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Nuclear Instruments and Methods in Physics Research B 254 (2007) 319–328

NIM B
Beam Interactions with Materials & Atoms

www.elsevier.com/locate/nimb

Electron beam monitoring for channeling radiation measurements

W. Neubert, B. Azadegan [1], W. Enghardt [2], K. Heidel, J. Pawelke, W. Wagner *

Forschungszentrum Rossendorf, Institute for Radiation Physics, P.O. Box 510119, 01314 Dresden, Germany

Received 8 June 2006; received in revised form 23 October 2006
Available online 2 January 2007

Abstract

A secondary emission monitor and an auxiliary Faraday cup necessary for calibration purposes have been constructed and installed at the radiation physics beam line of the electron accelerator ELBE. These devices are to be applied for the precise beam-current monitoring in measurements of channeling radiation. Miscellaneous simulations of underlying interactions of the beam electrons with the target material as well as with the materials of the monitor equipment have been performed to optimize the design and to evaluate possible correction factors inherent to transmission monitoring.

PACS: 41.75.Fr; 41.75.Ht; 79.20.Hx; 61.85.Fe

Keywords: Electron beam monitor; Secondary electrons; Channeling radiation

1. Introduction

The basic device of the radiation source ELBE [1] is a superconducting electron accelerator which provides brilliant electron beams for the production of different types of secondary radiation.

Recently, a setup for the generation of channeling radiation (CR) [2] has been commissioned [3]. It aims at further studying of the fundamental properties of CR [4] and, above all, serves as a prototype apparatus for a novel quasi-monochromatic X-ray source intended to be used for irradiation purposes in radiobiology research [5].

The effective generation of CR in general requires a beam with a sufficiently small transverse emittance. This includes an optimized beam transport from the accelerating cavities to the target station. The trajectory of the electrons through the source crystal is considerably influenced by multiple scattering. Consequently, downstream the target, a substantial broadening of the beam profile occurs. This is caused by the increase of the beam divergence, and the effect grows with increasing crystal thickness.

To observe CR at zero degree with respect to the beam direction, after passing the crystal, the electrons have to be deflected by a bending magnet and fed into an appropriate beam dump usually situated far away from the CR source. At low electron energies, the beam transmission from the target into the beam dump may take values far below 100% [6]. The measurement of absolute CR yields, however, requires a precise beam monitoring. The determination of the effective electron current through the crystal by monitoring the current at the beam dump may easily become incorrect, because even slight instabilities of the electron beam can effect relatively large variations of the transmission.

Since the ELBE facility is mainly designed to drive free-electron lasers, where one operates at beam currents of the order of 1 mA, most of the installed beam-current monitors are induction devices, which are sensitive to currents of $\geqslant 1\ \mu A$. At CR spectrometry, however, the average beam

* Corresponding author. Tel.: +49 3512602354; fax: +49 3512603700.
E-mail address: w.wagner@fz-rossendorf.de (W. Wagner).
[1] On leave from School of Sciences, Tarbiat Moallem University of Sabzevar, Iran.
[2] Present address: Technische Universität Dresden, Radiation Research in Oncology, OncoRay, P.O. Box 86, 01307 Dresden, Germany.

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doi:10.1016/j.nimb.2006.11.053

current typically ranges between 1 nA and several tens of nA. These specific conditions of CR measurement required the development of a transmission-type beam-monitoring system positioned immediately behind the source crystal. It should influence the beam transport insignificantly and has to be capable of measuring absolutely the beam current which actually passes the target.

In the following, we shall focus on the experimental conditions at the radiation physics beam line of ELBE, describe the design and construction of a secondary emission monitor, explain the calibration procedure by means of an auxiliary Faraday cup, and exemplarily demonstrate the feasibility of this device for CR-yield measurements [7].

2. The radiation physics beam line at ELBE

For the reason of radiation protection, the CR setup is not situated inside the accelerator hall of ELBE, but in a special cave separated from that by an about 2.6 m thick concrete wall. A schematic drawing of the beam-line elements of the radiation physics cave is shown in Fig. 1.

The electron-optical beam-transport system to this cave consists of a switching magnet, which defines the beam energy (E_e), and an adjacent achromatic setup of quadrupole lenses including another bending magnet (Dipole 1 in Fig. 1). It had to be optimized (i) to avoid beam losses, (ii) to focus the electron beam at the target station to a spot of diameter ≈1 mm, and (iii) to sustain a beam divergence of ≈0.1 mrad (rms) [9]. This was obtained by introducing a set of additional diaphragms into the low-energy injector stage of ELBE. In this way, the transverse emittance of the electron beam was reduced to ≃3π mm mrad (rms). The maximum available beam current, however, is limited to a value of about 100 μA.

For the purpose of beam setting, an 18 μm thick Al foil can be moved into the target position. It serves as a screen for the production of optical transition radiation (OTR) which is viewed by a TV-camera to watch the beam spot. Furthermore, this screen is used for the measurement of the beam emittance by means of the quadrupole-scan method [10]. Depending on the electron energy, the beam transmission through this foil to the beam dump typically amounts to (75–95)%.

The alignment of the crystal employed for CR production is accomplished by means of a goniometer which, at our setup, operates inside a dedicated goniometer chamber at the ultra-high vacuum (UHV) of the accelerator [11]. Since the diamond crystals utilized are considerably thicker than the above mentioned Al foil, namely between 42.5 and 500 μm [7], the beam transmission to the beam dump partly drops down to values of less than 10%. As has been established by means of simulations performed using the code GEANT 3.2, the beam divergence initially amounting to ≈0.1 mrad is modified due to multiple scattering in the crystals to values between 47 and 157 mrad, respectively.

As a consequence, a fraction of the beam electrons is scattered to the walls of the beam line [12]. Furthermore, this effect is increased by the dispersion of the second bending magnet (Dipole 2 in Fig. 1). In order to diminish beam losses as far as possible, the inner diameter of the adjacent beam tube downstream the goniometer chamber was successively enlarged from initially 40 mm to finally 100 mm, and an additional quadrupole doublet was inserted for transmitting a maximum fraction of the highly divergent beam into the beam dump.

It should also be mentioned that incomplete beam transmission to the beam dump results in an uncontrolled source of bremsstrahlung and neutron background which is highly undesirable in some investigations of the radiation damage of biological objects [5].

3. Transmission monitoring of the electron beam current

A common method of precise electron-beam monitoring consists in the installation of a very thin transmission device directly behind the target used for radiation production.

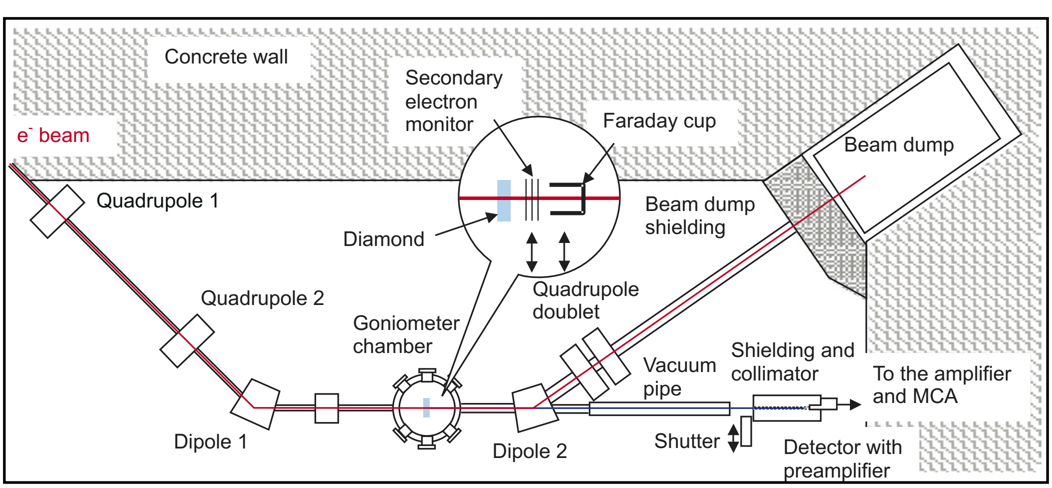

Fig. 1. Schematic drawing of the experimental area at ELBE [8].