COMPARISON OF ENAMEL AND STAINLESS STEEL ELECTRON CLOUD CLEARING ELECTRODES TESTED IN THE CERN PROTON SYNCHROTRON

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Abstract

During the 2007 run with the nominal LHC proton beam, electron cloud has been clearly identified and characterized in the PS using a dedicated setup with shielded button-type pickups. Efficient electron cloud suppression could be achieved with a stainless steel strip-line-type electrode biased to negative and positive voltages up to +/- 1 kV. For the 2008 run, a second setup was installed in straight section 84 of the PS where the stainless steel was replaced by a strip-line composed of an enamel insulator with a resistive coating. In contrast to ordinary strip-line electrodes this setup presents a very low beam coupling impedance and could thus be envisaged for long sections of high-intensity machines. Here, we present first comparative measurements with this new type of enamel clearing electrode using the nominal LHC beam with 72 bunches and 25 ns bunch spacing

INTRODUCTION

The electron cloud (EC) effect has been observed in several particle accelerators worldwide. Since the first production of high intensity LHC proton beams, intensive studies were performed at the CERN PS and SPS [1,2]. Apart from operational aspects with the existing synchrotrons, the EC effect may also constitute a serious limitation for the new CERN injector complex, namely the PS2 and SPS operated with PS2 beams [3]. Two possible approaches to suppress electron cloud are currently studied at CERN: vacuum chamber coatings, for example with amorphous carbon [4], to reduce the secondary electron yield (SEY) and clearing electrodes.

CHARACTERISTICS OF CLEARING ELECTRODES

For a large scale application in a particle accelerator, any type of distributed clearing electrode must fulfil several criteria, which are summarized below [5]:

- Good vacuum and mechanical properties. The clearing electrodes must be compatible with ultrahigh vacuum (UHV) conditions, provide low static and dynamic outgassing rates, which are comparable with stainless steel. They should be easy to clean for UHV and withstand a bakeout temperature up to 300°C, a good mechanical stability is also required to avoid deformation during installation, bakeout, and operation of the accelerator
- Limited aperture reduction. The aperture reduction of a clearing electrode should be very small, possibly only fractions of a millimeter. The necessity of an ante-chamber should be avoided.
- Low secondary emission yield (SEY). The efficiency of clearing electrodes is reduced when their SEY is higher than that of the beam pipe material.
- Bias voltage. Clearing electrodes should stand a DC voltage of the order of at least ± 1 kV. High-voltage contacts must be carefully designed to avoid sparking and clearing electrode degradation. For electrodes with a highly resistive coating, the voltage drop along the electrode due to the clearing current and leakage should be small comparable to the bias voltage.
- Good thermal coupling to a heat sink. In case high heat loads are expected, *e.g.* due to resistive losses in the electrode, a good thermal contact to a heat sink (*e.g.* the vacuum chamber) is needed.
- Radiation hardness and activation. The electrodes should withstand the beam losses impacting onto the beam pipe. The usage of materials susceptible to activation should be very limited.
- Magnetic properties. Ferromagnetic materials must be avoided to avoid an interference with beam diagnostics and the beam itself.
- Low longitudinal and transverse impedance. Clearing electrodes should not substantially increase the machine impedance.

BEAM COUPLING IMPEDANCE ASPECTS

One important motivation for using printed electrodes is a reduction of the clearing electrode related beam coupling impedance as compared to conventional metallic button or stripline electrode. The basic concept behind is the idea of the "invisible" clearing electrode [6].This is essentially some ceramic support structure with a resistive film which has an impedance per unit square much larger than 377 Ω. It turns out that a critical issue can be the

*now at Fraunhofer Institute for Solar Energy Systems, Freiburg, Germany presence of the dielectric support layer for the imaginary part of the transverse impedance [7]. The actual highly resistive coating itself is not very relevant in this respect if its resistive value is larger than 10 kΩ/square.

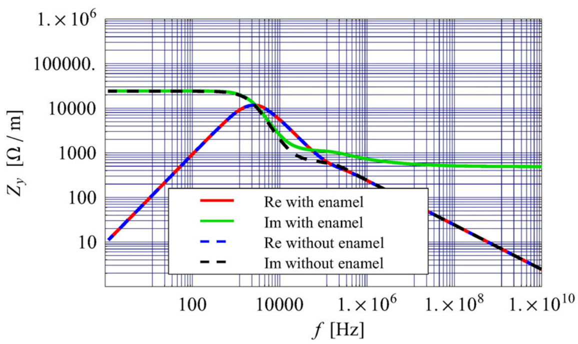

Figure 1: Calculation of the transverse impedance of a 0.5 mm thick dielectric layer (ε_r = 5) inside a 2 mm thick stainless steel pipe with 50 mm radius and 1 m length. For this rotationally symmetric structure the Burov-Lebedev formula was used [5].

TECHNOLOGICAL ISSUES

The considered electrode geometry requires the deposition of a thin dielectric layer inside the beam pipe. Due to the stringent requirements of the accelerator environment the properties of this dielectric are critical for the application. For reasons of dielectric strength, a thickness of about 0.1 mm or more is necessary. Potential technologies are the application of enamel and plasma spraying. Enamel has good mechanical stability, strength and adhesion and good thermal contact to the beam pipe. Its dielectric strength is good and it can stand baking at 300°C or more [5]. Plasma spraying offers similar features, however for both technologies vacuum properties, SEY, and radiation hardness have to be analyzed in more detail.

On top of the dielectric, a highly resistive coating, preferably in thick-film technology, has to be applied. Its surface resistance $R_\in$ must be chosen higher than the free space impedance of Z_0 = 377 Ω ("invisibility" condition) but small enough that the voltage drop along the electrode is not too high. Values of $R_\in$ = 10 kΩ to 100 kΩ appear to be suitable. There is a large body of experience with thick film coated surfaces in UHV applications [5]. The SEY of thick-film layers should be determined by measurements.

EXPERIMENTAL SETUP

An electron cloud diagnostic, installed in PS straight section (SS) 98, is operational since March 2007. It comprises shielded button-type pickups, a fast vacuum logging using a Penning gauge, a dipole magnet, and a 316 LN stainless steel stripline electrode for electron cloud clearing. A detailed description of the setup and the results obtained can be found in [1,8]. A second setup was installed in SS84 during the 2007/08 winter shutdown. The new installation is very similar to SS98 with the exception that the stainless steel clearing electrode is replaced in SS84 by an enamel clearing electrode. The setup is depicted schematically in Fig. 2.

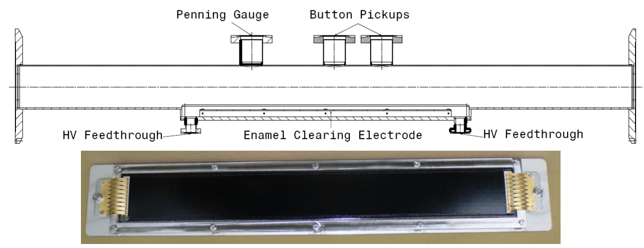

Figure 2: PS electron cloud experiment installed in SS84 comprising the enamel clearing electrode, a shielded Penning gauge and two shielded button-type pickups.

ENAMEL CLEARING ELECTRODE

The clearing electrode is composed of a 2 mm thick 316 LN stainless steel substrate, 426 mm long and 72 mm wide, coated with a 100 µm enamel layer on top of a 10 µm resistive layer with R ≈ 10 kΩ. At its extremities a conductive paint, gold coated CuBe fingers, and standard high-voltage feedthroughs are used to bias the enamel electrode up to ±1 kV (Fig. 3)

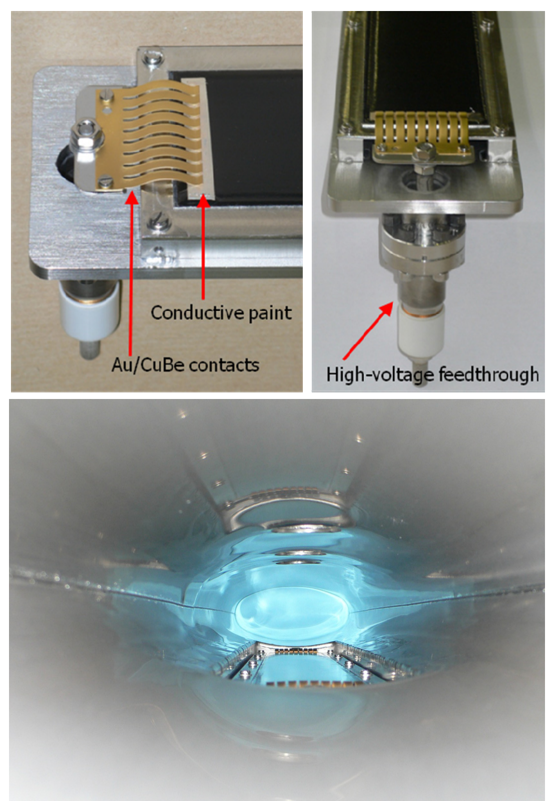

Figure 3: Enamel clearing electrode with high-voltage Au/CuBe contact fingers (top), downstream view into SS84 vacuum chamber showing the stripline electrode inside an antechamber (bottom).

RESULTS

Comparative measurements were performed in October 2008 using the nominal LHC beam with 72 bunches and

25 ns bunch length. The presence of electron cloud was immediately seen with the SS98 and SS84 pickups as well as the corresponding fast pressure rises measured with the Penning gauges on both setups. The pickup signals have been measured for clearing voltages ranging from -500 V to +500V. It was found that for positive stripline voltages U_{SL}, both clearing electrodes behave very similar, electron cloud suppressions is obtained for U_{SL} > +300 V.

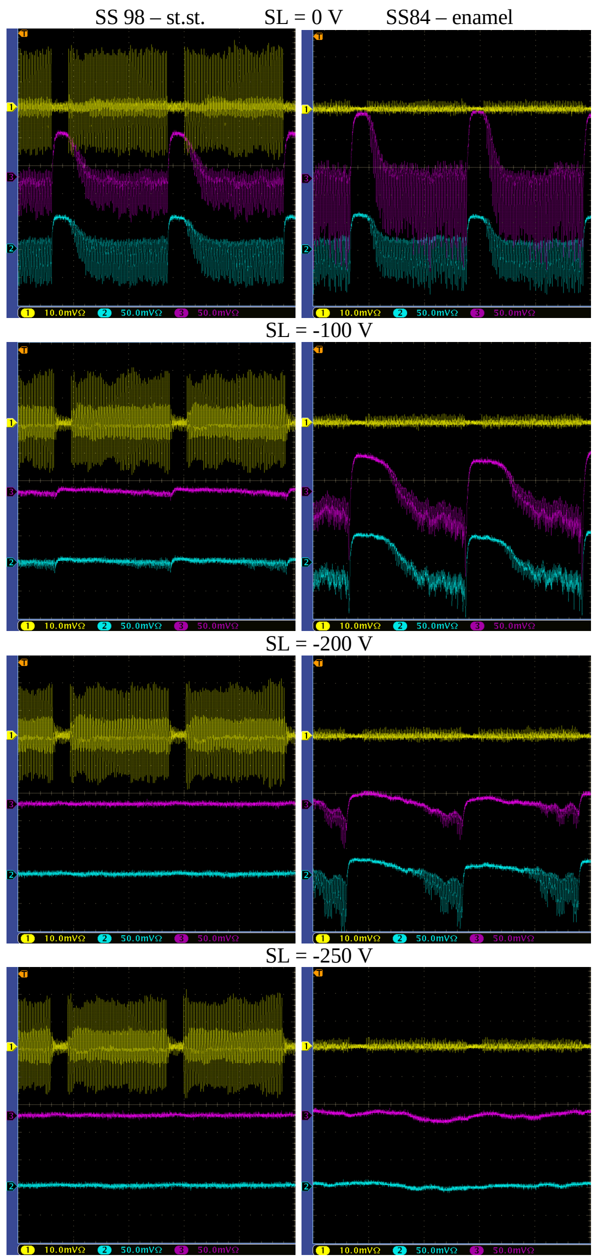

Figure 4: Measured electron cloud signals of the stripline electrodes (yellow) and the button pickups (magenta, cyan) during passage of the nominal LHC beam in SS98 (left column: stainless steel clearing electrode) and SS84 (right column: enamel clearing electrode) as a function of negative clearing voltages varied between 0 and -250 V.

For negative voltages a different behavior was found for U_{SL} < -300 V. The electron cloud suppression of the tested enamel is less efficient than bare stainless steel (Figure 4). This should be due to the different clearing field distributions, as the resistive layer of the enamel electrode is closer to the ground plane than for the stainless steel electrode and there is enamel with a permittivity of ~5 added. For U_{SL} > -500 V the enamel clearing electrode is as good as the stainless steel one although the SS84 pickup signals were a bit more "noisy" than in SS98. The induced beam signals on the enamel stripline are much smaller than for bare stainless steel. This implies that coupling between the beam and the enamel electrode is low, which demonstrates the principle of such low beam-coupling impedance clearing electrodes. The small residual coupling is due to the CuBe contact fingers and not to the electrode itself; it could be further reduced by optimizing the mechanical design, *e.g.* by "hiding" the contact fingers in an indentation.

We have not measured the SEY of our enamel electrode. Assuming a higher value than for stainless steel, this might also partly explain the slightly suppressed clearing efficiency for low negative bias voltages as shown in Figure 4.

CONCLUSIONS

In the CERN PS we have compared the efficiency of two different clearing electrodes. Enamel acts very similar in terms of electron cloud suppression as stainless steel. Thus the functionality of enamel as electron cloud suppressor with low beam-coupling impedance has been clearly demonstrated. However, for potential large scale application of this technology, practical production aspects, in particular for coating techniques inside a beampipe, have to be evaluated. So far, PS clearing electrodes have been placed inside ante-chambers to avoid a vacuum chamber aperture reduction. For future accelerator applications, *e.g.* in PS2 at CERN, any clearing electrode technique has to be applied to curved vacuum chambers over a considerable length, the necessary high-voltage biasing seems also not obvious without aperture reduction. Although distributed clearing electrodes are probably less critical than low SEY films with respect to their long term behavior (ageing) but they are certainly more demanding in hardware needs (vacuum feedthroughs, cables, power supplies, controls) and beam aperture optimization.

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