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A NEW TYPE OF DISTRIBUTED ENAMEL BASED CLEARING ELECTRODE

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Abstract

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INTRODUCTION

In many high-intensity particle accelerators the electron cloud effect turned out to be a serious issue. A potential remedy is clearing electrodes for suppressing the EC build-up. In several machines button type electrodes for electron or ion clearing have been installed [1–3]. Longer electrodes have also been used [1, 4, 5]. However, as the design length of such electrodes increases, many requirements become more stringent. Retrofittable clearing electrodes for the LHC cold arcs were proposed, as well [6].

Clearing electrodes must be compatible with the accelerator environment where they are to be installed. They must have good mechanical stability, good vacuum properties, acceptable aperture reduction, low longitudinal and transverse impedance, good thermal coupling to the chamber and a low secondary emission yield (SEY). Furthermore they should withstand baking, the DC clearing voltage and ionizing radiation.

In this paper a layout for distributed clearing electrodes is proposed and the beam coupling impedance, clearing efficiency and technological issues examined.

ELECTRODE CONFIGURATION

Numerical simulations in the literature showed that a single clearing electrode at negative polarity can efficiently suppress the EC build-up, while two electrodes at opposite polarities may even enhance the build-up [2, 7]. Flat electrodes are advantageous compared to wires, since the former provide a good electrostatic clearing field while keeping the aperture reduction to a minimum. For this reason we focus here on a single flat electrode at -1 kV.

The first option for implementing clearing electrodes is to build them as metallic electrodes. In this case we have a well-known stripline pick-up, which will have a substantial impedance and heat dissipation. Alternatively, a highly resistive layer on an isolating strip can be used. If the layer's surface resistance is much higher than the free space impedance ($R_\square \gg Z_0 = 377$ Ω) such a coating is "invisible" to the electromagnetic wave in the sense that it does not act like a metallic electrode [8]. The electrode together with the underlying insulator rather behaves like a bulk dielectric in the frequency range of interest, which typically extends up to a few GHz. This option was considered in more detail, since it appears most promising for long structures.

The reference geometry consists of a circular 50 mm radius chamber where a single 25 mm wide and 0.1 mm thick dielectric strip is deposited. This layer can be made e.g. of enamel or a ceramic such as alumina. On top of this strip a ≈ 20 mm wide highly resistive thick film coating with a few 10 µm thickness is applied. Each section of the electrode could have up to a few meters length and be installed both in straight sections as well as in magnets. At one or both ends of the electrode the bias voltage is applied by feedthroughs. The advantages of such a structure are good mechanical stability, small aperture reduction and a good thermal contact to the beam pipe.

IMPEDANCE

The impedance of the highly resistive clearing electrode described in the previous section was examined analytically as well as by numerical simulations. It was assumed that the dielectric strip together with the thick-film coating acts like a low-loss dielectric in the frequency range of interest. Such a structure acts like a microwave Cerenkov pick-up. For the analytical approach a rotationally symmetric structure consisting of a thin dielectric layer inside of a circular metallic chamber was assumed. The results were cross-checked with numerical simulations using CST Microwave Studio and HFSS [9, 10] and more general structures, in particular thin dielectric stripes were examined. The permittivity was assumed to be $\epsilon_r \approx 5$, as measured on a sample of enamel coating. The dielectric losses were neglected.

Longitudinal impedance

The analytic evaluation of the longitudinal impedance is based on the analogy of the field pattern of highly relativistic beams and TEM transmission lines. For a thin dielectric layer inside a circular chamber extending over the machine circumference the impedance is given to first order by

$$\Im\{Z/n\} \approx \sqrt{\frac{\mu_0}{\epsilon_0}} \left(1 - \frac{1}{\epsilon_r}\right) \frac{t}{R}, \qquad (1)$$

where t is the dielectric thickness and R the chamber radius. The properties of the longitudinal impedance are as

follows:

- Since to first order a thin layer of lossless dielectric can only delay the wakefield, only the $\Im\{Z/n\}$ is affected by the presence of the electrodes.
- In the relevant frequency range $\Im\{Z/n\}$ is constant.
- From Eq.1 it can be seen that for thin layers $\Im\{Z/n\} \propto t$. Numerical simulations showed that $\Im\{Z/n\}$ is in fact proportional to the dielectric cross-section.
- $\Im\{Z/n\}$ does not depend very strongly on ϵ_r.

To give concrete examples Z/n was estimated for chamber geometries similar to the CERN Proton Synchrotron (PS) and Super Proton Synchrotron (SPS) for electrodes all around the ring:

- PS: Round 50 mm radius chamber, one single 25 mm wide and 0.1 mm high strip (corresponds to reference geometry): $\Im\{Z/n\} \approx 0.07\ \Omega$. Today's broad-band machine impedance: $Z/n \approx 20\ \Omega$.
- SPS: Round 25 mm radius chamber, one single 20 mm wide and 0.1 mm high strip: $\Im\{Z/n\} \approx 0.3\ \Omega$. Today: $Z/n \approx 7\ \Omega$.

These results were cross-checked with simulations done using GdfidL, showing a very good agreement [11, 12].

Transverse impedance

The transverse impedance Z_{TR} of a multi-layer structure with rotational symmetry can be determined from the Burov-Lebedev formula [13]. Fig. 1 shows Z_{TR} for a thin dielectric layer covering the entire azimuth of a stainless steel pipe compared to a reference pipe without dielectric. At very low frequencies no change was found with respect to the resistive wall impedance of the reference pipe. Above 10 kHz $\Im\{Z_{TR}\}$ is increased, whereas $\Re\{Z_{TR}\}$ is not affected. For thin layers $\Im\{Z_{TR}\}$ is proportional to the layer thickness.

In numerical simulations, when the coating is reduced to strips at the top and bottom of the beam pipe, the horizontal $Z_{TR,x}$ is significantly decreased, whereas there is only a rather small impact on the vertical $Z_{TR,y}$. For two electrodes covering $36°$ each $Z_{TR,y}$ goes down by about a factor two. Going from two to one strip $Z_{TR,y}$ decreases by roughly a factor 2. For strips much narrower than the chamber radius $Z_{TR,y}$ is proportional to the strip width.

In the following rectangular chamber geometries as in EC build-up simulations in [14] were used. Scaling the results for the CERN PS and SPS we find for electrodes all around the machine circumference as a first approximation:

- PS: 80×40 mm half axes, one single 25 mm wide and 0.1 mm high strip: $\Im\{Z_{TR}\} \approx 0.04$ MΩ/m, today: $Z_{TR} \approx 3$ MΩ/m
- SPS: 80×20 mm half axes, one single 20 mm wide and 0.1 mm high strip: $\Im\{Z_{TR}\} \approx 4$ MΩ/m, today: $Z_{TR} \approx 20$ MΩ/m
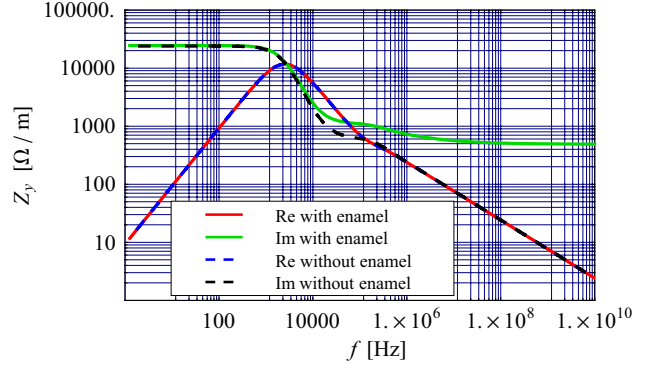

Figure 1: Calculation of the transverse impedance of a 0.5 mm thick dielectric layer ($\epsilon_r = 5$) inside a 2 mm thick stainless steel pipe with 50 mm radius.
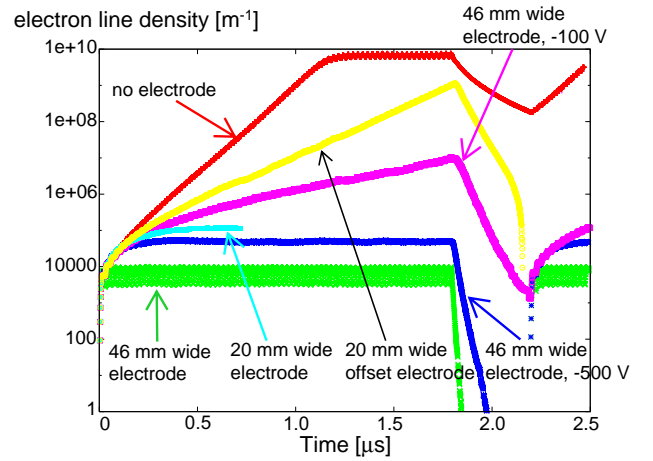

Figure 2: Simulation of the clearing efficiency of a single electrode having a clearing voltage of -1 kV for different electrode geometries at PS top energy (26 GeV/c).

The large difference between the two machines comes from the smaller SPS chamber size, which enters with the third power, and the larger SPS circumference. A cross-check with GdfidL results showed good agreement [11]. It would be possible to reduce $Z_{TR,y}$ by installing two off-center electrodes, however $Z_{TR,x}$ rises significantly in this case and the clearing efficiency for a given voltage decreases.

CLEARING EFFICIENCY

The clearing efficiency of several electrode types was simulated for the case of the PS straight section chamber at top energy and a magnetic field of 10 Gauss using the ECLOUD code [15]. Fig. 2 shows that the 46 mm wide electrode works best, but also the 20 mm wide centered electrode is effective for a -1 kV clearing voltage, while an off-center electrode does not suppress the EC build-up for this clearing voltage.

TECHNOLOGICAL ISSUES

The electrode geometry considered 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 of alumina. Enamel has good mechanical stability, strength and adhesion on metallic substrate and good thermal contact to the beam pipe. Its dielectric strength is good and it is thermostable at $450°$ or more [16–19]. Plasma spraying offers similar features, however for both technologies vacuum properties, SEY and radiation hardness have to be analysed in more detail.

On top of the dielectric, a highly resistive coating, preferably in thick-film technology, has to be applied. Its surface resistance $R_\square$ must be chosen higher than the free space impedance of $Z_0 = 377\ \Omega$ ("invisibility" condition) but small enough that the voltage drop along the electrode is not too high. Values of $R_\square = 10$ kΩ to 100 kΩ appear to be suitable. Depending on the resistivity of the coating a substantial voltage drop may appear for a large clearing current. However since the present concept is to prevent already the EC build-up, we would not expect clearing currents beyond a few μA. There is a large body of experience with thick film coated surfaces in ultra-high vacuum applications [5, 8]. The SEY of thick-film layers should be determined by measurements. Earlier, Aquadag (a graphite-based paint) has been successfully used as an antistatic high impedance coating on dielectric surface seen by the beam [20].

CONCLUSION

The concept of distributed electron cloud clearing electrodes installed in an accelerator beam pipe has been discussed. Any electrode should fulfil a number of requirements, including mechanical stability, vacuum compatibility and low beam coupling impedance. The latter can be achieved with a highly resistive layer applied on a dielectric strip. In order to minimize the impedance of such a structure as well as the aperture reduction, the dielectric should be made as thin as possible. A thickness of the order of 0.1 mm should be possible for a layer that stands typical clearing voltages of about 1 kV. Vitreous enamel appears to be an interesting candidate for the dielectric, but vacuum properties and other issues should be checked in more detail. Furthermore, the clearing efficiency of a typical electrode geometry was confirmed in numerical simulations.

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REFERENCES

[1] Pedersen, F., Poncet, Alain., Soby, L., *The CERN antiproton accumulator clearing system with ion current measurements as a residual neutralization diagnostic*, CERN-PS-89-17-ML, Geneva (1989)

[2] Wang, L. F., *Mechanism of electron cloud clearing in the accumulator ring of the Spallation Neutron Source*, PRST 7, 034401 (2004)

[3] Wei, L. et al., *Electron Cloud Effects: Observations, Mitigation Measures, and Challenges in RHIC and SNS*, CARE-HHH-APD Workshop 2004, CERN, Geneva (2004)

[4] Tavares, P. F., *Ion Clearing in the LNLS UVX-2 Soft X Ray Source*, Proceedings of the EPAC 1992, Berlin (1991)

[5] Spataro, B., Zobov, M., *Wake Fields and Coupling Impedance of the Daphne Electron Ring*, Daphne Technical Note G-64 (2005)

[6] McIntyre, P. M., *Killing the Electron Cloud Effect in the LHC Arcs*, Proceedings of the PAC 2005, Portland (2005)

[7] Zimmermann, F., *Beam Sizes in Collision and Electron-Cloud Suppression by Clearing Electrodes for KEKB*, CERN-SL-Note-2001-022, Geneva (2001)

[8] Caspers, F., Delahaye, J. P., Godot, J. C., Hubner, K., Poncet, A., *EPA beam-vacuum interaction ion clearing system*, Proceedings of the EPAC 1988, Rome, CERN-PS-88-37-ML (1989)

[9] http://www.cst.com

[10] http://www.hfss.com

[11] Bruns, W., *Wake Potential of an Array of Thin Electrodes in a Beam Pipe*, Proceedings of the ECL2 workshop, CERN, Geneva (2007)

[12] http://www.gdfidl.de

[13] Burov, A., Lebedev, V., *Transverse Resistive Wall Impedance for Multi-layer Round Chambers*, EPAC 2002, Paris (2002)

[14] Furman, M. A., *E-Cloud in PS2, PS+, SPS+*, Proceedings LHC-LUMI-06 (2006)

[15] Kroyer, T., Caspers, F., Metral, E., Zimmermann, F., *Distributed Electron Cloud Clearing Electrodes*, Proceedings of the ECL2 workshop, CERN, Geneva (2007)

[16] Behler, F.-J., Nose, G., Kunkel, H., *Industrial Enamel – Foundations, production, applications and CERN-tests*, Proceedings of the ECL2 Workshop, CERN, Geneva (2007)

[17] Wendel, J. C., Hellmold, P., *Vitreous Enamel - A Highly Effective Material Compound*, Proceedings of the ECL2 Workshop, CERN, Geneva (2007)

[18] Biscardi, C., Hseuh, H. and Mapesa, M., *Application of porcelain enamel as an ultra-high-vacuum-compatible electrical insulator*, J. Vac. Sci. Technol. A 18.4. (2000)

[19] Severgin, Yu. P., Filimonov, M. Z., *Insulating and Metal-Ceramic Materials for Particle Accelerators*, PAC 1993, Washington, DC, USA (1993)

[20] Didenko, A. N. et al., *Generation of High Power Ion Beams in Ballistic Focusing Diodes*, IEEE Transactions on Nuclear Science, Vol. NS-28, No. 3 (1981)