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Evaluation of the doctoral thesis by Kacper Łasocha

With pleasure, I reviewed and evaluated the doctoral thesis by Kacper Łasocha, entitled "Non-invasive Beam Diagnostics with Schottky Signals and Cherenkov Diffraction Radiation". The thesis was executed at the CERN accelerator facility under the supervision of Dr Diogo Miguel Louro Alves (CERN Geneva) and Prof Dr hab. Elzbieta Richter-Was (Jagiellonian University Kraków). Kacper Łasocha spent a significant fraction of the time for the thesis preparation at CERN within a close collaboration of members of the Accelerator Beam Instrumentation Group, as part of the Accelerator and Technology Sector.

The thesis describes relevant measurement technologies for particle beam diagnostics to be applied at circular accelerator with an application at CERN's LHC and single-pass beam transfer lines with test measurements at CERN's CLEAR facility. Innovative solutions are proposed, technically designed and tested with beams. The thesis describes the physical basis of the related methods, and the results are interpreted very competently concerning all relevant technical and physical aspects. The results were published in conference proceedings and high-impact referred journals. Two different methods are described, which are only loosely connected; however, this shows that Kacper Łasocha contributed significantly to progress in beam instrumentation related to two different topics.

The preface contains a good overview of the work executed by Kacper Łasocha where the scientific progress he achieved can clearly be distinguished from work executed beforehand. Publications with him as a main or co-author are listed. In particular, two refereed papers were published besides several conference proceedings for Schottky signal analysis. Moreover, Kacper Łasocha contributed to the progress of physics on subjects not related to the topics described in the thesis.

Chapter 1 acts as an introduction to the topic of particle accelerators, starting with a brief historical introduction to hadron and electron accelerators. Basic beam parameters and the related beam instrumentation for their diagnostics are introduced. (One minor criticism to a statement on page 9: The phrase 'natural chromaticity' is typically used in the sense that no correction, e.g. by sextuples, is applied, which is not clearly expressed by the chosen wording.) The chapter finished with a description of the beam diagnostics scopes concerning Schottky signal analysis and application of Cherenkov radiation, a very actual topic in beam instrumentation. Chapter 2 contains all descriptions concerning the Schottky signal analysis, while Chapter 3 concerns the Cherenkov Diffraction Radiation (ChDR) investigations.

Schottky Signal Analysis

Schottky signals have been used frequently for beam diagnostics since the 1970ies at proton or ion synchrotrons and storage rings, mainly for coasting beams. It offers a versatile method to determine the revolution frequency, momentum spread, tune, chromaticity etc. and their evolution during acceleration and possible cooling processes. The spectra might become relatively complex for bunched beams due to the interference effects of coherent and 'incoherent contributions as well as the amplitude and phase modulation. The goal of the thesis is related to a mathematical description of the spectra for bunched beams and the numerical evaluation of relevant beam parameters.

Besides a general introduction in Chapter 2.1, Chapter 2.2 introduced the well-known theory of longitudinal and transverse Schottly spectra for bunched beams for particles with constant synchrotron frequencies and no intra-bunch interaction between particles. As one result, the analytic solution of spectral shape is calculated for an arbitrary synchrotron amplitude distribution. Even though the formulas were also derived in earlier publications, the presented derivation of the related formulas is well formulated, presented consistently, and discussed competently. The chromaticity is related to the spectral width by a precise mathematical definition. It is clearly stated that the formulas can only be applied if interactions between the beam particles are neglected. It would have been valuable for the reader if an estimation of the related beam properties of LHC were given in the thesis as significant modification of the Schottky spectra appears for dense low energetic particles and cooled beams; related citations are given but not discussed in the thesis.

In Chapter 2.3, a formalism is developed for the first time, taking the discretization of the measurement into account for the determination of relevant parameters like synchrotron frequency, tune and chromaticity, and the synchrotron amplitude distribution using well-defined numerical methods. A novel approach to determining the synchrotron amplitude distribution is described in the thesis.

In Chapter 2.4, the mathematical methods are applied to the measurements at LHC top energy. Best fit values are calculated from the measurements, and numerical requirements are discussed appropriately. The accuracy and convergence of several numerical realizations are depicted and discussed in detail using the concept of cost functions; the implementation of the numerical fit algorithm is a significant part and well executed in the frame of the thesis. Detailed comparisons to measurements using the LHC Schottky Monitor operated at 4.8 GHz are described, and the accuracy of the fit methods is depicted. Results are compared to measurements of the same beam parameters using traditional techniques. Contrary to these traditional methods, Schottky signal analysis does not influence the beam in any manner; the thesis aims to enable automated measurement for the regular operation of LHC. In Chapter 2.5, the improvement related to the hardware gating of individual bunches is discussed to enable more precise fitting routines. The topic of Schottky signal analysis is summarized in the final Chapter 2.6.

Cherenkov Diffraction Radiation

Investigations concerning Cherenkov Diffraction Radiation (ChDR) are discussed in Chapter 3. Cherenkov radiation is well known. This innovative concept related to the diffraction radiation created within dielectric material mounted outside but close to the beam path is discussed; it is a non-invasive diagnostic applied for single-pass applications and proposed for circular accelerators. The properties of the radiation field and the design of an appropriate detection scheme are an actual challenge for beam instrumentation with implementations at several facilities.

The introduction in Chapter 3.1. summarizes the regular Cherenkov radiation for a charged particle traversing a material and the diffraction radiation where the material is mounted outside the beam path. For both cases, relevant publications are cited.

The theory of ChDR is described in Chapter 3.2. several models from the literature are cited, and the related formulas are given consistently. Stationary models are evaluated, which treat the dielectric material as continuous blocks of matter using permittivity and permeability as frequency-dependent parameterizations. The related light emission characteristic is depicted and discussed as described by analytic formulas. Non-stationary models are discussed, which use the polarization of the dielectric material as the basis. The emission characteristic differs between both model assumptions, which is clearly described and depicted in several plots.

In the following Chapter 3.3, the models are applied for typical electron beams available at the CERN test facility CLEAR. The text depicts and discusses some differences in the expected frequency spectrum. Expected spectra for various bunch lengths and shapes are shown. Chapter 3.4 continues with numerical simulations in two directions: Firstly, the electromagnetic field propagation is better described in terms of wake-field using a two-dimensional approximation. Secondly, a multilayer arrangement around the beam is used with different permeabilities and permittivities. Moreover, thin metallic layers can be introduced in the simulation, showing that spectral modifications occur; in particular, signal enhancements at some frequency bands can be used for beam instrumentation.

The experimental verification of the models is described in Chapter 3.6 using a 100 to 220 MeV electron beam at CLEAR with the detection of mm-waves. The experimental setup is appropriate for the required test measurements. In particular, the distance between the beam centre and the dielectric was varied as the introduced CHDR models predict different impact parameter dependences of the emitted power with the evaluation band. It is shown that neither the Ulrich model nor the PCA approximation can describe the experimental impact dependence sufficiently well. No satisfactory explanation is given in the thesis; however, this can be excepted as CHDR is a novel method in beam instrumentation and the relevant scientific modelling and experimental investigations are limited. Further theoretical and experimental investigations are needed but are outside this thesis's scope and time frame.

In Chapter 3.5, the theoretical models are applied to the typical beam parameters of LHC for proton and lead ions Pb^{82+}. The characteristic spectral modifications are discussed and distinguished in terms of coherent and incoherent contributions. Applications related to profile measurements and, in particular, determination of halo contributions are discussed as the distance of the individual particles to the dielectric modifies the emission characteristics.

Formal style of the thesis

The thesis is very well formulated and obeys all scientific requirements concerning the text and corresponding diagrams and schematic drawings. The basic ideas, analytical treatments, numerical simulations and achieved experimental results are described appropriately. Only very few weak formulations and typos are found and will be reported directly to the author.

Conclusion

The thesis is of high scientific quality concerning the content and the presentation. It confirms the deep understanding of the related physics and technology by Kacper Łasocha. Moreover, the thesis will serve as a durable publication concerning the spectral shape of Schottky signals, related evaluation of important beam parameters, and a basis for further investigation concerning ChDR.

The scientific quality of the thesis is excellent. I recommend admission for Kacper Łasocha to the subsequent stages of the PhD procedure and the public defence.

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