ICE Section Meeting - Coaxial Wire Measurements of Ferrite Kickers

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Introduction

- What is the wire method?
- Why do we use the wire method?
- Measurement methods
  - Transmission Method
  - Resonant Method
- Measurements of Ferrite Kickers
- Conclusions/Future Work

What is the Wire Method?

- We use a wire stretched through a device whose impedance we wish to measure to simulate the response the device would have to a charged particle
- This is based on the similarity of the field profile between an ultrarelativistic particle and a short pulse propogating along a coaxial wire (see 1)[1]

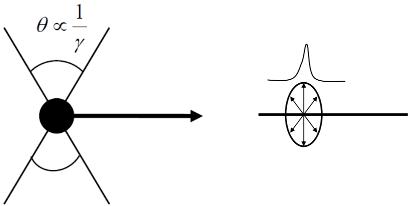

Figure: 1 - EM field profiles of relativistic charged particle and a coaxial wire carrying a short pulse

What is the wire method

- The set-up for one and two wire measurements is shown in figure 2
- We match the impedance of the connecting cables to the characteristic impedance of the device under test (DUT) to minimise the presence of reflections.
- The use of time domain gating can also be used to reduce reflections. However this is liable to remove parts of the signal subject to a high imaginary impedance. It is also not well suited to two wire measurements

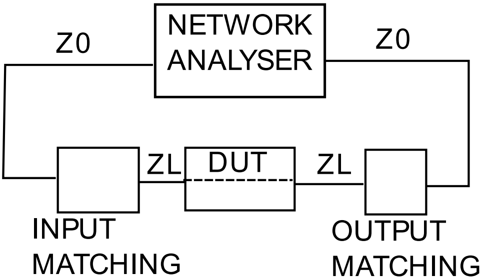

Figure: 2 - Experimental setup for the coaxial wire method

Why use the wire method

- Doesn't require the use of a particle accelerator. Allows remote testing
- Its possible to measure individual components
- Significantly quicker for practical measurements for cases of prototyping [2][3]

Measurement Methods

- There are two measurement methods used for to measure the impedance for ultrarelativistic beams
  1. Resonantor Method - Used to measure devices which would be expected to have a have a low impedance value i.e. collimators, shielded kickers
  2. Transmission Method - Used to measure other devices

Resonator Method

- Capacitors are connected in series with each connecting coaxial cable to create a small through capacitance to the DUT
- This creates a standing wave resonator. It is possible to measure the Q values of the peaks at the resonant frequency and compare these to those expected from a PEC cynlinder of equivalent dimensions to obtain the real impedance
- This provides a highly accrurate method of measuring the impedance at the resonant peaks, however the frequency resolution is not so good as with the transmission method
- We calculate the impedance from the lumped impedance model[4][5] for single wire measurements

$$Z = -2Z_c \frac{1 - S_{21}}{S_{21}} \quad (1)$$

where Z_c is the characteristic impedance of the DUT and S_{21} is the transmission coefficient through the DUT

Resonator Method

- It is possible to take advantage of the effect of the imaginary impedance to measure it
- We consider the imaginary impedance to change the electrical length of the DUT. By comparing resonant frequencies of the DUT to a reference pipe of equal physical length, we can deduce the imaginary impedance (see fig 3)
- Find that the imaginary component of the impedance $Im(Z) = Re(Z)tan\left(2\pi\left[f_1 t_1 - f_2 t_2\right]\right)$ where $f_{1/2}$ is the resonant frequency of the reference pipe and DUT respectively and $t_{1/2}$ is the transmission time of the electrical signal through the reference pipe and DUT respectively

Resonator Method

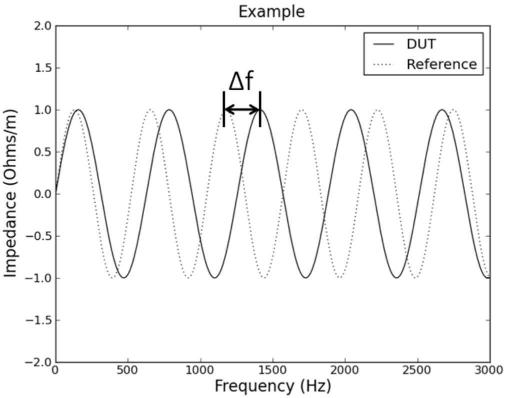

Figure: 3 - Calculating the imaginary impedance by comparing the

Transmission Method

- The tranmission method involves taking the complex transmission coefficient $S_{21,DUT} = S_{21,DUT} e^{i\psi}$ of a signal passed through the DUT and comparing it to the signal passed through a perfectly conducting reference pipe $S_{21,REF} = e^{j\phi}$
- Using a distributed impedance model [4][5] it is possible to determine the impedance of the DUT using eqn 2 for single wire measurements

$$Z = -2Z_c ln\left(\frac{S_{21,DUT}}{S_{21,REF}}\right) = -2Z_c \left[ln\left(\frac{S_{21,DUT}}{S_{21,REF}}\right) + j(\psi - \phi)\right] \quad (2)$$

- The same method is used for both the one and two wire measurements
- For two wire measurements, we normalise the derived impedance by the wave number and the displacement of the wires

$$Z_{x/y}^{driving} = \frac{Z}{k(2a)^2} \quad (3)$$

- where k is the wave number, and a is the half-seperation of the two wires

Analysis Methodology

- There are five impedances which we wish to measure
  1. Longitudinal Impedance
  2. Vertical and horizontal dipolar/driving impedance
  3. Vertical and horizontal quadrupolar/detuning impedance
- The longitudinal impedance and dipolar impedances can be measured directly using the single and two wire methods respectively. The quadrupolar impedance can not be independently measured however
- We have to use some creative thinking...

Analysis Methodology

- It is possible to generate a generic description of the impedance [7]

$$Z(a,\theta)_{tot} = A_1 + ae^{-j\theta}A_2 + ae^{j\theta}A_3 + a^2e^{-2j\theta}A_4 + a^2e^{2j\theta}A_5 + a^2A_6 \quad (4)$$

- where a is the radial displacement of the wire, θ is the angular displacement of the wire, and A_n are complex coefficients of the form $A_n = \Re e(A_n) + \Im m(A_n)$
- Through some mathematical derivation (shown in [7]) it is possible to show that for a structure exhibiting top/bottom, left/right symmetry

$$Z_{Total}(f) = Z_{long}(f) + Z_{l,1y}(f)y^2 + Z_{l,1x}(f)x^2 \quad (5)$$

where

$$\frac{Z_{l,1x}}{k} = Z_x^{dipolar} - Z^{quadrupolar} = Z_x \quad (6)$$

$$\frac{Z_{l,1y}}{k} = Z_y^{dipolar} + Z^{quadrupolar} = Z_y \quad (7)$$

and $k = \frac{\omega}{c}$ is the wave number.

Analysis Methodology

- This tells us that if a sweep of different wire displacements is carried out along one axis (x/y) we can determine the quadratic coefficient and thus the total transverse impedance
- Given that we can indepently measure the dipolar impedance, we can thus calculate the quadrupolar impedance

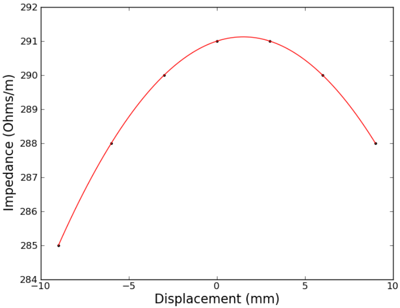

Figure: 4 - Example parabola from the SPS MKE

Measurements from the LHC MKI

- LHC MKI (Injection Kicker Magnet) T10 measured using the resonantor method
- Magnet was designed with impedance reduction in mind, so it is expected that the impedances will be small

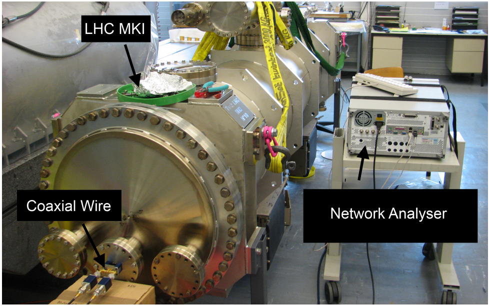

Figure: 5 - Experimental setup for the LHC-MKI

Measurements from the LHC-MKI

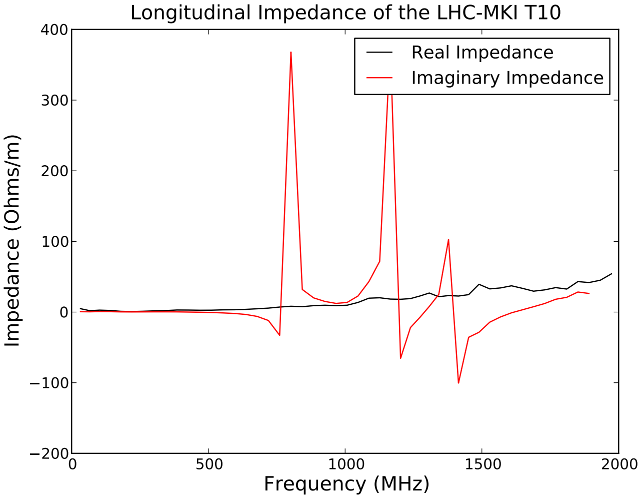

Figure: 6 - Longidutinal Impedance LHC-MKI T10

Measurements from the LHC-MKI

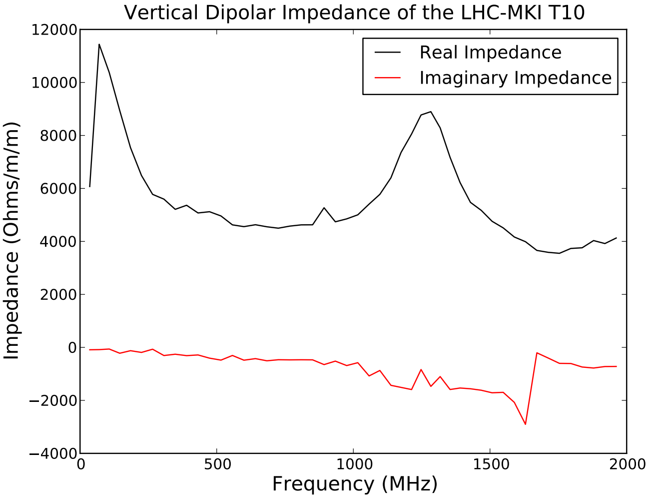

Figure: 7 - Vertical Dipolar Impedance LHC-MKI T10

Measurements from the LHC-MKI

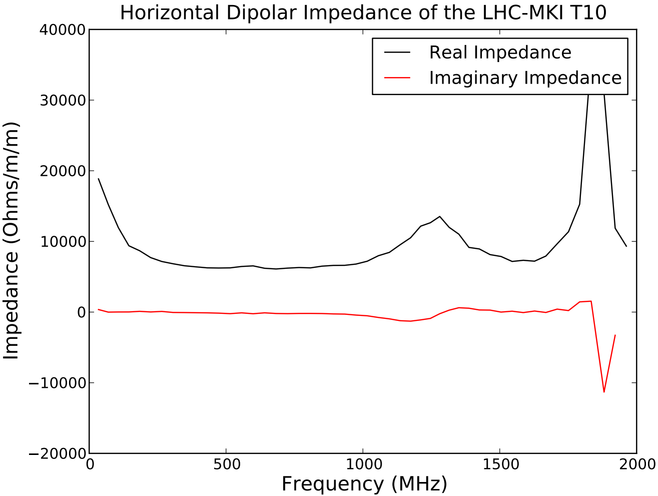

Figure: 8 - Horizontal Dipolar Impedance LHC-MKI T10

Measurements from the LHC-MKI

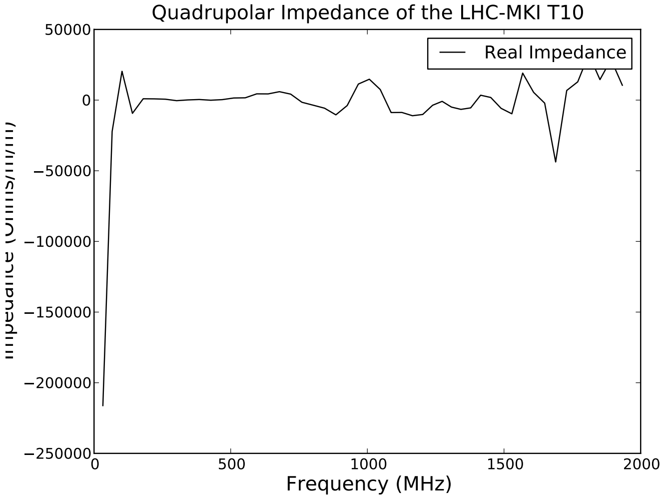

Figure: 9- Quadrupolar Impedance LHC-MKI T10

Measurements from the SPS-MKE

- SPS MKE (Extraction Kicker Magnet) is a c-core ferrite kicker magnet used for extraction of beam into the SPS. It is unshielded.

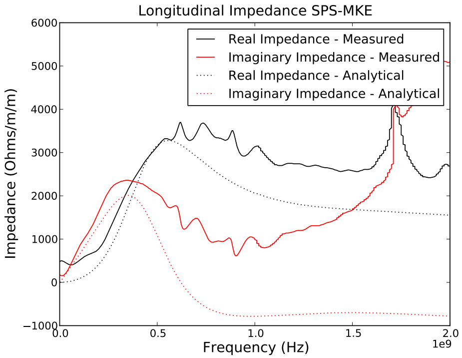

Figure: 10 - Longitudinal Impedance SPS-MKE

Measurements from the SPS-MKE

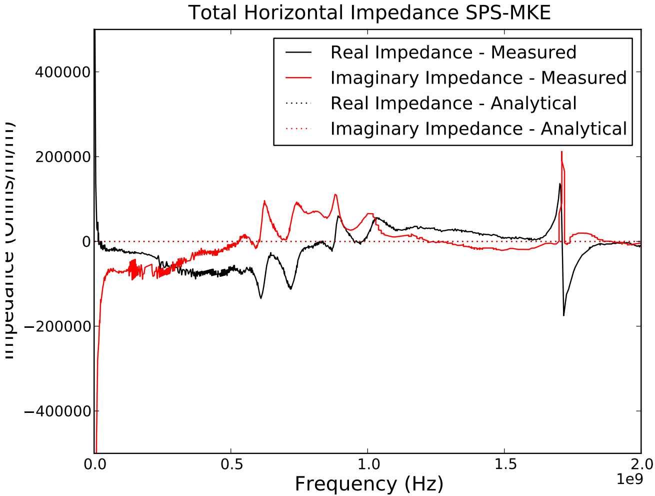

Figure: 11 - Total Horizontal Impedance SPS-MKE

Measurements from the SPS-MKE

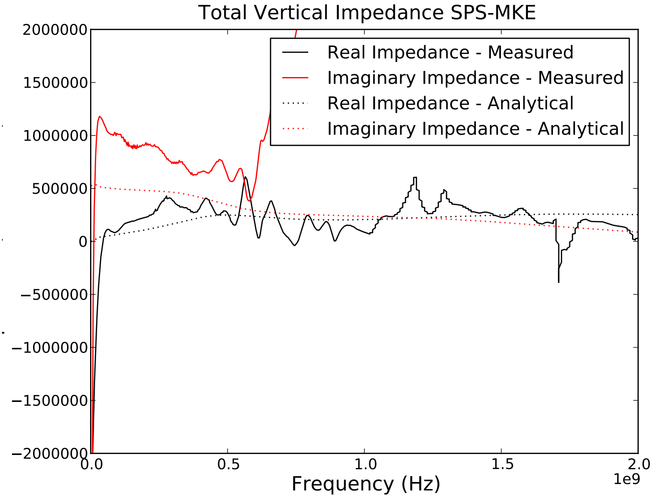

Figure: 12 - Total Vertical Impedance SPS-MKE

Conclusion

- Wire method provides a quick, relatively accurate way of measuring the impedance of specific devices
- The experimental setup is of key importance - DON'T MAKE AN ALREADY HARD JOB HARDER!
- Still developing area, particularly for the measurement of asymmetric devices. Also still much debate over what frequency range it is valid
- Thanks for listening. Any questions?

References

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