STUDY OF EFFICIENCY OF BEAM COLLIMATION AT U-70 ACCELERATOR BY USE OF CRYSTAL TARGETS

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Abstract

New crystal technique – bent crystal array and veer – type reflector based on straight crystals were used like first stage in collimation system at U-70 accelerator. Efficiency of collimation was enhanced up to 90% in two-stage collimation system which included first crystal stage and long steel absorber like second stage. For data taking and analysis of information modified modern beam diagnostic system was applied.

INTRODUCTION

The phenomenon of deflection of a charged particle beam in a bent crystal is well investigated and successfully applied at energies of about 10 GeV and higher [1,2,3]. However, the task of bending and extraction of charged particles with energies below 1 GeV presents a big practical interest, for example for the production of ultra stable beams of low emittance for medical and biological applications. There exists a big experimental problem in steering such energy beams, which is connected with the small size of the bent crystal samples. Potentially suitable tools in this case can be the bent quasimosaic crystals such as in [5], or thin straight crystals [6,7], but in both these cases it is necessary to increase a deflection angle of particles in some times.

CRYSTAL DEVICES

In this article we propose a novel crystal technique, which can effectively work in a wide energy range and is especially perspective for low energy below 1 GeV.

The first option is based on use of array of shot bent channeling crystals (Fig.1) with sub – millimeter length (special thin silicon wafers about 100 micron thickness were used for the production of such samples). Thus the bend of array occurs also, as a bend of the single well investigated silicon strip [8].

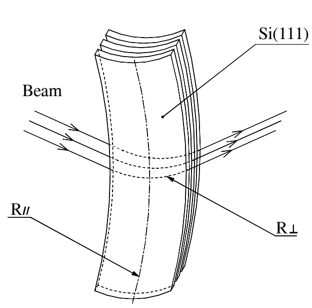


Figure 1: The array of bent silicon strips for beam deflection due to channeling.

The second option is based on the reflection of particles on very thin straight crystal plates with thickness, which is equal to an odd number of half-lengths of channeling oscillation waves $L = (2n+1)/2\times\lambda$, where $\lambda = \pi d/\theta_c$, $d = 2.3A^0$ – interplanar distance in silicon. It means, for example, that the optimum length of a crystal should be 10 microns for particles with energy 50 GeV. For the enhancement of the deflection angle, a few aligned plates placed like a veer are foreseen (Fig.2).

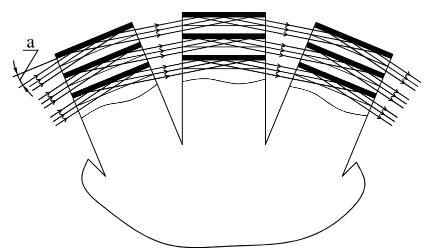
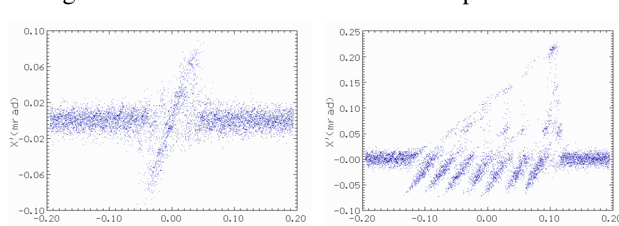


Figure 2: Veer-type reflector for bending of particle beam with use of thin straight crystals.

For an optimum deflection of a beam in this design each following crystal is unwrapped on angle $2\theta_c$. Then the total bend angle of beam can reach the value $2\theta_c \times N$, where N – is the amount of crystal plates. If the unwrap of a fan and thickness of plates are not optimal, the lower bend of particles occurs, and this picture is more difficult for interpretation. On Fig.3 for understanding the process of Monte Carlo calculations for unitary passage of a beam through a fan are submitted at its different parameters.



$dx' = 0\,\mu rad,\ L = 10\mu m,$ $dx' = 30\,\mu rad.$

Figure 3: Distribution of protons with energy 50 GeV on scattering angles after passage of a crystal fan from seven plates depending on its angular orientation X'tar with respect to the beam. The parameter dx' means a turn of the next plates of a fan in microradians.

Three different devices have been prepared for accelerator experiment: a usual crystal strip (the technology is described in [8]), a crystal array (Fig. 1), and assembly of veer - type (Fig. 2). The realized schemes of crystal devices are shown in photos Fig. 4.

Parameters of crystals are submitted in the table.

Crystal type	Length, mm	Thickness, mm	Bend angle, mrad
Strip	1	0.3	1.0
Array	0.9	7×0.2	1.1
Veer	7×0.25	3	~7×0.05

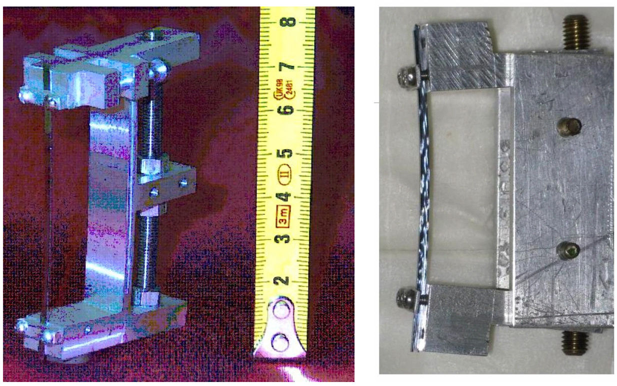


Figure. 4: The realized schemes of devices (left to right): the bent strip and array of strips.

DESCRIPTION OF ACCELERATOR EXPERIMENT

Experiment was performed during two runs of U-70 operation in 2009 and 2010. In experiment 3 crystals in high-vacuum goniometers were serially entered in a circulating accelerated. The angle of bending is sufficient to separate the circulating and deflected (by the crystal) beams in space. The beam deflection effect due to channeling was measured by secondary emission detector (SEM), located in vacuum chamber of an accelerator near to circulating beam. Parameters of the accelerator are described in [9]. Details of the experimental equipment are shown on Fig. 5.

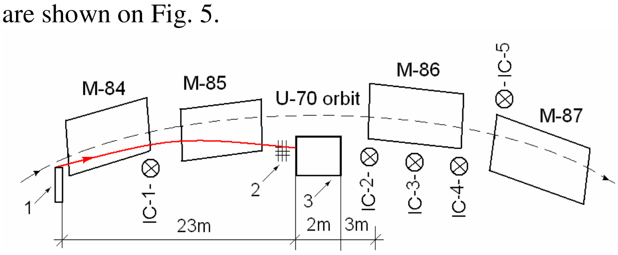


Figure. 5: An arrangement of the equipment in the U-70 accelerator: 1– crystal station, 2– profilometer, 3– absorber, IC – ionization chambers (loss monitors 1-5), M– magnetic blocks of the accelerator.

For carrying out of experiment the new automated diagnostic system of the beam, including 5 monitors of losses based on ionization chambers and 2 plane stationary profilometer has been created on basis of the secondary emission, established directly ahead of an absorber in vacuum volume and recording parameters of the deserted beam in horizontal and vertical planes.

The system of data taking and acquisition is based on use of an industrial computer with trunk PCI. In the tunnel of the accelerator two skeletons of preliminary electronics for integration of signals from electrodes of profilometer are placed. The first skeleton contains 24 measuring channels for registration of horizontal distribution of density of a beam and 8 channels for integration of signals from loss monitors. The second skeleton with 32 measuring channels is intended for 32 channel vertical profilometer. In each skeleton signals from integrators are multiplexed and on the common coaxial cables act on 2 inputs of 8-channel ADC, integrated in an industrial computer. On other inputs of ADC other necessary auxiliary information, somehow acts: intensity of a beam before its dump on an absorber, the voltage values proportional to currents of bump-magnets, to positions of crystals, etc. The software for data taking and acquisition has been based on application of platform LabVIEW.

RESULTS OF MEASUREMENTS

Measurements were carried out at two energies of the accelerated beam of protons: 50 GeV and 1.3 GeV (kinetic energy).

First measurements have been lead at energy of protons 50 GeV. For definition of collimation efficiency calibration of the detector with the help of fast kicker - magnet has been lead. In Fig. 6 the sums of signals of the detector are shown when the beam deflected by different crystals in comparison with effect of one-turn brought of a beam by fast kicker (in this last case whole beam with 6 mm size gets in the aperture of the detector).

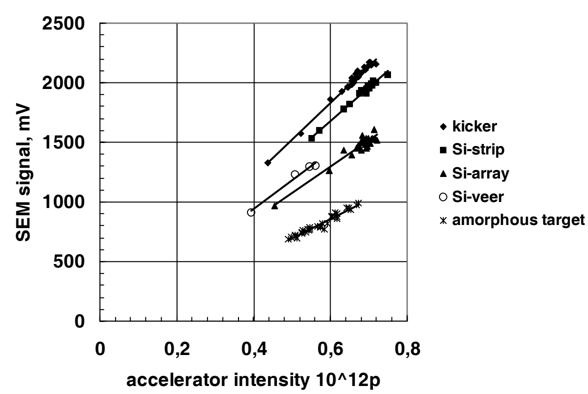


Figure 6: Comparison of the sum of profilometer signals at work of different crystals with effect of particle brought towards absorber by kicker.

Measured collimation efficiencies for three mentioned crystals are equal 91, 77 and 82%. The amount of particles in channeling peak is accordingly equal 86, 72 and 70%. That is all crystals well deflected 50 GeV proton beam. The received data are in agreement with computer simulation with use of program SCRAPER [10] which is taking into account multi-turn character of movement of particles in real structure of the accelerator and repeated their interaction with a crystal.

On the Fig. 7 the orientation dependences of collimation and channeling efficiencies are shown for crystal strip.

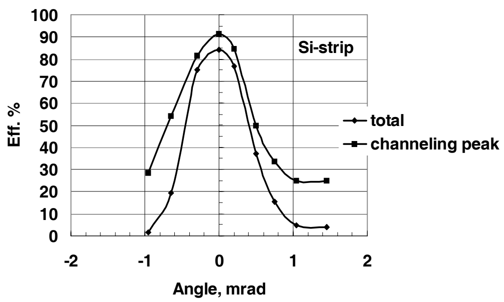


Figure 7: Collimation efficiency depending on angular orientation of a crystal strip with respect to the beam.

On the Fig. 8 are shown orientation curves of particle losses, measured on signals of 5 ionization chambers located in a vicinity of an absorber (see Fig.5).

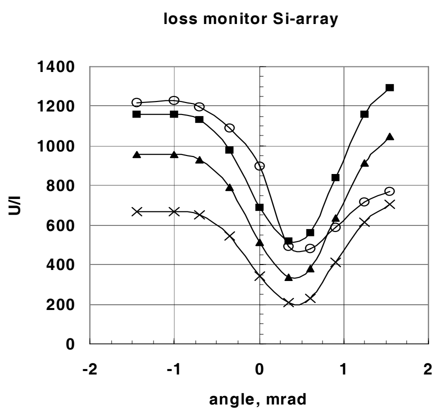


Figure 8: Orientation dependences of loss monitors for array of strips.

Particle losses at optimum alignment of crystals decrease in 2-3 times in comparison with disoriented crystals that corresponds to calculation. Approximately in as much time intensity of muon torch behind an absorber far from the accelerator should decrease that is the important factor at achievement of high intensity of beam of circulating protons in the accelerator.

At energy of a beam 1.3 GeV results of efficiency are much lower (see the table). The best result, channeling peak of about 20 %, has shown array from seven thin strip crystals. The big loss of efficiency is explained by non-optimal tuning of circulating beam towards the crystal by bump-magnet. At low energy because of sizable beam, about 50 mm, there is a drift of an incident angle about a half milliradian that should be removed at prompting a beam by high-frequency noise (this work is planned). In Fig. 9 the profile of 1.3 GeV beam deflected by silicon array is shown. The fraction of channeling peak is allocated by a thick line (channeling peak is well separated from a circulating beam and approximately corresponds to efficiency of a possible beam extraction from the accelerator).

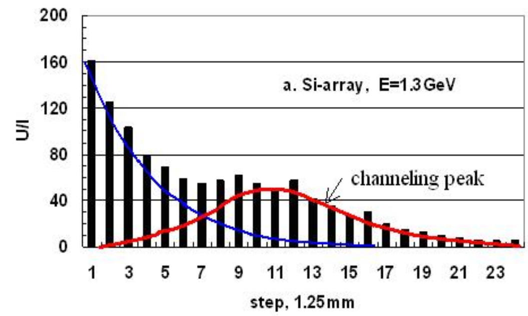


Figure 9: The 1.3 GeV proton beam profile at the absorber entry deflected by array of silicon strips.

CONCLUSION

Thus, it is shown, that the created crystal devices can work in a wide range of energy and have prospects for the organization of low energy medical beams on U-70 accelerator. For optimization of crystal devices for low energy experiments in a test area of laboratory LNF are planned where accessible beam of particles with 50-700 MeV energies exist [4].

Reduction of particle losses in 2-3 times on the accelerator was observed also at application of different crystals in comparison with the usual one-stage scheme of beam collimation by steel absorber. Approximately in as much time intensity of muon torch behind an absorber far from the accelerator should decrease that is the important factor for achievement of higher intensity of a circulating beam in U-70.

Work is supported by IHEP Directorate, State corporation Rosatom (the contract N 4e.45.03.09, 1047), the grant of the Russian Funding for Basic Research 08-02-01453-a, and also the grant 09-02-92431-KE of joint project of RFBR - Consortium EINSTEIN (Italy).

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