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Alexander Petrovich Potylitsyn
Mikhail Ivanovich Ryazanov
Mikhail Nikolaevich Strikhanov
Alexey Alexandrovich Tishchenko

Diffraction Radiation from Relativistic Particles

Springer

Prof. Alexander Petrovich Potylitsyn
Tomsk Polytechnic University
Lenin Ave. 30
634050 Tomsk
Russia
pap@interact.phtd.tpu.ru

Prof. Mikhail Ivanovich Ryazanov
National Research Nuclear University
MEPhI
Kashirskoe Sh. 31
115409 Moscow
Russia
ryazanov-m@mail.ru

Prof. Mikhail Nikolaevich
Strikhanov
National Research Nuclear University
MEPhI
Kashirskoe 31
115409 Moscow
Russia
MNStrikhanov@mephi.ru

Prof. Alexey Alexandrovich
Tishchenko
National Research Nuclear University
MEPhI
Kashirskoe Sh. 31
115409 Moscow
Russia
tishchenko@mephi.ru

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Foreword

This monograph presents the results of theoretical and experimental investigations of diffraction radiation accompanying the motion of charged particles near a conducting surface. The foundations of the theory of diffraction radiation are systematically presented for the first time. Particular attention is focused on radiation from periodic structures (Smith—Purcell radiation). Although some results refer to the nonrelativistic and moderately relativistic cases, the major part of the monograph is devoted to radiation generated by relativistic and ultrarelativistic charged particles and from bunches of these particles. The experimental results on diffraction radiation are presented in comparison with the theory. The problems of the application of diffraction radiation to non-invasive diagnostics of charged particle beams in modern accelerators are discussed. The monograph is addressed to researches in such fields as electromagnetic radiation and the accelerator physics. It also can be useful for higher year and postgraduate students.

Tomsk-Moscow, October 2009

Alexander Petrovich Potylitsyn
Mikhail Ivanovich Ryazanov
Mikhail Nikolaevich Strikhanov
Alexey Alexandrovich Tishchenko

Preface

Diffraction radiation appearing in the optical range when charged particles move in vacuum along a periodically deformed surface (grating) was observed for the first time in the early 1950s by S.J. Smith and E.M. Purcell [1]. This radiation was theoretically predicted by I.M. Frank in the early 1940s [2]. In the next two decades, this type of radiation was investigated in detail on beams of nonrelativistic electrons in the centimeter wavelength range. At the same time, theoretical methods were developed for calculating the characteristics of diffraction radiation for various configurations of measuring instruments and various parameters of a beam. A new field appeared in microwave electronics [3] and development of this field actively continues to date [4, 5].

At present, it has been shown that the intensity of visible and ultraviolet diffraction radiation generated by relativistic particles can be comparable with the intensity of transition radiation, which is widely used in high energy physics and accelerator physics. In contrast to transition radiation, diffraction radiation is not accompanied by the direct interaction of beam particles with a target and this circumstance opens prospects for non-invasive diagnostics of beams in modern accelerators.

Diffraction radiation can be used to analyze the structure of micron objects for which traditional X–ray methods are ineffective because of the absence of X–ray lenses with the required luminosity.

We point to the potentialities of coherent diffraction radiation generated by a beam of moderately relativistic electrons that are grouped into bunches shorter than 1 mm. In this case, the radiation spectrum covers the terahertz range, which is of considerable interest for applied investigations in physics, chemistry, and biology [6].

Diffraction radiation generated by relativistic particles is presented very briefly in modern monographs. Monographs [3] and [4] are completely devoted to diffraction radiation generated in periodic structures by nonrelativistic electrons. Among other problems, some applications of diffraction radiation generated by both nonrelativistic and relativistic particles were considered in monograph [5], but with emphasis on the specific features of microwave instruments (modulation of a beam in the process of its interaction with a target, comparatively low energies of the beam particles, and nonlinearity of physical phenomena), whereas the problems of diffraction radiation itself and modern experimental results in this field remained beyond the scope of that monograph. In each of more general monographs [7, 8] devoted to radiation generated by fast charged particles in a medium, diffraction radiation is discussed only in one section. At the same time, there are many theoretical and experimental studies, where the application of diffraction radiation to non-invasive diagnostics of electron beams and bunches is justified and the corresponding experimental methods are developed. This circumstance stimulates interest of both theorists and experimentalists in the properties of diffraction radiation.

Successes achieved in the past decade in this field of physics lead to significant progress in the investigation and application of diffraction radiation. In this monograph, we review the current status of theoretical and experimental investigations of diffraction radiation generated by ultrarelativistic particles.

Diffraction radiation is very close in nature to transition radiation. Indeed, both kinds of radiation can be treated as radiation from dynamical polarization currents induced in the target material by the Coulomb field of moving charged particles. However, in contrast to well-studied transition radiation, the situation with diffraction radiation is much more complicated, because the expressions for transition radiation (at least, widely known Ginzburg-Frank formulas) are derived for an infinite planar interface and for the far zone (wave zone or Fraunhofer zone in the optical terminology). However, diffraction radiation always implies a much more complex interface. As known, the strict solution of boundary value problems with complex boundary conditions involves significant mathematical difficulties. A number of physical approximations are usually used in real problems, e.g., in physical optics; they make it possible to obtain the results acceptable for applications (see, e.g., the wonderful monograph [9], where the approaches for solving diffraction problems of current interest in stealth technologies are analyzed). For this reason, many approaches presented in this book are different from each other and are based on some physical approximations. These approaches are obviously of interest for researchers working in this field and related fields; in addition, they are useful for young physicists to develop scientific insight into solving particular physical problems by the methods of classical electrodynamics.

Addressing to theoretical and experimental physicists, we aim to strictly justify the approaches used and briefly presenting recent experimental results. We hope that the monograph helps young researchers to acquire knowledge for active investigations in this field.

The problems concerning the effect of currents induced in the target on the characteristics of the beams are not included because of a limited volume of the monograph. Experimental data indicate that such a simplification is justified when energy loss to radiation is much lower than the kinetic energy of the beam. This simplification allows us, on the one hand, to avoid the inclusion of nonlinear phenomena and, on the other hand, to develop the foundations of non-invasive diagnostics of charged particle beams.

The list of references presents available studies used for writing this monograph.

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Alexander Petrovich Potylitsyn
Mikhail Ivanovich Ryazanov
Mikhail Nikolaevich Strikhanov
Alexey Alexandrovich Tishchento

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