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On the Influence of Imperfect Surface of the Crystal Deflector on the Multiturn Extraction Efficiency*

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Abstract

Results of the computer simulation of the SSC beam halo multiturn extraction by the crystal deflector with imperfect surface are presented.

1.0 INTRODUCTION

One of the essential features of the bent-crystal extraction schemes proposed for multi-TeV machines[1−3] is a very small value of the impact parameter b of the beam-crystal interaction. The first interaction of the proton of the circulating beam occurs in a very thin layer of the crystal edge. The maximal impact parameter b_{max} of the first interaction is expected to be of the order of a few microns.[2,3] Protons are distributed in this parameter from 0 to b_{max}.

For this reason, an appropriate quality of the crystal deflector surface is required. A lack of flatness or a misalignment of the deflector surface relative to the beam direction would result in an inefficient layer near the crystal edge. Protons hitting the crystal too close to its edge cannot be extracted by this pass; they may be lost due to the nuclear collisions or they may be captured into the short bent planar channels (or "dashed" channels) and deflected on an inappropriate angle. The protons, if not lost in this layer, experience some scattering in the correlated or uncorrelated collisions with the crystal nuclei.

We shall present below the results of the computer simulation of the Superconducting Super Collider (SSC) beam halo multiturn extraction by the bent-crystal deflector with an imperfect surface.

2.0 SIMULATION

The simulation was carried out using a crystal deflector consisting of two parts: an ineffective layer with the thickness t, adjacent to the crystal surface (the "skin" layer), and a perfect part of the crystal.

The interaction of protons with the ineffective layer was treated in one of three ways:

1. the ineffective layer was considered as an amorphous one;
2. the same as above, but with additional scattering on the angles of the order of the critical one, θ_c, due to correlated collisions;
3. all the protons which hit this layer are lost.

For the particles incident to a perfect part, the probability of being channeled was calculated as a function of the incident angle, as was the probability of the dechanneling (insignificant here) along the crystal. The nonchanneled particles make a pass, as in amorphous matter, experiencing multiple scattering and some probability of the nuclear interaction.

The betatron oscillations of the particles in the accelerator ring were represented by the two-dimensional matrix with the betatron tune Q being some integer plus 0.29, the beta function $\beta = 517\,\mathrm{m}$, and the alpha function $\alpha = 0.68$.

The 4-cm silicon crystal with (110) alignment bent on 100 μrad was used for the 20-TeV beam extraction. The crystal edge was 1 mm from the beam center. The impact parameter of the first interaction was uniformly distributed between 0 and $b_{max} = 2\,\mu\mathrm{m}$.

The results of the simulation are presented in Table 1 for a wide range of the "skin" thickness t and the three options mentioned above.

TABLE 1. THE BENT-CRYSTAL EXTRACTION EFFICIENCY AS A FUNCTION OF THE IMPERFECT LAYER THICKNESS.

Option	$0.1\,\mu m$	$0.3\,\mu m$	$1\,\mu m$	$3\,\mu m$	$10\,\mu m$	$30\,\mu m$	$100\,\mu m$	$300\,\mu m$
noncorrelated collisions	0.94	0.93	0.87	0.77	0.71	0.59	0.32	0.10
correlated collisions	0.94	0.92	0.86	0.77	0.74	0.68	0.49	0.28
disappearance	0.90	0.80	0.46	0	0	0	0	0

3.0 DISCUSSION

As seen in Table 1, the third option is the most elementary one: the extraction efficiency is roughly a linear function of the t parameter. For $t > b_{max}$ the efficiency is zero. With the $t = 0.1\,\mu\mathrm{m}$ value for the well-polished surface, the efficiency would be near 90%, lower than the efficiency with a perfect crystal by about $t/b_{max} = 5\%$.

For the first two options, understanding the depth of the beam penetration into the crystal is important. Let us consider the particles of the beam halo in touch with the crystal. The proton scattered on the angle θ_s at the point of touch with coordinate x_0 will hit the crystal after a few revolutions in the ring somewhere on the corresponding phase ellipse arc. The maximal depth of its penetration into the crystal would be

$$b_{pen} = \sqrt{x_0^2 + \beta^2\theta_s^2} - x_0 \simeq \frac{\beta^2\theta_s^2}{2x_0} \,. \tag{1}$$

The b_{pen} value after a pass through 4 cm of amorphous silicon would be about $30\,\mu\mathrm{m}$. The correlated collisions with the scattering angle of the θ_c value order would lead to a

penetration up to 200 μm, namely

$$b_{pen} \simeq \frac{\beta^2 U_0}{x_0 E} , \tag{2}$$

where U_0 is the interplanar potential well depth and E is the beam energy. The nuclear interaction length L_N limits a maximal number of nonchanneled passes, and so limits the θ_s value. By this reason the beam could penetrate into the crystal depth up to the following value:

$$b_{pen} \simeq \frac{\beta^2 \epsilon^2 L_N}{2 x_0 E^2 L_R} , \tag{3}$$

if there were only uncorrelated collisions in the "skin" layer; here $\epsilon = 14\,\mathrm{MeV}$ and L_R is the radiation length. The above estimate is about 200 μm. A larger angle of scattering due to the correlated collisions enlarges this estimate by a few hundred microns.

The above estimates explain the very slow dependences in the first two options in Table 1. A considerable change in efficiency occurs only when the t ("flatness") parameter crosses the b_{max} and b_{pen} values. The larger scattering angle means larger penetration; for this reason in the $t > 10\,\mu$m region the dependence in the first option significantly exceeds the dependence in the second option.

The dependence in the second option should be more realistic. For the $t = 0.1\,\mu$m value the extraction efficiency is only 1% smaller than the efficiency for a perfect crystal, being larger than 90%.

The $b_{max} = 2\,\mu$m value used in this simulation is rather conservative. The RF-noise methods of the halo generation can provide us with the value of the order of 10 μm.[2]

Another scheme has been discussed[4] using two crystals. The first crystal (an ultrathin one of 50 μm longitudinal size) works as a scatterer, and the second one (bent crystal) works as a septum. The two-crystal scheme could provide us with the b_{max} value of about 100 μm (with a Si scatterer), or 400 μm (with a W scatterer). Note that in our simulation the ineffective layer was playing the role of this scatterer.

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