First semester PhD report
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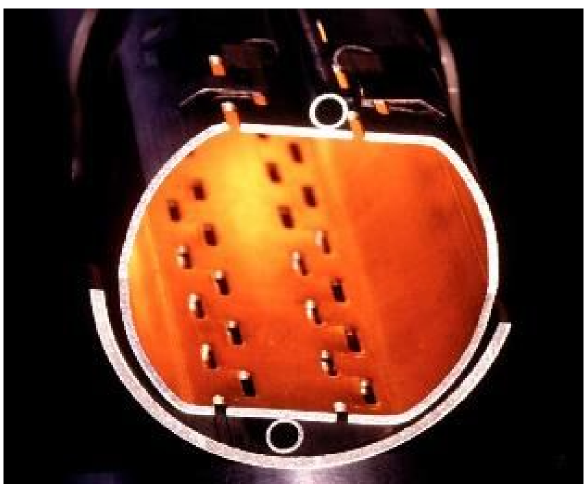
Design and realization of an RF impedance measurement system at cryogenic temperature

Introduction and project description:

In a particle accelerator the inside surface of the beampipe has to have especially good electrical and mechanical properties. Since the synchrotron radiation is heating up the pipe from the inside, it has to be able to dissipate the heat, and protect the rest of the machines from it. Another important thing is, that it needs to have good enough conductivity, so that the image currents induced by the beam (which in this sense can be considered a 25 MHz AC current) do not interfere with the beam too much. In modern accelerators the inner layer of the beampipe (the surface "seen by the beam") is called the beam screen.

In the case of the LHC in CERN and other superconducting synchrotrons another difficulty rises, namely that the magnets are at temperatures either 4.2 or 1.9 K cooled by liquid helium, to keep them in superconducting phase. At this temperature the cooling of the beam screen would not be efficient enough, so the beam screen is usually at much higher temperatures, (up to 20 K) only cooled by two thin tubes of helium on the top and the bottom, as seen in the image below. To make space for these cooling tubes inside of a pipe, the LHC beam screen is not cylindrical.



LHC beam screen

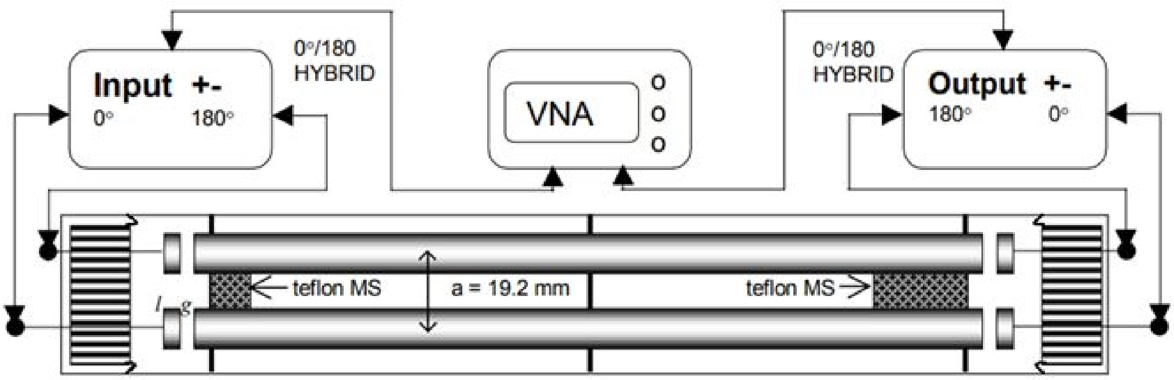
In the image one can see pumping holes on the top and the bottom of the beam screen. These are needed to apply ultra high vacuum in the pipe. They are randomly distributed, so that the induced surface current loops has as small effect on the beam as possible.

In the LHC the beam screen is made out of a stainless steel base, which provides the strength needed, and a thin copper coating on the inner surface, which is responsible for the electrical properties of the pipe.

From the RF resistive losses point of view the most important property of the beam screen is its surface impedance. This can usually be measured on flat samples of the same material, and the close to cylindrical impedance can then be deduced. But in special cases, such as in the case of thin coatings, there might be minor differences between the preparation of a flat sample or a tube (the thickness homogeneity of the coating for example can differ for different coating methods). For this reason, in the study phase of the LHC there was a series of experiments carried out to measure the surface impedance of real beam screen prototypes as well as flat samples (link to document).

The simplified measurement description is as follows:

- There are two metal rods inserted inside the beam screen.
- This system, if closed, forms a cavity with 2 fundamental modes (in our case both with the same resonance frequency of 160 MHz).
- The fundamental modes' frequency can be separated from each other by inserting dielectric material (Teflon "mode splitters" in our case) in between the rods
- At both ends we excite the rods with 2-2 antennas.
- We measure the reflection and transmission coefficients between the two sides of the tube, with a vector network analyser (VNA).
- From the measured properties and the known resistivity of the inner rods, we can deduce the surface impedance of the external tube, which is in our case the beam screen.
- This way we can measure impedance at the fundamental modes and at the harmonics of those, which means we have around 10 measurement points between 160 MHz and 2GHz (at higher frequencies the measurement is inaccurate).



Experiment setup

Now that there are new coating methods, and surface treatments suggested for the next generation of accelerator beam screens (eg. amorphous carbon coating, or laser surface structuring), the question can arise again, how to measure the surface impedance of them. My PhD project (completely carried out in CERN, Geneva) is aimed to measure the electrical properties of these new types of beam screens.

The greatest addition to the work carried out ~19 years ago is the fact that now we want to measure the properties in high magnetic field (~7 T), from 1.9 K up to room temperature. This will be done by inserting the whole measurement system inside the FRESCA superconducting dipole magnet.

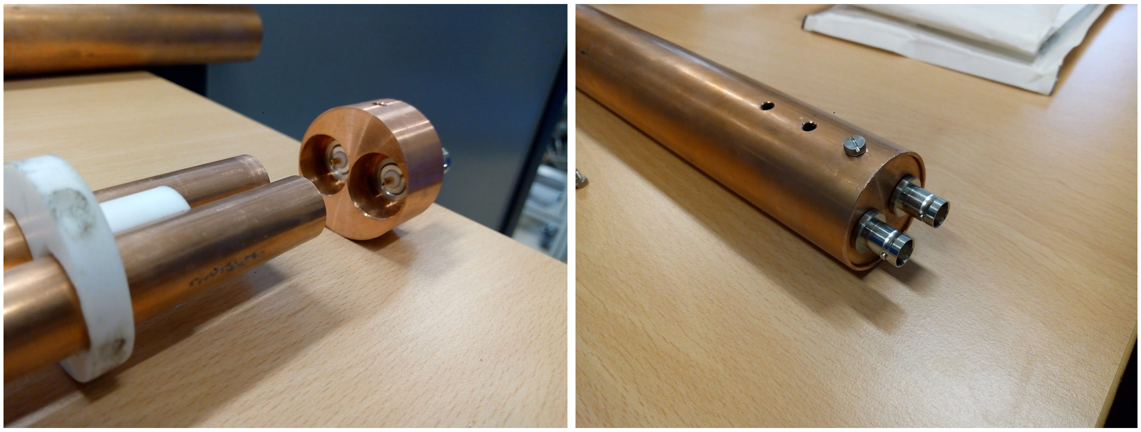
Work carried out during the semester:

First of all I run some simulations in HFSS to get a feeling on the range of frequency we can expect, and to decide the amount of dielectric needed in the setup. This was done before mid October.

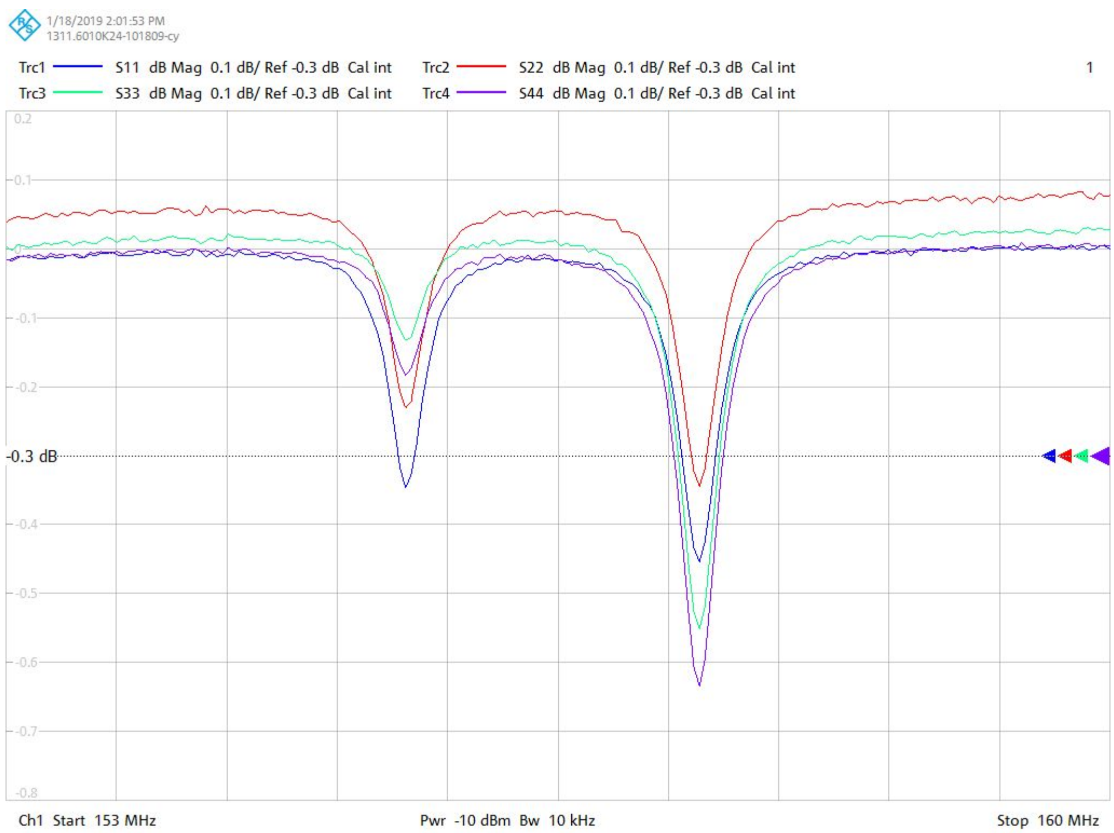
To identify the possible difficulties and learn how to do the measurement, as well as to experiment with different setups, I started to work on a prototype system, which measures the surface impedance of a copper tube (as a really simplified beam screen). I started working on this in the end of October, and last week (mid January) I managed to put together and to start the measurement of this first prototype. (With the help of the workshop preparing the pieces for me.)

Most of the work was to learn a CAD software (which I chose to be Inventor), and creating the drawings for all the necessary pieces, for the workshop to be able to make them.

A few images of the prototype, and the reflection parameters (S_{ii}) for all 4 ports of the device can be seen below.



Inner rods and endcap with antenna holder on the left, and assembled setup on the right



Reflected signal strength as a function of the frequency.
Two fundamental modes of the cavity at 155.3 and 157.5 MHz.

In the upcoming weeks I will be experimenting with slightly different setups and see what are the advantages and disadvantages of one or another. For example it is already clear from my tests carried out last week that currently the coupling between the antennas and the inner rods is too strong, making the 5th and higher harmonics not having separate peaks for the separate resonances, but just one wide peak.

University studies:

I was attending two courses in this semester, one of which was a course held in Debrecen in connection with neutrino physics, and the other held by Mate Csanad the aim of which was to analyze a dataset, and get information about the elliptic flow in a simulated heavy ion experiment.

In a few weeks I will attend the RF and vacuum course of the JUAS (Joint University Accelerator School) which is a one week long course for PhD students and professionals working in the fields accelerator physics. At the end of the course there is a possibility to give an examination, so that PhD students can earn ECTS credits. I will try to have the course accepted as one of my courses at the university.

Workshops and conferences:

I presented my project at a workshop dedicated to HTS (high temperature superconductor) coated beam screen studies in Barcelona in the beginning of December. It was a really interesting and "vivid" workshop, since all the people were working in close connection to each other, so most of the presentors received valuable feedback.