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European Laboratory for Particle Physics*Large Hadron Collider Project***LHC Project Report 403****EXPERIMENTAL EVALUATION OF THE RF SHIELDING PROPERTIES
OF A THIN RESISTIVE LAYER IN A CERAMIC CHAMBER**

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In order to better understand the RF shielding properties of a thin resistive layer inside a ceramic vacuum chamber, an experimental set-up has been installed in the Electron Positron Accumulator (EPA) at CERN. A 500 MeV single bunch of about 7×10^{10} electrons (rms $\sigma=1$ ns) is extracted into this dedicated beam line at a repetition rate of about 1 Hz. Wideband magnetic field probes are installed on the outer surfaces of a resistively coated ceramic test chamber as well as on a reference non-coated chamber located 2.5 m downstream the line. At the end of the extraction line, the beam passes through a thin Aluminum foil and is absorbed in an external dump. The experimental layout and the first results are presented. A comparison with theoretical expectations as well as possible implications for future machines are also discussed.

1 INTRODUCTION

Among the different studies related to the minimisation of the impedance budget for the LHC machine, a proposal to use ceramic chambers coated with a very thin resistive layer (thin as compared to the skin depth) has been presented as an advantageous solution for some of the LHC kickers. Such a project was supported by results based on simulations and measurements obtained with the coaxial wire method [1]. Although these results indicated excellent RF shielding properties for a layer of a few microns, some contradictory arguments emerged. The latter were mainly based on the fact that a similar set-up installed in LEP was suspected to present large temperature transients, possibly related to an inefficient RF shielding. Given this situation and considering the potential implications for the LHC machine, it was agreed that an experimental demonstration with beam would be highly desirable. A programme to find both the location and the availability of the required equipment was launched, resulting in the construction of a dedicated beam line in the EPA machine at CERN. Apart from very few exceptions, the line could be entirely built from spare and recuperated equipment.

2 THE EXPERIMENTAL SET-UP

A 500 MeV single bunch of about 7×10^{10} electrons (r.m.s. bunch length of about 1 ns) is extracted from the EPA machine and deflected into the beam line at a repetition rate of about 1 Hz. The beam first traverses a ceramic chamber coated with a thin Titanium layer of about $1.5 \mu\text{m}$ (DC surface resistance of 1Ω). About 2.5 m downstream, the

beam encounters a second (non-coated) reference ceramic chamber. Both chambers are equipped on their outside surfaces with similar wide band magnetic field probes, namely a low frequency probe (9 kHz - 30 MHz) and a high frequency one (30 MHz - 1 GHz). Just before leaving the line, the beam is crossing a beam position monitor used to measure the beam and to provide the reference timing signal. As a consequence of this layout, the times at which the beam passes through the chambers are indicated with negative offsets, since the origin of the timing events is located downstream of the chambers. At the end of the line, the beam passes through a thin Aluminium foil and is then absorbed in an external dump. The delay and the attenuation of each cable, connecting the experiment to an observation rack in the EPA control room 100 m away, have been carefully measured during the setting-up of the line.

3 PRELIMINARY RESULTS

Figure 1 illustrates the signals from the high frequency probes recorded in the EPA control room after the setting-up of the line. As can be seen from it, signals are present for both chambers (in the following, chamber 1 will be used to refer to the coated chamber and chamber 2 for the reference chamber). However, considering the quoted timing events allows for the following comments:

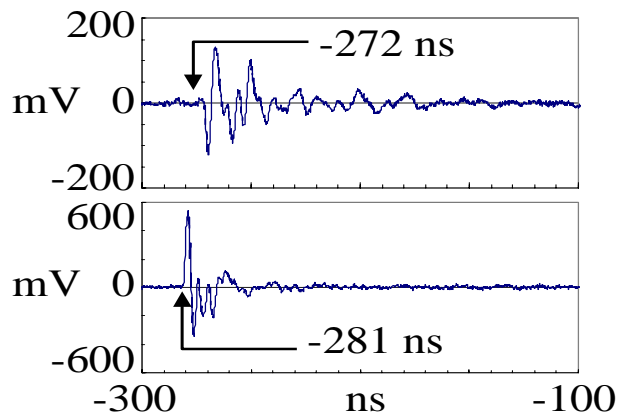


Figure 1: Upper plot: signals coming from the coated chamber 1. Lower plot: signals from the reference ceramic chamber 2.

- Although the chamber 1 (coated) is located upstream the line w.r.t. chamber 2, one observes with the timing tags, that the first signal to reach the scope is that

from chamber 2. The signals from the upper plot cannot therefore come from the beam traversal itself. It could be traced back to be a reflection signal coming from the chamber 2. In fact, when the image current reaches the uncoated chamber 2, it is reflected and travels back towards chamber 1 on the outside surface of the vacuum chamber. The difference in arrival time of the two signals is consistent with the time required for the reflected signal to reach the probes installed on chamber 1.

It should be emphasized that the presence of reflected signals had been anticipated by the time of the experiment's set-up. To highlight this effect, a second measurement was planned where the second chamber was then covered with a fine wire mesh made of brass, but maintaining the magnetic probes outside of the covered chamber. The expected effect was to shield the chamber and therefore suppress both the direct beam signal in the chamber and the previously observed reflection. Under these conditions, signals were still expected in both chambers, since a similar reflection would then occur when the beam leaves the vacuum chamber at the end of the line. The signals should simply be delayed as compared to Fig. 1. This behaviour is confirmed by the signals recorded and illustrated in Figure 2. The following comments are in order:

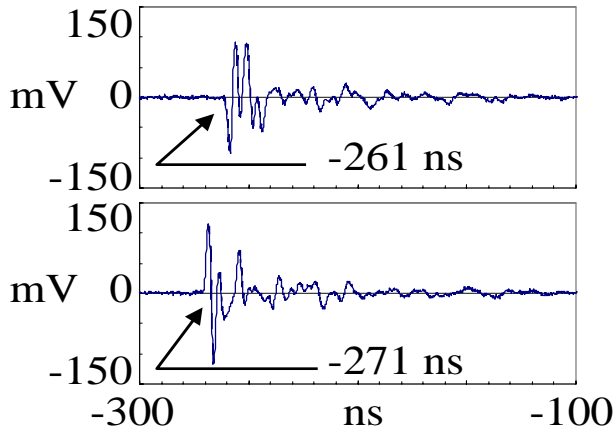


Figure 2: Upper plot: signals coming from the coated chamber 1. Lower plot: signals from the reference ceramic chamber 2. Chamber 2 is shielded.

- As expected, the signals reach the probes later. Actually, the signal from the second chamber (lower plot) shows a time delay of 10 ns w.r.t. the first measurement. The expected difference (time to go to the end of the line and come back to chamber 2) was 9.6 ns, therefore fully consistent with the hypothesis of reflected signals.
- By shielding the second chamber, it was also expected that the proper beam signal (direct signal) would disappear. Indeed, as can be seen from the lower plot of

Fig. 2, there is no signal anymore at $t=-281$ ns. Furthermore, the amplitude of the signals has reduced from ± 600 mV (Fig. 1) down to about ± 150 mV (Fig. 2).

Since the original objective was to study the shielding properties of the coated chamber, the next step consisted in completely suppressing the reflected signals and perform a third measurement. This was achieved by putting an additional shield at the end of the line, similar to what was done in the previous step for chamber 2. The corresponding results are presented in Fig. 3 and can be interpreted as follows:

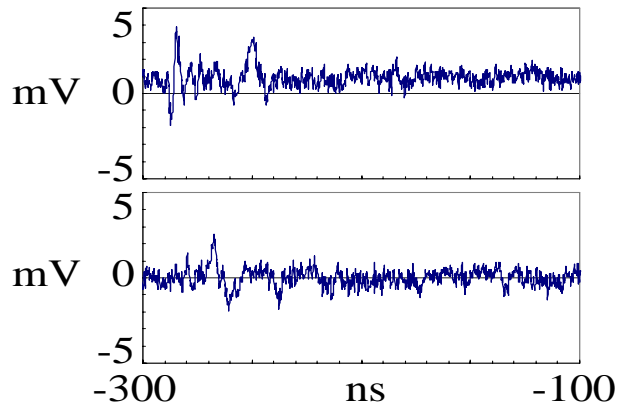


Figure 3: Upper plot: signals coming from the coated chamber 1. Lower plot: signals from the reference ceramic chamber 2. Chamber 2 and end of the line are shielded (the beam dump is in air).

- Signals from both chambers have practically disappeared (see the vertical scale as compared to previous measurements). A very careful examination of the upper plot allows to detect the passage of the beam. However, this signal is very weak and almost at the noise level. With this measurement, the shielding properties of the thin resistive layer are fully confirmed.

For the last (but by far not the least) measurement, the chamber 1 was also shielded with the same fine wire mesh of brass. However for this measurement, the magnetic probes of chamber 1 are installed inside the shielding (contrary to chamber 2 where the probes are outside). Doing so is equivalent to creating a low impedance by-pass around the coated chamber. The results are presented in Fig. 4 and are extremely interesting:

- From the first chamber one observes a very clean signal of the beam going through.
- Signals from the second chamber (lower plot) remain at the noise level.
- This clearly shows that, when a low impedance by-pass is added around the coated chamber, the shielding properties of the thin layer are completely cancelled.

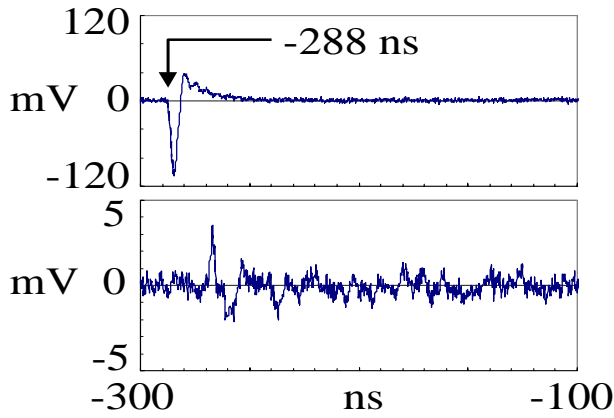


Figure 4: Upper plot: signals coming from the coated chamber 1 with low impedance by-pass. Lower plot: signals from the reference ceramic chamber 2. Both chambers and the end of the beam line are shielded.

4 EXPERIMENT'S MAIN OUTCOME

The available data already allows to draw a few interesting preliminary conclusions:

- When the coated chamber is not surrounded by anything but air (as it was the case in EPA), a single thin layer provides a nearly perfect shielding in the range of frequencies measured. In this respect, the EPA measurements fully confirm the conclusions presented in Ref. [1].
- At very low frequencies (say below 1 MHz) there is probably some penetration of the fields (due to the imperfect connections of the line itself). This penetration effect was not measurable in the EPA set-up and should therefore still be carefully evaluated.
- The shielding cancellation due to the presence of a by-pass might have important consequences for the LHC: indeed, an improper design might allow for the creation of an undesired by-pass and therefore partly annihilate the expected shielding properties.

5 POSSIBLE IMPLICATIONS

It should be kept in mind that a simplified set-up like the one used in EPA does not really reflect the situation existing in a machine. Indeed, machine components (e.g. kickers) are relatively long and always surrounded by tanks and detection equipment located very close to the chamber. In other words, the possibility of having numerous by-passes is very large. Consequently, the design of these by-passes has to be carefully optimized such as to prevent field penetration. There are still a few additional aspects worth to be considered:

- At high frequencies, the thin layer is expected to carry the full image current and therefore provides excellent

shielding. However, at low frequencies, its DC resistance (1Ω in our case) would be totally unacceptable in terms of resistive wall effect. For this range of frequencies, an inductive by-pass is therefore mandatory. The solution is certainly feasible, but this aspect has to be kept in mind.

- The EPA measurements have been simulated with HFSS [1] and the simulation results were in excellent agreement with the experimental ones. A second set of simulations to study the effect of a capacitive coupling (object located near to the chamber but without direct connection to it) indicated that with an increasing length of the structure the shielding properties got weakened. Unfortunately, the study could not be pushed into the range of realistic parameters, due to internal limitations of the simulation code. It might nevertheless be anticipated from these simulations with HFSS, that the shielding properties are a function of the aspect-ratio (length/radius) which, if confirmed, could have very important implications for the LHC machine. This question definitively requires further investigations

6 CONCLUSIONS

The EPA experiment significantly improved our understanding of the RF shielding properties of thin layers. The major outcome can be summarized as follows:

- The shielding properties described in Ref. [1] are fully confirmed.
- Although the presence of a low-impedance by-pass should be carefully avoided for high frequencies (loss of shielding), such a by-pass is mandatory at low frequency for resistive wall considerations.
- Although not experimentally measured so far (neither in EPA nor with the coaxial wire method), simulations indicated a variation of the shielding properties in the case of a capacitive coupling as a function of the length of the equipment. The LHC kickers being rather long objects, this point definitively deserves some more attention.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

- [1] F. Caspers et al., 'RF Screening by Thin Resistive Layers', Proceedings of the 1999 Particle Accelerator Conference, New York (1999), p. 1408