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TRANSVERSE IMPEDANCE COAXIAL WIRE MEASUREMENT IN AN EXTENDED FREQUENCY RANGE

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Abstract

The low energy accelerators tend to have some instabilities especially coming from the beam coupling impedances due to the interaction between the beam and accelerator components. As long as the longitudinal impedance are important, transverse impedance determination is crucial to determine the instabilities which will affect the working efficiency of the accelerators. However due to their small amplitudes and measurement setup configuration they are hardly measurable especially in wide frequency ranges. We developed a specific setup for small diameter pieces (28-40 mm) for moving and two wire transverse impedance measurements. The measurements were performed for the dipolar and quadrupolar impedance measurement even with a few Ohm level up to 6 GHz for the Transverse feedback kicker, the 4 button Beam Position Monitor, the bellows and the pumping port for ThomX. The bellow measurements will be presented in this paper. Comparison with electromagnetic simulations shows agreement for the peak frequencies.

INTRODUCTION

Accelerator physics science is the area of expertise in designing and operating the particle accelerators with understanding the charged particle dynamics. The defining interaction of particles with the accelerator components and itself is quite crucial especially for the low energy and high charge accelerators. This interaction is defined as collective effects which can be seen in many different forms such as geometric and resistive wakefields, space charge, ion cloud etc. For pushing the limit for the beam current, the works on the instabilities and collective effects are of primary importance. ThomX is a Compact X ray source which has a designed energy of 50 MeV and contains storage ring, linear accelerator part and transfer line. As the damping effect of the synchrotron radiation is neglected during the storing time, the beam should be precisely injected into the storage ring. However, the collective effects cause longitudinal mismatch, orbit errors, emittance growth and many other problem on the transfer line. Especially, the matching between transfer line and storage ring should be done carefully and twiss parameters should be checked. To do this, the transverse impedance measurements and simulations should be performed.

The transverse impedance measurements can be done with wire measurements called two wires and a moving wire method. The both measurements have to be performed to fully define both types of the transverse impedance. In fact, transverse impedance can be split in two terms as the dipolar and quadrupolar impedance. Both dipolar and quadrupolar terms are related with the transverse momentum kick. Dipolar component is only affected by the sources particle location as a result of coherent effect which is transverse deflecting field. On the other hand, quadrupolar terms are dependant on the witness particle location which gives incoherent effect like the focusing or defocusing field. In this work, first I will detail the general theory about the wire measurement and simulations with the designed bench and the parameters that will be used in simulation. After that I will show the measurements, simulations and analysis of the bellows.

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WIRE MEASUREMENTS

In the general electromagnetic theory interaction of the beam with itself and its surroundings are described with the wake function in time domain and impedance in the frequency domain. If the Maxwell's equation with beam specifications and specific boundary conditions, the solution will be the wake fields. In theory, the electromagnetic field distribution of the ultrarelativistic beam is similar to TEM (Transverse Electromagnetic) line. So, the impedance measurements can be done with single or two wires which could be used in TEM mode. The basic wire is stretched inside the device under test (DUT) and then the S parameters can be measured by Vector Network Analyser (VNA) which is connected with matching network. The relation between the S parameters and impedance is [1]:

$$Z = -2Z_L \ln(\frac{S21_{DUT}}{S21_{REF}}), \quad (1)$$

where Z_L is the line impedance$S21_{DUT}$ is the measured s parameter of the device under test and $S21_{REF}$ is the measured s parameter of the reference section. For one wire measurements, the line impedance can be calculated from [1]:

$$Z_L = \frac{Z_v}{2\pi} \ln(\frac{D}{d}), \quad (2)$$

where Z_v is the vacuum impedance which is around 376.73Ω, D is the diameter of the beam pipe and d is the diameter of the wire and for two wire measurements the line impedance equation is:

$$Z_L = 120 \operatorname{arccosh} \frac{\Delta}{d}, \quad (3)$$

where Δ is the offset between two wires.

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The single wire on axis measurements will give the longitudinal component of impedances. The symmetric accelerator device total longitudinal impedance is lead to [1]:

$$Z_T = Z_L + Z_{1x}x^2 + Z_{1y}y^2, \qquad (4)$$

where Z_L is the longitudinal impedance which was measured at x and y equal to zero, Z_{1x} and Z_{1y} are related to transverse impedance. First we will set an offset $y = 0$ mm, then we will measure $Z_T = Z_L + Z_{1x}x^2$ for different x positions of the wire. A polynomial fit of the from $ax^2 + b$ for each frequency of the spectrum will allows us to deduce the Z_{1x} values. The fitting coefficient obtained at zero abscissa should be in agreement with the longitudinal impedance measured on axis. These allow us to cross-check the fitting procedure.

The two wire measurements will only give the dipolar component of the transverse impedance. The two wire data needs to stretch two wires with small offset and drive them in opposite phases. When producing the test bench for holding two wires with a specific offset, the 3D printed pieces were used to have flexibility. Despite of the fact that they are easy to produce, 3D print material is an electrical insulator which will not affect the measurements. As can be seen in Fig. 1, the multiple holes were added to the pieces with specific offset for using the same setup also for mowing wire measurements. The printed pins sticked to these holes and the wires bended around them to have precise distance between two wires. All measurements were performed with 1 mm wire and repeated five times to define the error comes from human effect.

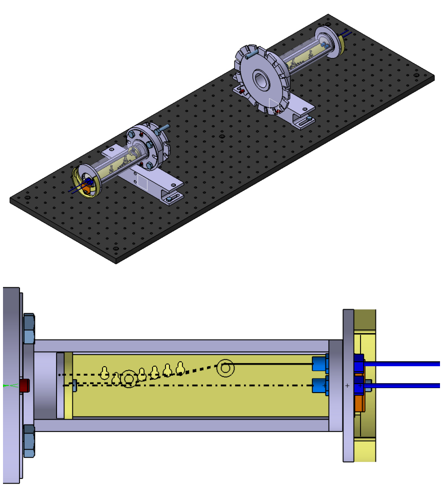

Figure 1: top :The representative picture of measurement setup. down: The endcaps of the measurement setup.

The measurements were performed up to 6 GHz due to the cut of frequency of the beam pipe.The wire inside the beam pipe perturb the electromagnetic field and creates higher order modes which can not happen in the beam case. ThomX beam pipe is not round but octogonale with dimensions of 28 mm to 40 mm to reach ellipticity while minimising the cost, for calculating the radius R can be used as $(D_eq/2)$ where equivalent diameter D_eq is 30.9 mm for ThomX storage ring. The cut-off frequency for ThomX is around 5.7 GHz. The wire measurements are not valid above the cut-off frequency.

SIMULATIONS

The electromagnetic simulations were performed with wakefield sover of CST particle Studio [2]. The beam was modeled as Gaussian distributed in longitudinal which has a standard deviation of 2 mm. The transmission line injection scheme and indirect interface solver were used in the simulations. The reason for using the indirect interface solver is the solver itself is more accurate for cavity-like structures. The simplified model of bellow for CST simulations can be seen in the Fig. 2

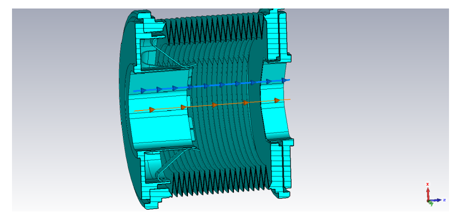

Figure 2: The simplified model of bellow for CST simulations. The orange line is the beam and blue line is the integration path.

For the first measurements the bellow is chosen. Bellows are frequently used in accelerators and storage rings. They give flexibility for thermal expansions and misalignment. However, without shielding, they are one of the main source of impedance and instabilities which makes them a good choice for checking the test bench and measurement limitations. For reducing the high impedance the RF shieldings were placed inside the bellow. Also impedance measurements are useful to check the efficiency of the RF shieldings.

MEASUREMENTS

Longitudinal Impedance

The longitudinal impedance measurements were performed with 1 mm wire. This measurement can be used for extracting the transverse impedance from moving wire but also it can be used for crosschecking the efficiency of the fitting process. The longitudinal impedance measurements and simulations was detailed in the former work [3]. The measurements were only performed on axis for checking the new setup which is adapted to two wire and moving wire measurements.

Many sharp peaks and high impedances are expected with the bellows with many corrugations [4]. However, it is impossible to find the impedance results of the bellows through analytic calculations. The measurements and simulation was needed to describe the frequencies and the amplitude of the bellow impedance peaks. In the simulations without RF fingers [3] four peaks at 2.08 GHz, 3.51 GHz, 4.38 GHz and 4.89 GHz was observed.

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Of course the simulation results need to be cross-check with the wire measurements. The measurement with 1mm wire diameter have been performed as shown in Fig. 3. The only two peaks are measured at 2.2 GHz and 4.3 GHz which is consistent with the former measurements and simulations [3]. There is a maximum deviation on the measurements about 5% which is expected due to the movable nature of the bellow and mechanical tolerance.

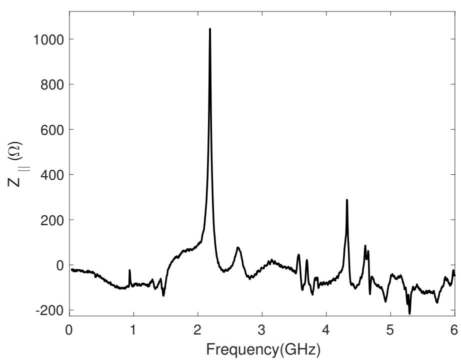

Figure 3: Longitudinal impedance which is measured on axis with 1 mm wire.

Two Wire Measurements

The Bellow measurements were performed with two wires to determine the dipolar component of the transverse impedance. The distance was chosen as 1 cm [1]. If we simplify our model to step in-out structure like the bellow which has only one corrugation, the strong dipolar impedance peaks were expecting [4]. Like in the longitudinal impedance it can not be defined from analytical calculations due to tens of small corrugations. First the CST simulations were performed to find high resonant impedance peaks and the validity was checked with the two wire measurements with 1 mm wire.

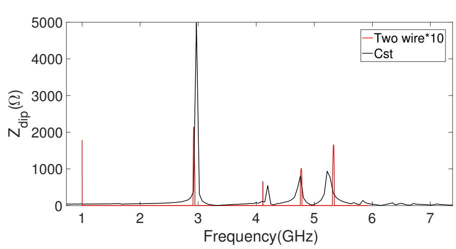

Figure 4: Two wire measurements which performed with 1 mm wire comparison with the CST simulation results.

All four peaks in the cst simulations were also seen in the measurements with acceptable frequency shifts which can be seen in Fig. 4. The first peak on the simulation at 2.69 GHz is slightly shift to 2.92 Ghz on the measurements. It is around 4% error on the frequency span. The second at 4.19, the third at 4.77 and fourth at 5.33 GHz are shifted around 0.08, 0.01 and 0.1 GHz in the measurements. These level of deviation is expected due to the thickness of the wire, movable geometry of the bellow and the mechanic tolerance of the manufacturing.

Moving Wire Measurements

The distance should be big enough to measure the electromagnetic interaction but also to stay in the approximation range it should be small enough [1]. In fact, impedance formula is deduced from a taylor expansion over the distance. Ref [5] highlights that optimum wire spacings are from 10% to 20% of the beam pipe diameter. The measurements were taken with on axis, 4 mm , 5 mm, 6 mm and 6.5 mm offsets. The maximum offset here correspond to 23% in horizontal and 16% in vertical. The fit were performed with all offset each has 5 measurements and total 25 measurements.

Polynomial fit to mowing wire measurements will give the longitudinal and total transverse impedance components. The total transverse impedance is the sum of the dipolar and quadrupolar impedances. The two wire measurements can be used for extracting the quadrupolar impedance from moving wire. In this sense, the peaks at 2.93 GHz and 4.83 GHz in Fig. 5 are coming from the dipolar impedance which is proved from the two wire measurements and CST simulations in Fig. 4. The other two peaks at 2.19 GHz and 3.54 GHz should be the contribution of the quadrupolar component which was already checked from the simulation results.

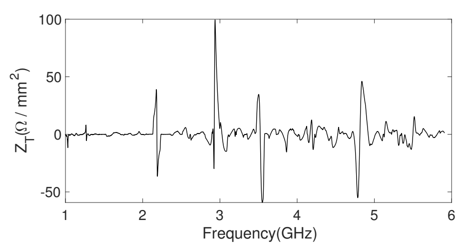

Figure 5: The transverse impedance results of the bellow performed with 1 mm wire with 5 different offset and extracted from moving wire data by fitting parabola.

CONCLUSION

Longitudinal and dipolar impedance results from moving wire, one wire and simulation are in great agreement in frequency scale. The signal amplitude difference was expected due to loss in the resistors and the attenuation coming from the thickness of the wire [6]. The simulation results can help us to find real amplitude. Also ThomX ring has a small aperture which also put additional non linear effects. The error on the frequency scale is around 4% which is quite acceptable for these measurements. The quadrupolar impedances can be extracted easily from the moving wire measurements. The setup is valid for on axis, moving wire and two wire measurements which allows us to measure all the components of the impedances. The impedances can be measured from a few Ohms to thousand Ohms. As a result, the setup is reliable for using it in other pieces such as BPM, FBT and pumping port or more generally to measure impedance of any device even small.

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REFERENCES

[1] T. Kroyer, F. Caspers, and E. Gaxiola, "Longitudinal and transverse wire measurements for the evaluation of impedance reduction measures on the mke extraction kickers", CERN, Geneva, Switzerland, CERN-AB-Note-2007-028, 2007.

[2] CST, `https://www.cst.com/`.

[3] A. Gamelin, "Collective effects in a transient microbunching regime and ion cloud mitigation in thomx", Ph.D. dissertation, University of Paris-Saclay, 2018.

[4] K.-Y. Ng, "Impedances of bellows corrugations", in *Proc. 12th Particle Accelerator Conf. (PAC'87)*, Washington D.C., USA, Mar. 1987, pp. 1051–1054.

[5] C. Zanini, "Electromagnetic simulation of cern accelerator components and experimental applications", Ph.D. dissertation, Ecole Polytechnique Federale de Lausanne, 2013.

[6] J. F. David Large, *Broadband Cable Access Networks*. Burlington, MA, USA: Elsevier, 2009.