Measurements and Simulations of Impedance Reduction Techniques in Particle Accelerators

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Hugo Alistair Day

School of Physics and Astronomy

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Abstract

Wakefields and the corresponding frequency-domain phenomenon beam coupling impedance have been well studied for some time in the accelerator physics community. They are known as an important driver of beam instabilities which can limit the operation intensity of accelerators. As accelerators have pushed to higher beam currents and tighter beam parameters the side effects of beam impedance, especially driven instabilities and beam-induced heating, have increasingly become a limiting factor in energy frontier machines. Devising methods to reduce the beam impedance of key structures is a vital part of increasing beam intensity limits and machine protection procedures for high current machines.

In this thesis is presented a critical study of impedance reduction techniques applied to two key sources of beam impedance in the LHC that pose a limitation to accelerator performance: the LHC Injection Kicker Magnets and the LHC collimators. This is begun by giving an introduction to wakefields and impedance as well as their visible effects on beam dynamics and machine interactions to quantify the effect an impedance has on machine operation. The phenomenon of beam-induced heating is examined in depth, identifying the effect on beam length, longitudinal bunch profile and changing the properties of resonances on the resulting power loss by the beam. The tools used to evaluate impedance reduction techniques are introduced, both analytical models, simulation methods, beam-based and bench-top measurement methods. Bench-top measuring methods are covered in detail, including a new analysis technique allowing the measurement of the quadrupolar and constant transverse impedance terms of asymmetric structures. A variety of different impedance reduction techniques are introduced, and an in depth study of the

location of power loss in ferrite damped cavities is presented.

These methods of impedance reduction and measurement and simulation techniques are then applied in the context of examining the limitations due to beam-induced heating in the LHC injection kicker magnets and proposing and evaluating new beam screen designs to shield the large ferrite yoke. Measurements of the current beam screen using the coaxial wire technique are presented, and evaluated using simulation tools to identify the causes of high impedance, and solutions to this proposed with awareness to non-impedance based restrictions to the screen design. Additionally, a study of a part of the LHC collimator upgrade is discussed, covering the choice of jaw material for the phase 2 secondary collimator and a detailed study of the 3D design of the TCTP collimator using a number of different impedance reduction techniques to select and optimal geometry.

Declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institution of learning.

Hugo Alistair Day

School of Physics and Astronomy

University of Manchester

Oxford Road

Manchester

M13 9PL

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The Author

The author grew up in the south of the UK, leaving King Edward VI Grammar School in 2005 to read physics at the University of Southampton. In 2008 he was lucky enough to be selected for a summer studentship at CERN studying particle behaviour in the spectrometer of the 3MeV test bed for the Linac4 H- source. After graduating from Southampton in 2009 with an MPhys in Physics he went north to study for a PhD in the School of Physics and Astronomy at the University of Manchester. He was able to acquire a Doctoral Studentship from the CERN Doctoral Student Programme and subsequently spent three exceptional years at CERN, Switzerland.

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