BEAM EXTRACTION WITH USING OF VOLUME REFLECTION EFFECT IN CRYSTALS

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Abstract

The new possibility of the slow beam extraction from circular accelerators with using effect of volume reflection is presented in this work. The analytical and computation calculations show that efficiency of such extraction for UNK1 may achieve $\sim 95\%$ for two techniques differing by various orientations of the nuclear planes with respect to the beam. Unlike of traditional extraction with the help of channeling effect it is not so critical for angle alignment, thermal overloading, availability of perfection of crystal lattice and surface.

I. INTRODUCTION

Tendency of application of bent monocrystal for a slow extraction of a beam from circular accelerators with using channeling effect of particles [1,2] was recently scheduled. Main difficulties of such extraction are necessity of exact angular position maintenance of a crystal concerning a beam and use of high purity monocrystal with an ideal surface. By use of volume reflection effect the adjustment and work of a system is simplified, as the efficiency of extraction does not practically depend on angular alignment of target and quality of monocrystal manufacturing.

In this work two variants of plate crystal arrangement concerning a beam are investigated. In first (fig.1(1)) particles of a beam are stepsized normal to the nuclear planes, and in second in parallel (fig.1(2)).

As well as in case of conventional slow noneresonance extraction by a bump-magnets system or otherwise the particles of a beam are guided slowly to a target consisting from one or several bent monocrystal plates situated on a course of a beam. Deviating in a target on some angle the particles through some turns fall in a clearance of a septum and are extracted. During the extraction the part of particles leaves owing to their nuclear interactions with the crystal η_c, other fall on a septum partition η_s, and part put down on the equipment of accelerator η_a, that is value of complete losses: $\eta = \eta_c + \eta_s + \eta_a$.

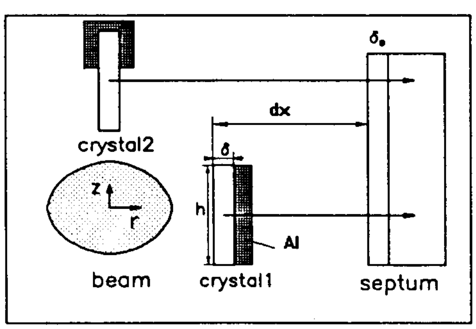

Figure. 1. The circuit of beam extraction for two variants of crystal arrangement.

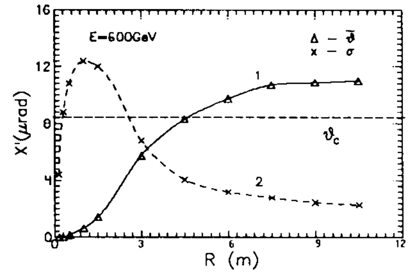

Figure. 2. Average angular deviation $\bar{\vartheta}$ (1) and root-mean-square scattering of protons σ(2) versus radius of curvature R of a crystal.

The optimum quantity of used crystals, from the view point of a losses minimum, depends on energy and sizes of a beam, thickness of a septum partition and longitudinal sizes of crystal.

We shall consider how volume reflection of particles in a bent monocrystal occurs. At hit of particles in a bent monocrystal body under the large angle to source nuclear planes they cross them so long as transverse energy will not become less than potential energy of nuclear plane eU_n, then they will be reflected from appropriate planes and will acquire a change of transverse energy $\Delta E < 2eU_n$. The average angular deviation of particles will be $\bar{\vartheta} < \sqrt{2} \cdot \vartheta_c$, and if on a course of a beam we shall put N bent plates, with radius of curvature considerably more than critical $\bar{\vartheta} \approx N \cdot \sqrt{2} \cdot \vartheta_c$. The dependencies of average angular deviation $\bar{\vartheta}$ (1) and root-mean-square scattering of protons σ(2) from radius of curvature R, received by the computer modeling at volume reflection of particles on the crystal Si(110), with the consideration of only nuclear planes potential, is indicated on fig.2.

The particles, which have the angle of fall with an external surface of bent monocrystal less than critical ϑ_c, will be reflected from it. Such particles at realization of a multiturn extraction will be less than 0.1%. The particles will be reflected from a crystal surface if size of impact parameter $\Delta < \vartheta_c^2 \cdot R$.

II. COMPUTER SIMULATION RESULTS OF EXTRACTION

The calculation of extraction was made with the help of program complex "SCRAPER" [3]. The trajectories of particles in a crystal were defined by the numerical decision of movement equations in field of bent nuclear planes in view of multiple Coulomb scattering on electrons and nucleuses, electromagnetic radiation and nuclear interactions. The movement of particles in an accelerator was simulated by matrix method. In computer experiment a halo proton beam is guided slowly toward the deflec-

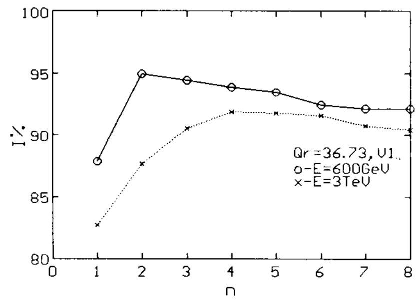

Figure. 3. Extraction efficiency versus quantity of used crystals in the first variant.

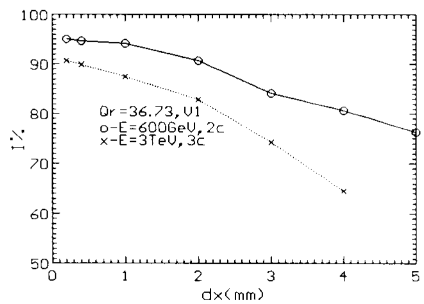

Figure. 4. Extraction efficiency versus displacement of a septum in the first variant.

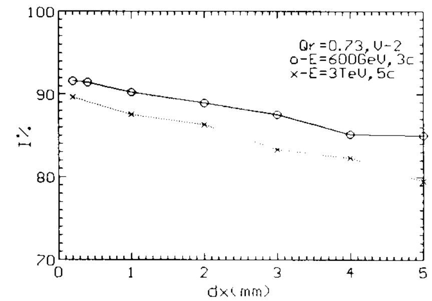

Figure. 5. Extraction efficiency in the second variant.

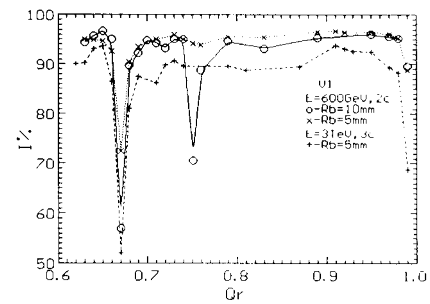

Figure. 6. Extraction efficiency versus frequency of betatron oscillations in the first variant.

tor. Computer modeling of extraction process has shown, that the most optimum from the view point of minimization losses, to use 2-3 silicon crystals of long 5mm each for the first stage and 4-5 for the second (fig.3) by use of electrostatic septum with thickness of 0.2mm.

Calculated dependencies of extraction efficiency from the displacement dx of a crystal from a septum (fig.1) for the first and second variant are shown on fig.4 and 5. The target needs to be put closer to a septum as in this case average number of particle passages through it decreases, that is drops η_c and impact parameter of particles on a septum is increased, that results in decrease of losses on it.

The extraction efficiency is also influenced with frequency of betatron oscillations (fig.6 and 7).

The heaviest extraction efficiency occurs in a region of the betatron oscillations frequency $Q_r \simeq 0.7 - 0.73$.

It is explained by that the particles scattered on a crystal fall through 4 turns on a septum with a reasonably large impact parameter. The significant increase of losses near to resonance lines of the betatron oscillations $Q_r \times m = n$ is observed, that is explained by that of a scattered particle through n turns will get on a phase plane almost in a same place and the impact parameter of particles on a septum decreases.

III. TARGET HEATING

At slow guiding of a beam on a target almost all particles fall on forward edge of a crystal by thickness a few microns. Whereas the length of a target on a beam much less nuclear and radiating,the energy deposition density of proton dE/ds is insignificant and is weak depends on its energy and length of target. Escaped heat stationary spread over to lateral surfaces of a crystal and is removed through the holders or substrate(fig.1) in case of target.

The value of the energy released into the crystal during slow extraction can be estimated as $\Delta E = dE/ds \times Il_c$, where $I = I_0 \bar{N}$ is the number of protons hitting the front surface, $\bar{N}$ -average number of proton passages through a crystal. If is not present heat removal, or in case of emergency at beam extraction for some dozens of turns, the heating of a crystal will be: $\Delta T = dE/ds \times \bar{N} I_0/\rho CpS$, where ρ and Cp - density and heat capacity of a crystal substance, S - its cross area. In our case the value $\bar{N} \simeq 1$ and if the total intensity beam $I = 6 \cdot 10^{14}$p is dumped on crystal with $S = h \times \delta = 10 \times 2mm^2$ its heating is $\Delta T \approx 1500^0$C that is even more than the melting temperature, Si ($T_{mel} = 1410^0$C), where h is height of a crystal, δ is its thickness. That is in emergency it is necessary to provide a beam abort, that a large part of beam intensity to extract from accelerator before interaction it with target.

We shall assume, that the beam particles cross the area of a crystal face by the size $\approx 2z$ in regular intervals, where z is half-size of a beam in a cross plane perpendicular to output. Then for the first variant of extraction, in case of removals warm through a substrate, the heaviest heating will be on edge:

$$\Delta T = \frac{dE/ds \cdot I\delta}{2t\lambda z}, \qquad (1)$$

Where λ - specific heat conductivity of a crystal.

Crystal Si (110) heat up to value $\Delta T \simeq 10°C$, at an extraction of complete beam intensity from UNK1 (z$\simeq$4mm) by duration

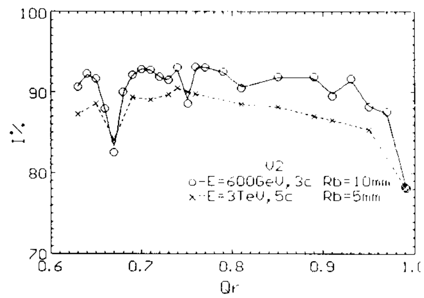

Figure. 7. Extraction efficiency versus frequency of betatron oscillations in the second variant.

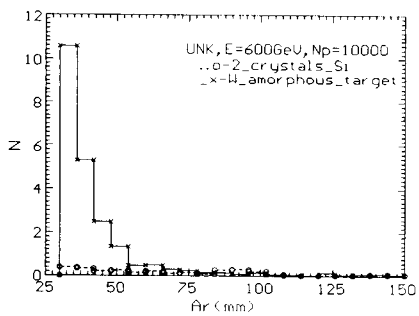

Figure. 8. The distribution of scattered protons on amplitudes on collimators and equipment.

t=20 second. In case of heat removal from lateral surfaces the value of a heating will increase in some times.

In the second variant of beam extraction, at good cooling of back surfaces of a crystal(fig.1), the heating as is insignificant - some dozens of degrees.

IV. ANOTHER USING

The effect of volume reflection in monocrystal can be used in a scraper system. Then by use of a bent crystal in as the scattering target the output of high energy protons from a system (target and scraper) can be reduced on the order, that it is very important in case of superconducting accelerator operation.

The appropriate distributions of protons on amplitudes, scattered from the system with Cu scraper and lost on the equipment and collimators UNK, are shown on fig.8.

V. CONCLUSION

Computer modeling has shown, that the efficiency of a beam extraction for UNK with use of volume reflection effect in the first variant of target arrangement will be $I \sim 95\%$ for the first and $\sim 90\%$ for the second stage, at effective thickness of a septum partition $\sigma = 0.2$. The losses of particles from the nuclear interactions in this case will be ~ 3 and 5%, and on septum partition less than 1 and 2% for first and second stage accordingly. At the second variant of a crystal arrangement the efficiency on some percents will be less than in first. Calculations have shown that by similar use of amorphous scattering target the total losses will increase more than in two times.

The heating of a crystal does not exceed some dozens of degrees at a beam extraction of complete intensity in twenty seconds .

References

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[3] I.I.Dyagterev, A.E.Lokhovitskiy, I.A.Yazynin, VI Russian conferences on radiation shielding of nuclear installations, Obninsk, 1994, v.3, page 218.