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A STUDY ON IMPLEMENTATION OF MULTISTRIP CRYSTALS TO PROTECT THE SEPTUM-MAGNETS AND TO GENERATE THE GAMMA RADIATION ON THE U-70 ACCELERATOR

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Abstract

Recently started studies on the application of volume reflection of particles in crystals for the steering beams (for extraction and collimation of a circulating beam in accelerators). Volume reflection is more efficient than channeling, but requires amplification of the deflection angle by applying multicrystals. The report discusses two new applications of multicrystals made like multistripe structures: 1. The property of effective deflection of particle beam was used to protect the septum-magnets of the U-70 in the process of extraction of the proton beam with energy of 50 GeV. 2. The possibility of generation of gamma radiation was studied in the secondary electron beam with energy of 7 GeV. In both cases, promising preliminary data were obtained.

INTRODUCTION

Important in the physics of interactions of charged particles with single crystals was E. Tsyganov's proposal [1] to use bent single crystals to rotate positively charged particles. It turned out that the processes of interaction of particles with bent single crystals differ from processes in straight crystals. Thus, the so-called phenomenon of volume reflection [2.3] of a particle beam from bent crystallographic planes was discovered. In addition, the radiation of electrons and positrons in the plane fields of bent single crystals was predicted [4] and then measured [5], which accompanies the process of volume reflection. These two phenomena were the basis for our experimental study.

The physics of the process consists in the fact that at certain angles of entry of particles into the crystal with respect to the crystallographic planes, these particles are reflected from these planes. However, even under optimal conditions, the mean reflection angle (the mean angle of volume reflection) does not exceed 1.5 critical channeling angles (i.e., relatively small). Despite this fact, the process of volume reflection is of some interest because it has a high efficiency of reflection. When the reflected particle moves, its transverse coordinate in the plane of the bend undergoes apereodic oscillations. Due to this character of motion, the electron (positron) involved in the process emits gamma quanta. A theoretical description of this radiation process can be found in the papers [6, 7]. The first experiment to detect such radiation was performed at electron energy of 10 GeV [8] and showed satisfactory agreement with the calculations.

The present experiment is devoted to the study of scattering (volume reflection) of 50 GeV protons and radiation losses of energy by 7 GeV electrons in a multistrip crystal deflector.

MULTISRIP CRYSTAL DEFLECTOR

The appearance of the prepared multistrip crystal device is shown in Figure 1. The device comprises 24 bent crystals in the form of bent strips. The method of bending several strips in one holder was developed in experiments on volume reflection of proton and negative pion beams [9]. Six strips along a beam of 2.5 mm each reinforce the radiation effect, and four layers of 0.5 mm across the beam provide the necessary transverse dimension of 2 mm (thick crystals cannot bend to the required angles, so a sandwich is needed). After optical verification, the device was placed in a two-axis goniometer . The bending angle of each strip is 1.1 mrad. It is larger than the Coulomb scattering angle of electrons with energy of 7 GeV on a chain of six crystals, which is equal to 0.8 mrad.

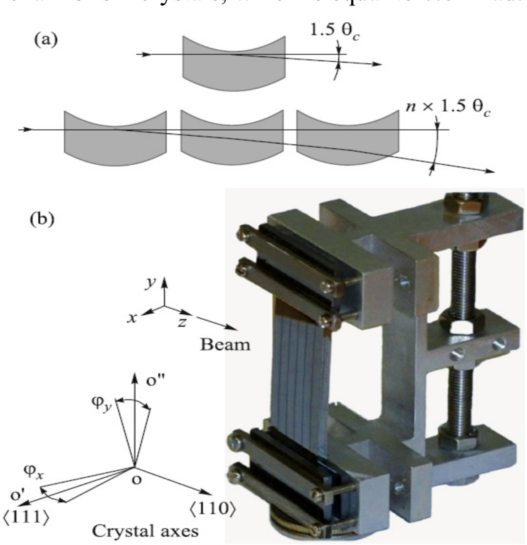

Figure 1: Multilayer crystal radiator for the beam: (a) the schematic of operation and (b) the appearance and arrangement with respect to the beam.

For each individual strip, its characteristics for deviation and ability to radiation were calculated. So according to these calculations, the average reflection angle of

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50 GeV of the proton beam for the 2.5 mm silicon strip (in the (111) plane) is 38 μrad, and for 7 GeV electrons 81 μrad.

We also calculated radiation losses of 7 GeV electrons in the plane fields (111) of a bent silicon single crystal (see Fig.2). The calculation was performed for two different thicknesses along the beam equal to 2.5 and 15 millimeters. In fact, energy losses for radiation in bent and straight single crystals represent the sum of two terms of the coherent and incoherent [10]. The coherent term is due to the interaction with the electromagnetic field of the crystal, while the incoherent term is due to the interaction with the individual atoms of the crystal. Moreover, the incoherent term does not depend on the orientation of the beam relative to the crystallographic axes. We can assume that this term is approximately equal to the energy loss in amorphous silicon.

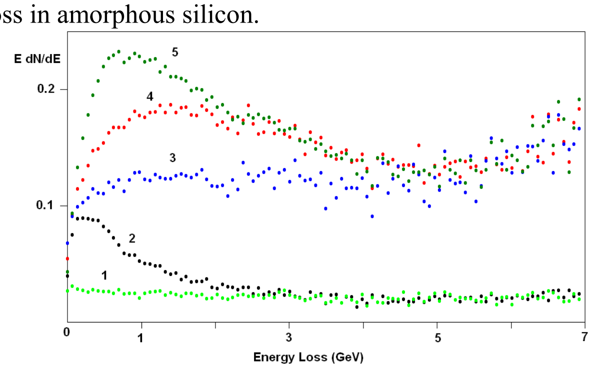

Figure 2: The calculated energy losses:1) in one 2.5 mm long nonoriented strip; 2) in one strip oriented in planar orientation; 3) in nonoriented multistrip, 4) in single crystal with the thickness 15 mm:; 5) multistrip with 6 strips in planar orientation.

The calculations were performed by the Monte Carlo method. Thus, the calculated total energy losses (integrated over energy) are equal to 0.158, 0.229, 0.878, 1,072 и 1.148 GeV for the curves 1-5, correspondingly. In the accordance of these calculations the radiation energy losses are most large in the multistrip crystal..

EXPERIMENTAL SETUP

The experiment was performed in the 4a beamline of the U70 accelerator (Fig. 3). The 7-GeV electron beam with an intensity of ~10^4 per cycle was guided to the crystal device placed in the goniometer. The step of the horizontal and vertical rotation of the goniometer was 0.02 mrad. A telescope of scintillation counters S_1, S_2 , and S_3 separated a fraction of particles entering the crystal radiator and formed an angular divergence of $\sigma_x \sim$ 0.5 mrad and $\sigma_y \sim$ 1 mrad. The last counter had a 2x30-mm cross section, coinciding with the cross section of the crystal assembly; it was mounted on the end of the radiator and could be displaced with it in the goniometer owing to a fiber optic connection to a photomultiplier. A vertically deflecting magnet M with a magnetic-path length B_l = 0.33 T×m separated the emitted photons and interacting electrons. A 5-mm-step scintillation hodoscope with the recording of information on the hodoscope photomultiplier could spectroscopically measure the energy of electrons. The energy of photons was measured by a leadglass calorimeter C_2 20 radiation lengths long. A miniature calorimeter C_1 with transverse dimensions of 10x20 mm and a length of 7 mm made of CeF_3 heavy scintillator was used as the first step of detection (so-called pre-shower detector) for the rejection of the background. For the arms of increasing of the efficiency of detection of photons the 5 mm tungsten converter Cw (standing before C_1) was used in some measurements. In addition, it was used for the fast adjustment of the planar and axial orientations of the crystal targett.

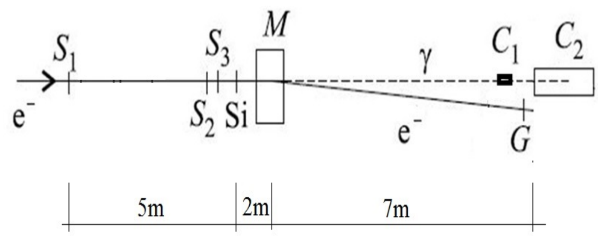

Figure 3: Schematic of the Crystal setup: (S_1–S_3) scintillation counters, (C_1, C_2) calorimeters for the determination of the energy of generated photons, (G) hodoscope for the determination of coordinates of electrons behind the magnet and (Si) crystal in goniometer.

The experimental set up was insignificantly changed for measurements with the use of 50 GeV proton beam. The magnet M was switch of and electromagnetic calorimeters were removed from beam line. The special scanning scintilator counter (placed on distance 7 meters after multistrip crystal) was used for measurements beam profiles in the horizontal plane. Proton beam was extracted from accelerator with the help standing in the vacuum chamber (in 27 accelerator block) of the silicon crystal deflector with the bending angle equal to 89 mrad. The proton beam has sizes about 1cm in the both transverse planes. We used in measurements the relatively small intensity equal to 10^5 protons per cycle. The coordinate sizes (horizontal and vertical) of proton beam were about 1 cm on the crystal device.

THE EXPERIMENTAL RESULTS

Reflection of the 50 GeV Proton Beam

The horizontal coordinate distributions of 50 GeV proton beam were measured with help of scanning counter for two orientations: a) disoriented and b) oriented in the maximum of planar volume reflection. Fig. 4 illustrates the results of these measurements. For every orientation the coordinate of centre of distribution was found. Accordingly to measurements the difference of distribution centres was equal to 1.1 mm. It is easy to see that such value of displacement corresponds to deflection angle of the beam equal to 0.16 mrad. The maximal theoretical value of this angle is equal to 0.038x6= 0.228 mrad. Thus

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we can conclude about satisfactory agreement between experiment and theoretical expectation.

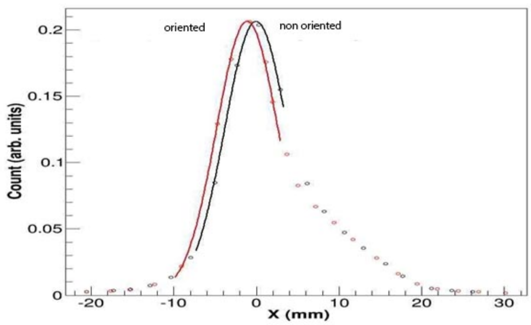

Figure 4: The beam profiles in orientation and nonoriented cases.

Measurement the Radiation Energy Losses of 7 GeV Electron

The value of radiation energy losses of beam of the 7 GeV electrons in multi strip crystal was investigated as a function of energy for the three orientations. In the experiment the value T_1/T_0 was measured where T_1 is the coincidence of counters S_1 S_2 S_3 C_1 C_2 and T_0 is coincidence of counters S_1, S_2, S_3. The energy loss for every event (defined by the relation T_1/T_0) was determined with the help of C_2 calorimeter.

It is easy to see that T_0 is the number of electrons passed through the multistrip and S_1, S_2, S_3 counters. In the multi strip, some of the electrons emit photons, which are recorded with calorimeters C_1 and C_2. Then all electrons deflected by the M magnet. However, some part of the emitted photons moving from the multistrip into C_1-calorimeter is lost due to geometrical reasons. Taking into account that for photon energies above 0.2 GeV [11], the detection efficiency of photons with a C_1 calorimeter is independent of their energy, therefore some of the lost photons are determined by the geometrical parameters of the electron beam and do not depend on energy.Thus, the value T_1/T_0 determines the form of the distribution of the radiation energy losses.

The first preliminary results of this experiment were published in the paper [12]. Here the measured quantities of radiation energy losses were presented in relative units. This paper presents experimental data as a probability density function per one electron passed through a multistrip device. The results based on calculation of radiation energy losses in the non-oriented single crystal. Such energy losses are similar to radiation energy losses in an amorphous medium

The results of measurements of radiation energy losses of 7 GeV electrons in natural (absolute) scale are presented in Fig. 5.

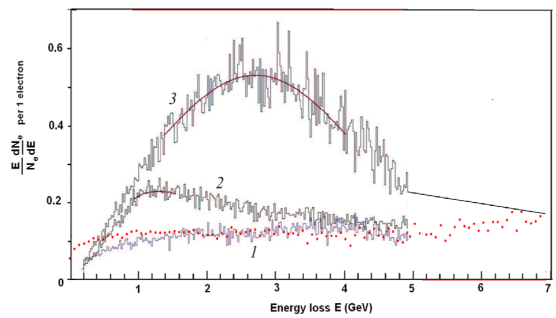

Figure 5: Measured distributions of energy losses of 7 GeV electrons in the multistrip device: the curves 1, 2 and 3 are for the cases of non-oriented, planar orientation and axial orientation, correspondingly. The red points are calculation for non-oriented case.

It should be noted that the dynamic range of measurements in the C2 calorimeter limited the radiation loss energy to 5 GeV. However, from theoretical estimations and from Fig. 5 one can see that at energy losses more than 5 GeV all the curves have approximately the same meaning. From Fig. 5 we see that the form of experimental curve for non-oriented crystals in a good agreement with the theoretical calculation. From here we find the absolute scale of radiation losses of energy. Small difference between curves (experimental and theoretical for non-oriented crystal) at small energies less then 1 GeV one can explain more wide propagation of electromagnetic shower in transverse space in comparing with more energy losses. According our estimation the influence of energy resolution of calorimeter on the form of curve is weak. Thus we can find the mean radiation energy losses for various orientation of crystal. They are 0.889 GeV for the curve 1, 1.19 GeV for the curve 2 and 2.65 GeV for the curve 3.

DISCUSSION

In presented paper the interaction of high energy particles with multi strip crystal device was investigated experimentally. It was demonstrated that observed in measurements effects (as reflection and radiation power) increase in this device. The measured increasing is less than multiplication of the number strips on the value for one strip. For reflection this result was considered previously in the corresponding section. For radiation it also follows from our measurements. So, for one strip the calculated value of energy losses for planar orientation is equal to 0.229 GeV. The multiplication is 6*0.229 = 1.374 GeV. This is not much more than measured value equal to 1.19 GeV.

We propose to use the reflection of proton beam in multi strip for protection of septum magnets on accelerators and for collimations of electron, positron and high energy photon beams on the future electron-positron colliders.

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