Abstract

Bent crystal can effectively deflect charged particle beam by means of coherent effects in the electric field of crystal lattice. Since this field is more than one order of magnitude stronger than the field that can be achieved in modern superconducting magnets, a bent crystal can be considered as a very perspective accelerator element. It can be applied in particular, for crystal-based extraction or collimation purposes. Moreover deflection in strong cristalline electric field is very promising for generation of intense electromagnetic radiation.

Therefore the development of the new schemes for high efficiency steering of charged particles by means of coherent effects is of crucial importance for accelerator physics. In this work the new schemes are proposed and developed. These schemes are studied through computer simulations by specially developed CRYSTAL simulation code. Moreover, some of them are verified experimentally, not only giving an insight into the physics of coherent interactions in a bent crystal, but also providing a feedback concerning simulations reliability.

The CRYSTAL simulation code has been designed to calculate charged particles trajectories in interplanar or interaxial electric field taking into account incoherent scattering on both nuclei and electrons. The advantage of this code is simulations of suppression of incoherent multiple scattering due to the presence of crystal structure. Moreover, the code supports the varying the initial parameters, allowing one to calculate a set of data for a set of values of initial parameters during only one run of the code. MPI parallelization allows one to apply the code at supercomputers, though a lot of cases can be calculated at a personal mashine. This code was applied for simulations of all the coherent effects, studied in this work.

Different schemes of steering of protons at the Future Circular Collider energy of 50 TeV were studied, simulated and optimized, in particular, the effects of volume reflection, multiple volume reflection in one bent crystal (MVROC) and in a sequence of bent crystals. Another importan scheme was the combination of the planar channeling effect and MVROC by means of channeling in skew crystal planes. This allows one both to increase the angular acceptance of channeling and to apply MVROC to the particles not captured under the channeling conditions. The bent crystal in this case will work also as a beam splitter. Moreover channeling itself can be amplified by the application of the narrow plane cut, reducing the phase space of positive channeling particles. It was shown, that the combination of this effect with channeling in skew planes allows one to achieve the deflection efficiency up to 99.9%.

In this work channeling and volume reflection of sub-GeV electrons in a bent crystal is also studied both experimentally and by simulations. A record channeling efficiency of 40 % of 855 MeV electrons in a silicon bent crystal at Mainzer Mikrotron MAMI is reported. This becomes possible by the application of ultrashort bent crystal of 15 μm, considerably reducing the incoherent scattering contribution with respect to all the cases previously considered. Moreover, the first evidence of negatively charged particle channeling in germanium bent crystal at sub-GeV energies is reported. For both cases the measurements of dechanneling length, channeling efficiency and the volume reflection angles were carried out. The results are in agreement with theory and simulations.

New effects, related to the planar channeling process, are predicted, namely planar channeling and quasichanneling oscillations in the deflection angle distributions. The idea of these effects consists in transformation of oscillations of a particle, being under channeling conditions, or of an over-barrier particle, moving still at rather small angle w.r.t. a crystal plane, into a series of peaks in the angular distribution of the beam deflected by a bent crystal. Planar channeling oscillations in the deflection angular distribution represent themselves by equidistant peaks and can be revealed only for positive particles. The quasichanneling oscillations are represented by non-equidistant peaks and can be observed for particles of either sign. The theoretical model of both kinds of peaks was created and verified by simulations.

Moreover the first experimental observation of planar quasichanneling oscillations is reported for both 20.35 GeV electrons and positrons. The experiment was carried out at the SLAC Facility for Advanced Accelerator Experimental Tests. The measured peak positions were in agreement with both theory and simulations by the CRYSTAL code.

Both kinds of oscillations can be applied for measurement and adjustment of the crystal alignment in order to reach higher channeling efficiency. In particular the fitting procedure of the peak positions of quasichanneling oscillations, carried out in this work, allows one to measure both crystal alignment and its curvature by using only one deflection angle distribution.

All the results of this work are relevant for the application of bent crystals in future accelerator and collider projects for beam collimation and extraction purposes as well as for intense electromagnetic radiation generation.