameters of the proton beam.

Table 1: Parameters of the proton beam after degrader

E, MeV	Degrader length g/cm^2	Beam intensity after degrader, %	<x> cm	<x'> mrad	Δp/p %	Emitance cm·mrad
900	65,19	58,8	1,30	0,10	1.0	0.11
795	128,67	35,6	1,65	0,14	1.0	0.19
693	189,99	22,1	2,30	0,17	1.4	0.28
590	248,77	14,3	3,20	0,20	1.8	0.42
490	304,26	9,7	4,25	0,24	2.5	0.64
380	355,45	6,9	5,30	0,28	3.6	0.95
274	400,94	5,1	6,40	0,32	6.1	1.36
160	438,93	3,8	6,80	0,39	13.7	2.01

CONCLUSION

Variable energy proton beam has been developed within ISTC-1405 project. It has been successfully used for measurement of total cross sections of fission of heavy nuclei and actinide-nuclei with protons of variable energy: 200 MeV - 1000 MeV. However the beam may have much more extensive use, for example for investigation of different problems of nuclear physics (radiation hardness of radio-electronic components, radio-biological studies in medicine and so on). There is also a possibility to increase intensity of 200 MeV proton beam in a few times that will make it usable for proton therapy.

Calculation method based on the GEANT3 code and beam line simulation codes “MEZON” and “OPTIMUM” has been experimentally tested at 1 GeV synchrocyclotron in PNPI and proved to be a reliable tool for the designing of the beam lines with degraders [4]. We suppose that it could be used on other accelerators.

REFERENCES

[1] N.K.Abrossimov et al., Proceedings of the VII All-Union Conference on Charged Particle Accelerators, Dubna, Russia, 14-16 October 1980, Moscow 1981, v2, p. 75-78.

[2] N.K Abrossimov, V.A.Volchenkov, G.A.Riabov, Proceedings of the IV All-Union Conference on Charged Particle Accelerators, Moscow,18-20 November 1974,Moscow 1975 ,v.2,p. 231-235.

[3] N.K.Abrossimov, V.A.Volchenkov, G.A.Riabov, Proceedings of the VI All-Union Conference on Charged Particle Accelerators, Dubna, Russia 11-13 October 1978 ,Moscow 1979 , v.2, p. 175-177.

[4] G.A. Riabov, V.G. Riabov, M.G. Tverskoy, Abstracts ICAP 2004, St. Petersburg, p.169.