Measurements and Simulations of Impedance Reduction Techniques in Particle Accelerators

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Abstract

A review of the first two years of study are presented. These topics consist of; Simulations of coaxial wire measurements of the impedance of asymmetric devices, coaxial wire measurements of ferrite kicker magnets for use in the SPS and LHC and impedance studies of a number of potential collimator upgrades for the LHC, focusing on the phase 2 secondary collimators for the LHC. Also disucssed is future work towards completion of the PhD and a timetable of writing to ensure timely completion.

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.

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What is new that is presented in thesis?

- Localisation of heat loss in trapped modes/damping trapped modes with ferrite
  - Localising heat loss using loss density plots in HFSS
  - Investigating the effect of ferrite in damping cavity modes - where does the heat loss go and how does R/Q change with the addition of ferrite.
- Using the coaxial wire method to measure the quadrupolar impedance of symmetric and asymmetric structures (also the constant transverse term?)
- Simulations of complex devices (is this really that new or exciting?)
- To sell that this is a piece of work that has been valued highly - The LHC-MKI impedance simulations. A problem was observed - heating, shown by temperature probes and a decrease in vacuum quality. This was traced back to beam induced heating due to a large beam coupling impedance. Measurements of the existing LHC-MKI were carried out using the coaxial wire technique to acquire the longitudinal and transverse (dipolar and quadrupolar) impedances. Subsequently simulations of the device were carried out to compare to the measurements. The agreement is exceptionally good for such a complex device. This model was then modified to simulate alternative beam screen layouts. Both modifications of the existing design, and new designs. The predictions of power loss were made for a number of beam operation modes (nominal, 50ns operation, HL-LHC operation), and based on the results and the limitations placed on the screen designs by concerns of electrical breakdown, a new kicker magnet was constructed with 19 screen conductors as a good compromise in the reduction of heating and avoiding too much electrical breakdown. Measurements were subsequently made and the agreement was similarly very good with simulations. The magnet will be placed in the LHC in the August technical stop. We plan to observe the heating of the device to confirm the reduced heat load.

- Show a step-by-step breakdown of how the different major components alter the impedance profile of the device. For example - just the ferrite yoke. Then add the ceramic tube. Then the screen conductors. Explain that this kills the field rise time. So we add capacitive coupling at one end. Show resulting oscillations. We add damping ferrites and the screen conductor resonances disappear.

Whether this is sufficient, only Crom will tell

1. Introduction

   - The purpose of accelerators and introduction to the CERN
   - An introduction to longitudinal and transverse single-particle motion - Possibly an additional short chapter.

2. Wakefields, Impedances and the associated Beam Dynamics Effects

   (a) Theory - Covering the definitions and assumptions of wakefield and impedance studies. Also some simple examples, i.e. resistive wall and cavity modes

   (b) Examples of Effects

      - Beam-induced heating
      - Single bunch and coupled bunch instabilities in the longitudinal and transverse planes - To be introduced and summarised. No in depth analysis needed - others have done it before and better than you can at the moment.
      - Example - LMCI with broadband (and space charge - maybe explain implementation) impedances studied in HEADTAIL.
      - Comments - Beam induced heating is important to a lot of the work so will be explained in some detail, including reviewing the effects of bunch spectra/bunch length, narrow band, broadband impedances. Also commented on will be location of heating. Will be expanded on further in the examples chapter (TCTP and RF fingers for examples).

3. Impedance Evaluation Tools (title likely to change)

   (a) Simulations

      - Time Domain
      - Frequency Domain - Including eigenmode simulations AND simulations of the coaxial wire technique. Covering symmetric and asymmetric structures

   (b) Measurements (Frequency domain primarily)

      - Bench Top
         - High Q impedances
         - Low Q impedances
      - Beam-Based Measurements - to demonstrate some knowledge of beam dynamics and because it fits with the section - NOT ALL EQUIPMENT CAN BE MEASURED ON A BENCH
         - Longitudinal Measurements (synchronous RF phase shift, quadrupolar synchronous frequency change with intensity, longitudinal mismatch whilst crossing tradition)
         - Transverse Measurements (Tune shift, rise time vs. chromaticity)

4. Impedance Reduction Techniques

   (a) Resistive Wall Impedance - material conductivity. Using coatings, adjusting material impedance peaks. Phase 2 jaw material as an example. Material, and pipe radius (1/b for longitudinal, $1/b^3$ for transverse)

   (b) Gaps - TCTP for geometric, Phase 2 for resistive

   (c) Tapering Angles - TCTP as example (for example the change of tapering angle causing a broadband impedance increase)

   (d) RF fingers - Simulations of RF fingers making the impedance of cavities/transitions

(e) Damping materials - i.e. the use of ferrite to lower the Q value of resonances. Description of placement and material choice. Heat loss in ferrite.

(f) Serigraphy - For use on ferrite kicker magnets

(g) Ceramic chambers - LHC-MKI

(h) Others

5. Indepth studies of 2 Impedance Reduction Techniques

   (a) LHC-MKI - Particular attention to be paid to the limitations of the technique (electrical breakdown), the measurements and also to a comparison of beam induced heating with different configurations and beam spectrum measurements

   (b) LHC Phase 2 Collimator Design - Secondary collimator and TCTP, comparison to current collimator

   (c) RF Fingers - Measurements of existing RF finger designs - Measurements (and simulations?) of the new design.

6. Conclusion