A NEW TYPE OF DISTRIBUTED ENAMEL BASED CLEARING ELECTRODE

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Motivation

- In many high-intensity particle accelerators the electron cloud (EC) effect turned out to be a serious issue.
- A potential remedy is clearing electrodes, which have been installed in several machines for suppressing the EC build-up or for ion clearing. So far, however, the experience with clearing electrodes is mostly limited to button-type electrodes, but longer electrodes have also been used.
- In order to suppress the EC effect over longer sections of a machine, distributed clearing electrodes are desirable.
- However, as the design length of such electrodes increases, a set of stringent requirements and limitations shows up.

Desirable features

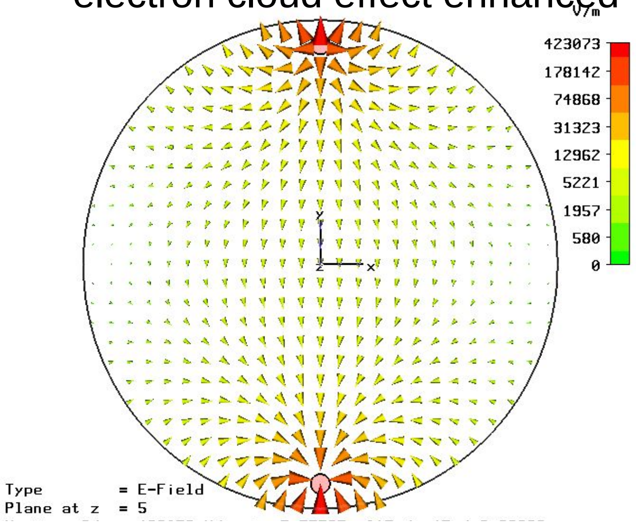
Clearing electrodes should fulfil as many as possible of the following points:

- Good mechanical stability
- Good vacuum properties
- Limited aperture reduction
- Low longitudinal and transverse impedance
- In case a significant heat load is expected: good thermal contact between the electrode and some heat sink, e.g. the beam pipe
- Low secondary emission yield (SEY)
- Electrodes should stand baking in case this is needed
- They should stand a DC voltage of the order of 1 kV
- Radiation hardness

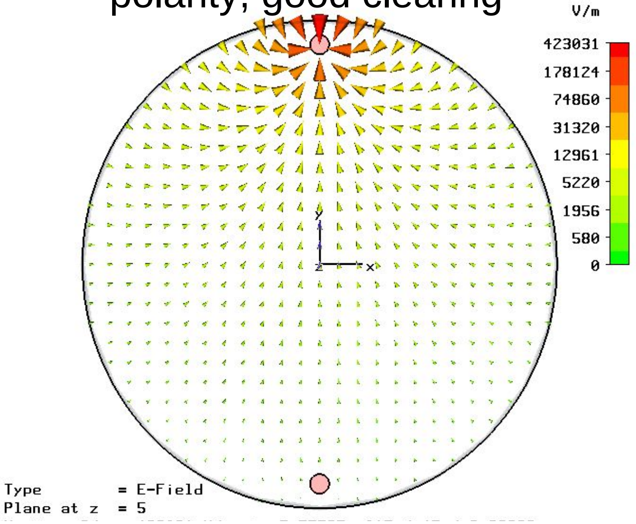
How many electrodes?

- Simulation results for the electron cloud clearing efficiency with two wire electrodes in KEKB show an interesting effect [1]
  - With one electrode at +1 kV and the second at -1 kV multipacting is enhanced, due to high energy gain close to positive electrode (Fig. a)
  - For only one electrode with negative polarity good electron clearing is found (Fig. b)
  - With both electrodes at negative polarity the clearing effect is slightly enhanced (Fig. c)
  - A similar effect was found by Wang et al. [2]
- If these results can be applied to other machines, one single cleaning electrode should be enough => good for impedance, aperture, manufacturing,…

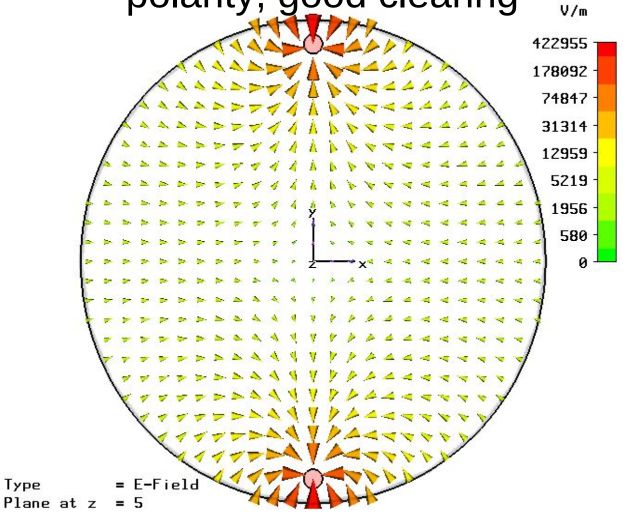
(a) Electrodes at opposite polarity, electron cloud effect enhanced



(b) One electrode at negative polarity, good clearing



(c) Both electrodes at negative polarity, good clearing



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

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

Flat electrodes versus wires (1)

- Let's consider two electrode geometries among the many options: Flat electrodes and wires
- When wires are moved close to the beam pipe wall, the electrical field in the center E_c and the potential U_c decrease fast
- For a comparable spacing from the wall flat electrodes provide a higher clearing field in the center while keeping the aperture reduction to a minimum

Beam pipe radius 50 mm

Top electrode at -1 kV

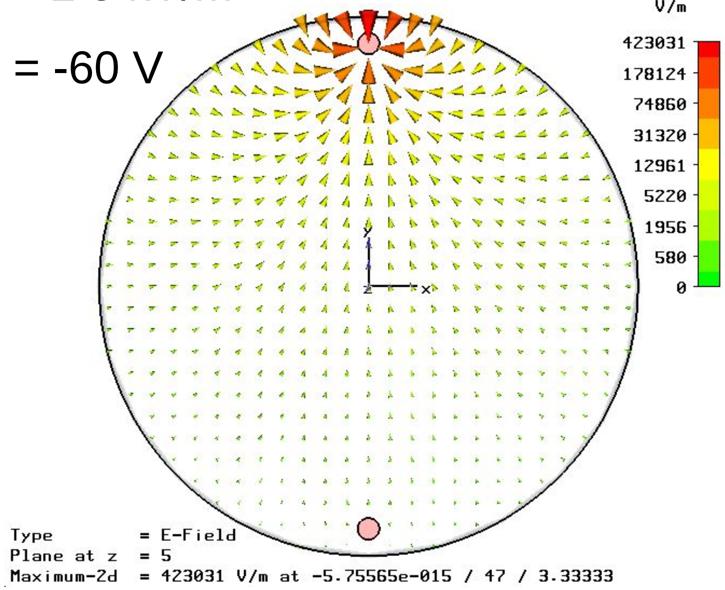
Electric field plotted [log. scale]

Left: 2 mm radius electrode 5 mm from the wall

Right: 20 mm wide and 1 mm thick electrode 1 mm from the wall

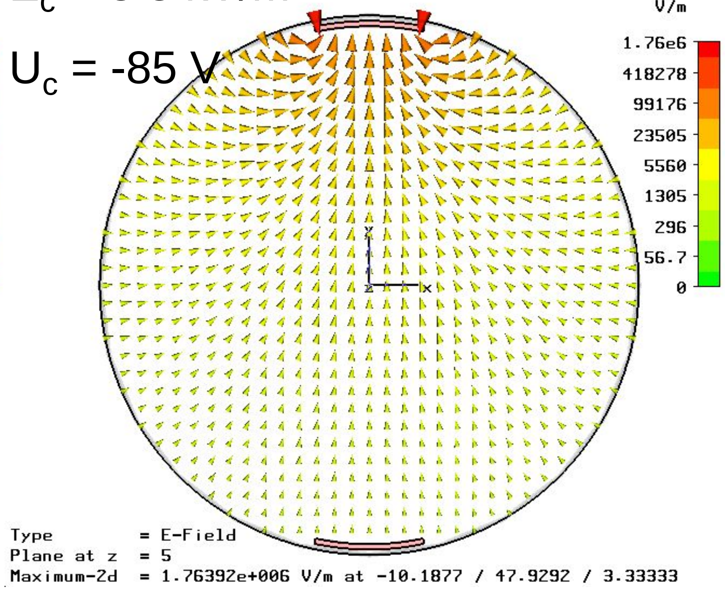
E_c = 2.5 kV/m

U_c = -60 V



E_c = 3.8 kV/m

U_c = -85 V



Metallic versus high resistivity electrodes

In dependence of the conducting material we can have

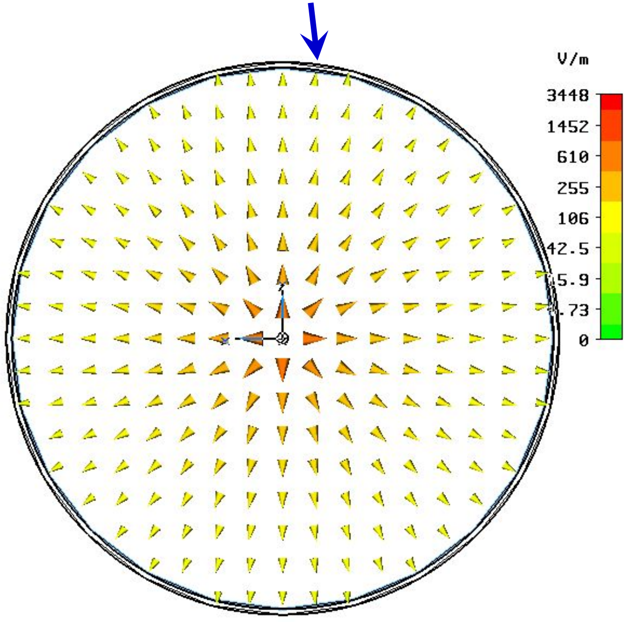
- Metallic clearing electrodes:
  - A good conductor supported only by the feed-throughs, e.g. a classical strip-line
  - A good conductor supported by some dielectric layer on the inner surface of the beam pipe
- A highly resistive layer on a dielectric substrate: If the layer’s surface resistance is much higher than the free space impedance such an electrode is “invisible” to the electromagnetic wave in the sense that it does not act like a metallic electrode. The electrode rather behaves like a dielectric. In analytic calculations and simulations this electrode was approximated as a dielectric strip.

High resistivity electrode

- We all know about the properties of conventional stripline electrodes. They have in general a substantial impedance.
- Now we focus on a highly resistive coating on a dielectric substrate.
- The idea consists of building a thin electrode structure directly attached to the beam screen. Let’s assume a 50 mm radius pipe.
- As the insulating dielectric a thin enamel layer can be used, e.g. a single 25 mm wide strip with 0.5 mm thickness
- On top of that a highly resistive 20 mm wide strip is deposited
- At one end of the strip a feedthrough is installed to bias the resistive strip to say -1 kV to ground (beam pipe)
- Each section of the electrode could have to length of up to a few meters and be installed in straight sections as well as in magnets
- Such a structure has a several advantages:
  - Good mechanical stability
  - Small aperture reduction
  - Good thermal contact to the beam pipe
  - The SEY of the electrode should probably not have such a large impact, since it repels electrons

High resistivity electrodes – Z/n (1)

- The insulating and the highly resistive dielectric strips are approximated by a dielectric with permittivity ε
- The longitudinal impedance was estimated analytically for a structure with rotational symmetry
- It was assumed that in analogy to a TEM line the dielectric acts mainly by introducing a phase shift => imaginary part of longitudinal impedance Im(Z/n)
- This corresponds to the change in group velocity on a TEM line
- For thin dielectric layers
  - Im(Z/n) is proportional to the dielectric cross-section
  - Im(Z/n) increases with ε
- A quick scaling yields the simulated Daphne clearing electrode impedance [1] to within a factor 2

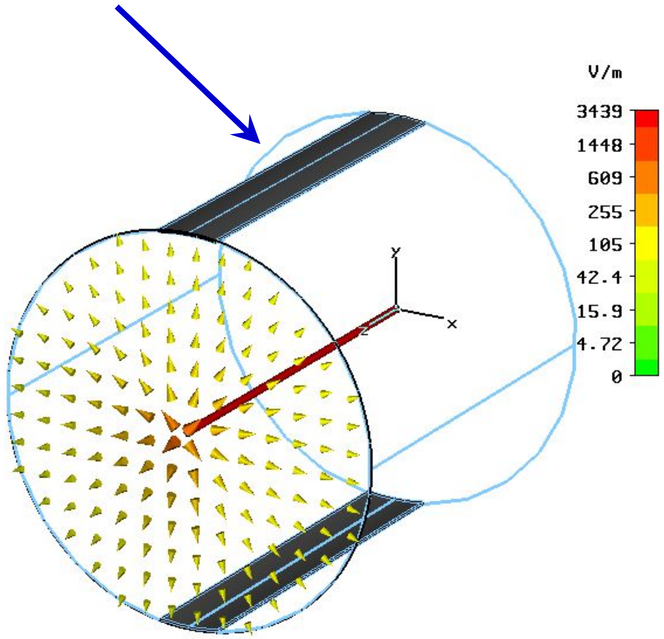


1 mm dielectric layer inside a radius 50 mm pipe

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

High resistivity electrodes – Z/n (2)

- The analytical results were checked with numerical simulations under CST Microwave Studio and HFSS.
- A very good agreement was found for thick layers (within 10 % for a 10 mm thick layers in 100 mm diameter pipe), for thinner layers the maximum discrepancies are somewhat higher (within 50 % for a 1 mm thick layer)
- In addition, in simulations it was verified that Im(Z/n) is about proportional to the dielectric volume also when the dielectric does not cover the full azimuth
- Im(Z/n) is flat up to very high frequencies
- Estimations for one 0.1 mm thick electrode with $\varepsilon = 5$ in a round pipe around the entire machine
  - PS (pipe radius 50 mm, 25 mm dielectric width): Im(Z/n)= 0.07 Ω (entire machine today: $Z/n \approx 20\ \Omega$)
  - SPS (pipe radius 25 mm, 20 mm dielectric width): Im(Z/n)= 0.3 Ω (entire machine today: $Z/n \approx 10\ \Omega$)



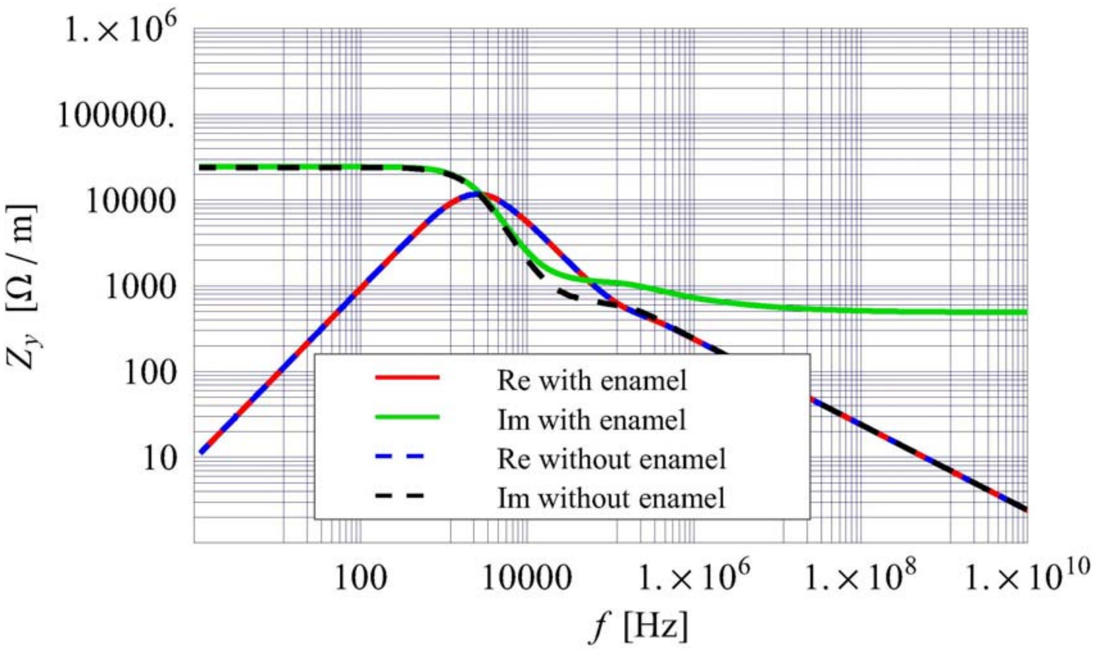
Two 0.5 mm thick dielectric strips inside a radius 50 mm pipe

High resistivity electrodes – Z_{TR}

- The transverse impedance was estimated analytically for structures with rotational symmetry using the Burov-Lebedev formula and simulated using CST Microwaves Studio and HFSS [1]
- Preliminary results scaled to one 0.1 mm thick centered electrodes with $\varepsilon = 5$ along the entire machine
  - PS (electrode width 20 mm):

    Im($Z_{TR,y}$) = 0.04 MΩ/m (entire machine today: $Z_{TR} \approx$ 5 MΩ/m)
  - SPSx (electrode width 15 mm):

    Im($Z_{TR,y}$) = 4 MΩ/m (entire machine today: $Z_{TR} \approx$ 20 MΩ/m)
- The huge difference between PS and SPSx comes from the smaller SPSx vacuum pipe and the larger ring



[1] T. Kroyer, F. Caspers, E. Metral, F. Zimmermann, Distributed electron cloud clearing electrodes, Proceedings of the ECL2 Workshop, CERN, Geneva, 2007

Clearing efficiency

- The electron cloud build-up in the PS was simulated with ECLOUD for different clearing electrode geometries
- For a magnetic field of 10 G substantial multipacting in predicted (red trace)
- A single very wide electrode (46 mm width) is very efficient in suppressing the e-cloud (green trace)
- A single 20 mm wide enamel electrode in the center of the beam pipe at -1 kV works, too (light blue trace)
- For a single 20 mm wide electrode 30 mm offset from the beam pipe center -1 kV does not suffice (yellow trace)

Courtesy: Frank Zimmermann

Parameters:

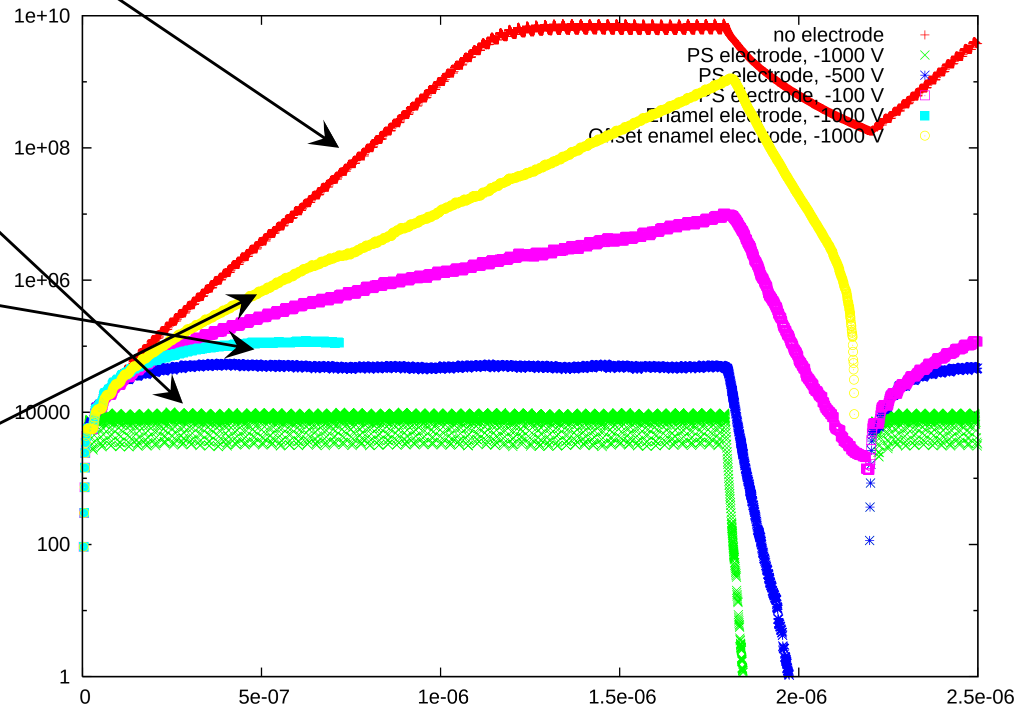
10 nanoTorr pressure, SEYmax =1.5

primary electron energy at max.SEY =239.5 eV

73mm x 35 mm = half aperture

rms beamsizes: σ_x = 1.58 mm, σ_y =0.42 mm, σ_z =75 cm

10 Gauss dipole field



The properties of enamel

Enamel as an insulating dielectric deposited in the beam pipe offers

- Good mechanical stability, strength and adhesion
- Good thermal contact to the beam pipe
- It can stand a several kV
- Thermostable up to 450 degrees C or more depending on the material
- For these reasons it will be an interesting candidate for the insulator of clearing electrodes
- With appropriate electrode geometries it is possible to minimize the aperture reduction by the electrode
- Vacuum properties, SEY and radiation hardness have yet to be analysed in more detail
- Enamel coatings have been used at several occasions in accelerator high vacuum systems

How to adapt existing enamel technoly

- Conventional enamel technology cannot be applied in a straightforward manner to produce strip-like coatings inside a beam pipe
- First results of a recently developed coating technique are shown here
- On top of this enamel strip an isolated conductive layer (Ti) has been deposited using sputtering technology
- In parallel enamel coating tests are underway on thin stainless steel and also on copper sheets to implement retro-fittable inserts for beam-pipes

Conclusion

- The potential of enamel as a material for electron cloud clearing electrodes was discussed
- A high resistivity coating on an insolating enamel strip looks like an interesting candidate for distributed clearing electrodes
- A sufficient clearing field can be applied with such electrodes, and a clear clearing effect is predicted by simulations for the CERN-PS
- However, such structures do have a non-negligible impedance, but it should be possible to limit it by minimizing the enamel thickness
- Vacuum properties, SEY and radiation hardness of enamel will be investigated in more detail

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