USE OF BENT-CRYSTAL DEFLECTORS TO STEER BEAM IN U-70 ACCELERATOR OF IHEP- STATUS AND PROSPECTS

A.G.Afonin, V.T.Baranov, Yu.A.Chesnokov, V.A. Maisheev,
V.I.Terekhov, I.A.Yazynin, IHEP Protvino, Russia

Abstract

The report presents an overview the results of IHEP activity in the field of study and using bent crystals to steer high-energy proton and ion beam obtained during 2010-2012. The hardware installed to study crystal collimation and extraction is described. A new dedicated beam transfer line was arranged to study the performance of crystals. It has been shown that the crystal deflections developed are capable of sustaining long-term operation to deliver high-energy extracted beams for fixed-target physics. Experience with practical applications of bent crystals are outlined. First results on the extraction

24.1 GeV nucleon carbon ions are also presented.

BEAM EXTRACTION FROM U-70

The method to use bent crystals to extract protons has found the widest practical application on U-70 accelerator of IHEP during more than 20 years.

Different types of extraction schemes with bent crystals and technical equipment are realized now as for extraction so as for experiments to test new crystal devices and to study beam collimation processes.

The location of the stations with bent crystals in U-70 is presented on Table 1.

Table1:Crystal location in U-70.

Crystal station	Si-19 Si-22 Si-106	Si-24	Si - 27	Si-30	Si-84 Si-86
Beam line	8,22,23	2,14	4	8,22.23	absorber

The subscript means the straight section index or the index of a magnet in which the crystal or internal target is installed..

On U-70 three different possibilities to use bent crystals for physics are realized.

1. One way to use bent crystals is to extract proton by crystal directly. In this case we use long crystals which gives the possibility to receive big angles of deflection. We have two station of this type Si-24 and Si-27.

They extract the beams of protons to experimental facilities, which usually work with secondary particle from internal targets. The angles of bending for such deflectors (80-90) mrad and efficiency ~ 10^{-5}.

2. Second way is to use short crystals with small deflection angle.

The small deflection angle (in our case 0.5-2 mrad, it depends on scheme) is sufficient to put the beam into aperture of septum-magnet, which then provide the larger deflection angle need for the extraction

For this purposes we have crystal stations Si-106, Si-19, Si-22 . The length of deflectors 2-5 mm and the efficiency in this case was achieved 85% [1,2].

3. Third way is to split extracted beam by crystal for two directions. For this regime we use Si-30, which is intended to remove a small fraction of a beam (it can be ~ 10^7 protons per cycle) to beam line 8 or 22.

Beam extraction using bent crystals allows simultaneous operation with internal targets. The diagrams of the beam extractions using bent crystals is shown on Fig 1.

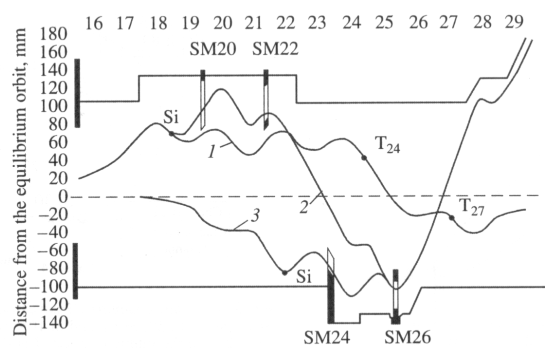

Figure 1. Schematic diagrams of proton beam extraction using bent crystals: (1) the trajectory of circulating beam during its simultaneous guidance onto the crystal in straight section no.19 (Si) and internal target T24 and T27, (2) the trajectory of beam extraction from crystal SS-19 (Si), and (3) the trajectory of beam extraction from crystal Unit 22 (Si).

Since RuPAC-2010, the U-70 complex has been working for four runs in total. Table 2 presents the results of bent crystal extraction during this period.

Table2: The use of slow extraction by bent crystals on U-70 in 2010-2012.

Run of U-70	2-2010	1-2011	2-2011	1-2012
Duration of a run (hours)	744	240	744	288
Crystal extraction (hours)	846	636	672	240

A crystal can extract from 10^6 up to (5-6)* 10^{11} ppp without special cooling technique during hundreds hours without degradation seen. This extraction is a good addition to the slow extraction existing at the U-70 IHEP accelerator, which provided proton beam with intensities of 5*10^{11} – 10^{13} particle per pulse. It shows reliable, reproducible and predictable work.

During the runs, all the beam extraction system available in the U-70 were engaged- fast single- turn, slow resonant

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(stochastic and classic), internal targets and slow extraction by bent crystal.

Typical picture of cycle flattop utilization presented on Fig.2

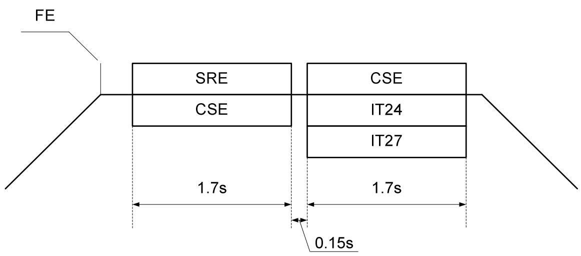

Figure 2. The utilization of the U-70 magnetic cycle flattop.FE- fast extraction, SRE- slow resonant extraction, CSE- slow extraction by crystal, IT- internal target.

EXTRACTION OF CARBON IONS

During last years the program of accelerating light ions in the accelerator complex U-70 is successfully developed..

In spring run of this year the beam of carbon ions was accelerated to kinetic energy 24,1 GeV per nucleon with intensity up to $5*10^9$ nucleon per cycle and then the carbon ions beam was extracted from accelerator in one of external beam line. It was done by all system of extraction- fast, slow resonant and by bent crystal.

In order to extract carbon beam by crystal we have used crystal station Si-22 (Fig.1) and scheme Si 22-24-26-30. It was silicon deflector S-type with dimensions (2*40*0.5) mm^3 (length along the beam, height, thickness) and bending angle ~ 0.9 mrad.

The modeling of carbon ions extraction was performed before of experiment. The results presented on Fig.3

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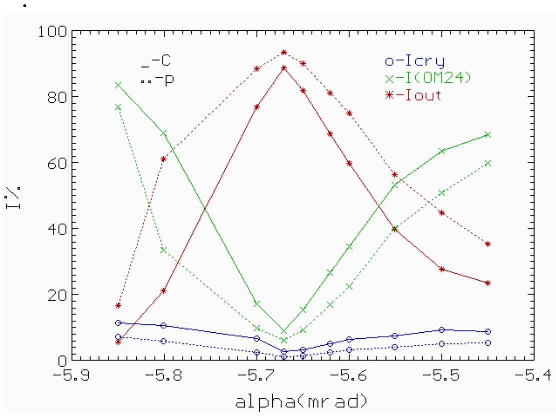

Figure 3. Extracted beam intensity (*) and beam losses (o,x) as a function of the crystal orientation.

The beam of carbon ions was successfully extracted to the beam line №22 and was registered on physical setup FODS.

On Fig.4 one can see the profile of beam in beam transfer line and signal from photomultiplier during extraction process. The efficiency of extraction was defined as 60%.

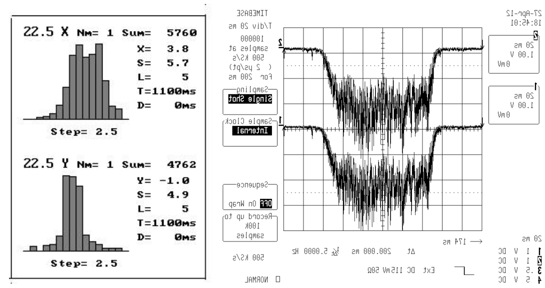

Figure 4. Profile of carbon ions beam (left) and beam spill.

The first results of this experiment should be and will be refined in future sessions of the U-70 operation.

NEW EXPERIMENTS

The novel crystal device for beam focusing was constructed in IHEP. It presents the silicon plate which has been cut out along plane (111). The sizes of a plate are equal $x*y*z=1*70*20$ mm^3. It was bent in a longitudinal direction by metal holder

Due to anisotropic properties of material of a plate there is a transversal bend which is used for bending and focusing of a beam [3]. Experiment on focusing beam with such device was carried out with 50 GeV proton beam of U-70 IHEP accelerator [4]. The effect of focusing has been registered with the help of nuclear photoemulsions.

The result of calculation and experiment is shown on Fig.5.

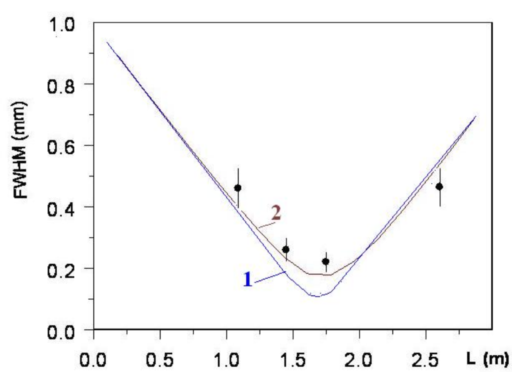

Figure 5: The size of a beam depending on distance from a crystal. Points - experiment. The curve 1 - calculation for transportation of particles in vacuum, the curve 2-calculation for scattering on air and emulsion layers.

Thus, it was evidently presented, as the beam equal on the size to thickness of a crystal (1 mm) was compressed in a line in with width 0.22mm.

The focusing property of the developed device can be applied on the accelerator of high energy to research of low-angular processes. The crystal can be align on a fix target by focusing end face, as shown in Fig.6. Rotating the crystal around of an axis O, one can deflect the particles from the target and create clean conditions for registration of the necessary particles. Other motive of application of such scheme is reception of a secondary particle beam of high energy by rather simple way.

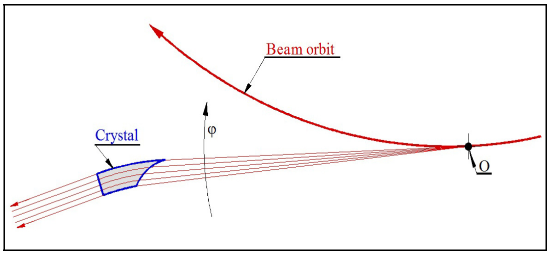

Figure 6: An example of application of a focusing crystal for research of low-angular processes. The same scheme can be a source of a parallel beam of secondary particles.

Recently IHEP group together with employees of several Russian and foreign centers have opened the new physical phenomenon - reflection of high energy protons from the bent atomic planes of silicon crystal [5]. The phenomenon of reflection occurs in wide area of angles and is more effective, than usual channeling.

But for real application the increase in angle of reflection in few times is required. Two ways were proposed for this purpose:

- Reflection on a chain of crystals (multiple volume reflection - MVR in sequence of crystals [6].
- Reflection near to an axis in total potential of several skew planes (MVR in one crystal [7]).

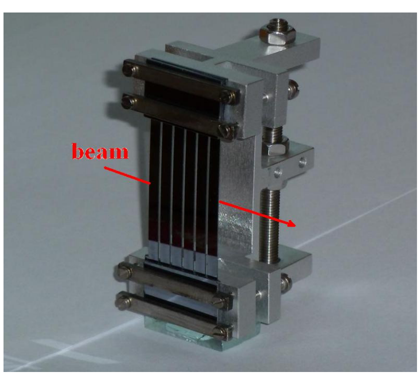

Figure 7: Crystal multistrip structure.

During two last runs we tested amplification of reflection angle due to both effects (multi-crystals and axial enhancement) for improvement of beam collimation scheme in U-70 synchrotron [8]. Multicrystal structure, 6 silicon bent strips (Fig.7), was installed in biaxial goniometer in U-70 circulating beam like a first stage of collimation system.

In experiment reduction of particle losses registered by ionization chambers downstream of collimator was observed during planar crystal rotation and this reduction was increased by vertical rotation (Fig. 8).

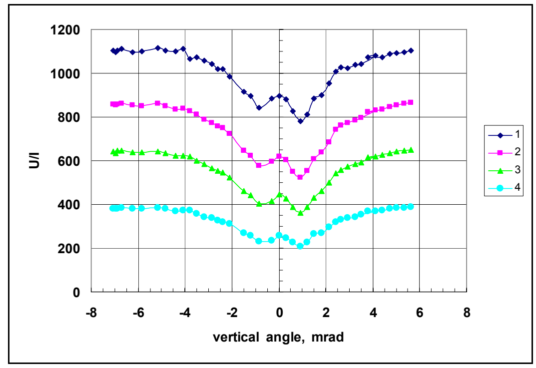

Figure 8: Reduction of particle losses of circulating beam downstream collimator versus vertical crystal rotation.

This effect is confirmed Monte Carlo simulations.

Thus the new method of beam steering was demonstrated, based on reflections of particles in multi-crystal enhanced by axial effect.

CONCLUSION

In this article we briefly describe the IHEP activity, which aims to use the crystals in the practice of extraction system, as well as to explore new aspects of the use of crystals for extraction and collimation. As a part of this topic we work closely with the international collaboration of UA9 at CERN [9] as well as with colleagues in the Ukraine [10]. Our activities are supported by the Directorate of High Energy Physics, the Russian Foundation for Basic Research (grant № 4.45.90.11, 1080 (Russia) and by SFFR grant № F40.2/092 (Ukraine).

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