Electron cloud mitigation via new materials and material coating.

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The "e-cloud" phenomenon (in pils)

The accelerated particle beam produces SR and/or $e^-$ that, by hitting the accelerator’s walls generate photo-$e^-$ or secondary-$e^-$. Such $e^-$ can interact with the beam (most efficiently for positive beams) and multiply, inducing additional heat load on the walls, gas desorption and may cause severe detrimental effects on machine performance.
The Secondary $e^{-}$ Yield depends on the surface type and condition:

And has a tremendous impact to simulations (see calculation for LHC).

arc heat load vs. intensity, 25 ns spacing, ‘best’ model

heat load

Frank Zimmermann, LTC 06.04.05

heat load for quadrupoles higher in 2nd batch; still to be clarified
Towards mitigation Strategies….

✓ We measure and feed material parameters (R, PY, and SEY) into simulations.
✓ Understand their profound nature to:
✓ Optimize chemical (mechanical) process to reduce their detrimental influence on beam.
✓ Search for new material / coatings with intrinsically “good” parameters.

**XPS**

**SEY**

**SR Reflectivity and PY (@BESSY-II)**
Most of the existing and planned accelerator machines base the reaching of their design parameters to the capability of obtaining walls with a $SEY \sim 1.3$ or below!

**Mitigation Strategies**

- **Surface Scrubbing** (or conditioning)
- Intrinsically low $SEY$ material
- Geometrical modifications
- Electrodes in the lattice
- External solenoid field
Surface Scrubbing (or conditioning) → Efficiency (time & final SEY)…

Geometrical modifications → Impedance. Space, Machining costs.

Intrinsically low SEY material → Stability and material choice…

Electrodes in the lattice. → If possible… (Impedance, costs.)

External solenoid field. → Not always possible…
External solenoids: one example.

8-10-2010

450 GeV – 150 ns bunch spacing: Merged vacuum @ LHC
Exotic Vacuum behavior @ LHC:

450 GeV – 150 ns bunch spacing: Merged vacuum
Easily solved: Installation of Solenoids
Solenoids effect on pressure

After 20 min
\[ \Delta P \approx 7 \cdot 10^{-10} \]

Remove multipacting
Still primary electrons
Electrodes at DAΦNE
Electrodes at DAFNE

(a) Evolution of the averaged cloud density for different values of the electrode voltage. (b) e− cloud density at the end of the bunch train.
The Beam “scrubbing” effect is the ability of a surface to reduce its SEY after e⁻ bombardment.

from LHC PR 472 (Aug. 2001):

“…Although the phenomenon of conditioning has been obtained reproducibly on many samples, the exact mechanism leading to this effect is not properly understood. This is of course not a comfortable situation as the LHC operation at nominal intensities relies on this effect…”

co-laminated Cu for LHC beam screen

R. Cimino et al. PRL 109 064801 (2012)
co-laminated Cu for LHC beam screen

R. Cimino et al. PRL 109 064801 (2012)
Theo Demma (LAL) simulation:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>beam particle energy</td>
<td>GeV</td>
<td>7000</td>
</tr>
<tr>
<td>bunch spacing $t_b$</td>
<td>ns</td>
<td>25; 50; 75</td>
</tr>
<tr>
<td>bunch length</td>
<td>m</td>
<td>0.075</td>
</tr>
<tr>
<td>number of trains $N_t$</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>number of bunches per train $N_b$</td>
<td>-</td>
<td>72; 36; 24</td>
</tr>
<tr>
<td>bunch gap $N_g$</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td>no. of particles per bunch</td>
<td>$10^{10}$</td>
<td>10; 3.0</td>
</tr>
<tr>
<td>length of chamber section</td>
<td>m</td>
<td>1</td>
</tr>
<tr>
<td>chamber radius</td>
<td>m</td>
<td>0.02</td>
</tr>
<tr>
<td>circumference</td>
<td>m</td>
<td>27000</td>
</tr>
<tr>
<td>primary photo-emission yield</td>
<td>-</td>
<td>$7.98 \cdot 10^{-4}$</td>
</tr>
<tr>
<td>maximum $SEY \delta_{max}$</td>
<td>-</td>
<td>1.2(0.2) 2.0</td>
</tr>
<tr>
<td>energy for max. $SEY E_{max}$</td>
<td>eV</td>
<td>237</td>
</tr>
</tbody>
</table>

- Optimize the “scrubbing” process @ LHC with beam parameters enhancing the presence, in the cloud, of higher energy el.
- Give a more reliable estimate of the needed scrubbing time.
One research line is concentrated on creating very thin (some layers) “graphene” - like coatings on metal substrates to be used in accelerator to mimic what is actually happening during scrubbing.
**a-C films**
magnetron sputtering @ RT
$p(\text{Ar}) = 10^{-2} \text{ mbar}$  $\Delta t = 2\text{ min}$

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**C films on polycrystalline Cu**

$\delta_{\text{max}} = 1.3$

$\delta_{\text{max}} = 1.17$

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R. Larciprete, A. di Trolio and R. Cimino: in preparation
C films on polycrystalline Cu

R. Larciprete, A. di Trolio and R. Cimino: in preparation

TWWICE – 2014, Soleil 16-1-2014
the graphitization of the C films corresponds to a lower SEY

Larciprete, A. di Trolio and R. Cimino: in preparation
CERN Strategy (thanks to P. Costa Pinto)

SEY versus the energy of primary electrons

Coatings obtained by sputtering are similar. PECVD coatings have high SEY
The influence of Hydrogen in sputtered coatings is confirmed by experiments where $H_2$ is deliberately injected during the coating process.
COATING TECHNIQUES @ CERN
(thanks to P. Costa Pinto)

Coat actual beampipes by DC Hollow Cathode Sputtering (DCHCS)

Graphite targets (cells)

Pressure: 2.4 \times 10^{-1} \text{ mbar (Ar)}
Power: 1.8 \text{ kW (3A @ 600 V)}
0.5 \mu m in 20 hours

THE TECHNIQUE IS ALMOST MATURE FOR LARGE SCALE PRODUCTION
Geometrical Mitigation:

$\delta_{\text{max}} < 0.8 \ldots$ Impedence?
**Impedance enhancement factor**

(Code : Finite Element Method, PAC07 THPAS067, L Wang)

\[
\frac{Z_{\text{groovedsurface}}}{Z_{\text{smoothsurface}}} = \frac{H^2 ds}{H_0^2 W}
\]

The total impedance enhancement = \(\eta^*\) percentage of grooved surface

- \(p=1.25\text{mm}\) (period)
- \(d=2.5\text{mm}\) (depth)
- \(t=0.125\text{mm}\) (thickness)

\(= 1.64\)

- \(p=1.25\text{mm}\)
- \(d=2.5\text{mm}\)
- \(t=0.25\text{mm}\)

\(= 1.42\)
Sponge materials:
R. Cimino, A. Romano S. Petracca, I. Masullo etc: in Preparation
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Impedance, vacuum behaviour, desorption properties are still under study but seems very promising.
Conclusion

- E-cloud mitigation strategies are coming closer to mature solutions
- There is still a lot to do and to learn
- Synergic efforts, dedicated Surface, Material and Vacuum science laboratories are required to reach desired understanding and performances.
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