SPS: Scrubbing or Coating?

José Miguel JIMENEZ

On behalf of the LIU-SPS WG
Main Topics

- Introduction
- Status Report
- Pending Issues
- Review of objectives
- Conclusions
LIU-SPS Electron Cloud issues

- **SPS has to be prepared to digest:**
  - High bunch intensity: up to $2.5 \times 10^{11} \text{ ppb} @ 25 \text{ ns}$; $3.5 \times 10^{11} \text{ ppb} @ 50 \text{ ns}$
  - Small emittances (LHC requirements)

**cannot be guaranteed since electron cloud limitations have been identified:**
- **Beam instabilities:** transverse emittance blow-up and single bunch vertical instability
- **Pressure rise:** beam gas scattering, dose rates to tunnel and components

- **Improvements considered against Electron Cloud:**
  - Suppression of the build-up: *Clearing electrodes* and very low SEY ($<1.1$) coatings
  - Mitigation of the build-up: *Scrubbing Runs*
  - Cure of the induced effects (single bunch vertical instability): *High bandwidth feedback systems*
Criteria for decision

• **Safety**
  – The solution shall be safe for the operation of **ALL** SPS beams
  – The implementation shall not induce major **personnel safety issues** e.g. radiation, handling...

• **Performance**
  – The solution shall allow a **routine operation** with the bunch populations required by HL-LHC

• **Reliability**
  – The solution **shall not degrade with time** and behaviour shall be **predictable** and **reproducible**

• **Operation margin**
  – The solution **shall provide contingency** in case real situation is worst than our expectations

• **Other important criteria**
  – “**Best value for money**”
  – **Implementation duration** compatible with a long shutdown
  – **Infrastructures** required must be compatible with CERN existing options
Feasibility study is being completed…

- **Effective suppression** at all tested B fields with low (<100 V) bias voltage
- **Clearing electrodes** can ONLY be applied on few places of the machine: aperture restriction
- No solution found to apply clearing electrodes inside existing main magnet chambers
- **Feasibility studies** will be stopped (only one validation left: last version provided by KEK)
Validation being completed…

- **Very low SEY achieved by purifying the discharge during the coating process**
  - SEY below 1 obtained systematically

- **Lifetime**
  - Very small effect (drift up to 1.1) visible after 3 years in the SPS

- **Effect of venting**
  - Small increase up to 1.1, still below the EC threshold

- **Industrialisation of coating solutions**
  - Coating ex-situ (new beampipes)
    - Magnetron sputtering has been validated for both MBB and MBA beampipes
  - Coating in-situ (existing beampipes)
    - **Hollow cathode as baseline**
      - Successfully industrialised for MBB profiles
      - Successful for MBA over 2 m, tooling for 7 m beampipes should be ready by March’12, validation expected by end April’12
Status Report

EC Suppression – Very low SEY a-C Coatings

Reliability and Performances...

- **Static outgassing of a-C coating**
  - As expected, static outgassing is higher but **no difference** can be seen **after 2nd pump down**
  - **Dynamic vacuum** is expected to be **lower** because of the intrinsic good properties of a-C coating
Is it required to coat the entire beampipe?

- In dipole magnets, coating the top and bottom surfaces is required.
- In field free regions, coating the entire inner surface is required.

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Status Report

EC Mitigation – Scrubbing Runs

What’s required?

- Beam scrubbing is **successfully** used since 1999 to **reduce** the EC activity, **BUT**:
  - No scaling rule exists: EC builds-up can be non-monotonic and depends on:
    - Parameters which **totally change** the picture: Chamber’s shape and size, Bunch spacing, Presence of an externally applied magnetic field
    - Minor changes are also observed passing from the 26GeV to the 450GeV scenario due to change in: Bunch length, Geometrical emittance
  - **SPS** is more demanding than LHC

<table>
<thead>
<tr>
<th>Beampipe profile</th>
<th>SEY threshold @ $1.1 \times 10^{11}$ p/bunch</th>
<th>SEY threshold @ $2.5 \times 10^{11}$ p/bunch</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID 156 (LSS)</td>
<td>1.4</td>
<td>1.1</td>
</tr>
<tr>
<td>ID 130 (LSS)</td>
<td>1.45</td>
<td>1.05</td>
</tr>
<tr>
<td>MBA (Dipole)</td>
<td>1.4</td>
<td>1.45</td>
</tr>
<tr>
<td>MBB (Dipole)</td>
<td>1.15</td>
<td>1.25</td>
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- **Full suppression** was never achieved except in field free regions
- Corresponds to a **mitigation** solution and NOT to a suppressing method
Some issues to be followed…

- **Beam scrubbing has intrinsic limitations:**
  - Reaching smaller SEY ($\delta$) need larger electron bombardment doses: log behaviour
  - Lower bombardment dose when going closer to threshold for a given bunch population: ~3 orders of magnitude decrease!
  - Some materials like Stainless Steel show saturation of the dose effect in the Lab
  - Induces collateral effects: heating of kickers, internal dump heavily loaded

SPS = StSt / LHC = Copper
Scrubbing and limitations linked to material

Aluminium MUST be avoided!!
Except if coated...
How to enhance the EC close to threshold?

- **Strategies of e-cloud enhancement (input for SPS scrubbing run tests):**
  - 5ns bunch spacing
  - Slip stacking
  - 5-10% uncaptured beam
    - (alternative to) Filling SPS with 8 x 72 b @ 25 ns and 26 GeV
  - PS bunch splitting deregulation (Bunch intensity modulation)

<table>
<thead>
<tr>
<th>Beam configuration</th>
<th>Scrub. dose enhancement factor</th>
<th>Entirely scrubs the required region</th>
<th>Additional remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 ns beam</td>
<td>4</td>
<td>NO</td>
<td>At least two batches required</td>
</tr>
<tr>
<td>Slip stacking</td>
<td>5</td>
<td>YES</td>
<td>(10+15)ns much better than (5+20)ns</td>
</tr>
<tr>
<td>5-10% uncaptured beam</td>
<td>1.3</td>
<td>YES</td>
<td>In worst case, it can be employed to scrub with 3 batches (factor 2000) instead of 4 (less heating, less outgassing)</td>
</tr>
<tr>
<td>PS splitting deregulation</td>
<td>&lt;1</td>
<td>YES</td>
<td></td>
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At SPSU-BD meeting (12 October) it was pointed out that the first two options are not feasible with the installed RF system.
R&D for SPS high bandwidth transverse feedback system

*supported by US-LARP and LIU project, joint effort of CERN, SLAC, LBNL

- **Status reviewed in November 2011 by the LIU project:**
  - [https://indico.cern.ch/conferenceDisplay.py?confId=162989](https://indico.cern.ch/conferenceDisplay.py?confId=162989)

- **Aimed at:**
  - Demonstrating transverse damping of intra bunch headtail motion caused by impedance and e-cloud, GHz bandwidth
  - Full system implementation could be ready for 2018 if proof of principle shown before LS1, i.e. 2012
  - Test-set-up operational in SPS

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Scrubbing or Coating?

- **Secondary electron yields**
  - SEY measurements and dose effects, venting to atmosphere

- **Multipactor test bench**
  - Testing the multipacting performances of the coatings combined with:
  - Pressure gauges which provide also indication of multipacting in the beampipe

- **Coating features**
  - Dynamic behavior (electron stimulated desorption), static outgassing
  - Ageing, peel-off
Scrubbing or Coating?

- Strip detectors, pick-ups, sample extractor, Pressure rise...
  - Nothing yet inside real long magnet: MBB or MBA
  - Installing an electron probe at the centre of a dipole magnet was abandoned

- Simulations and observations made with the strip detectors with dipole fields confirmed that the EC build-up will not take place or will be strongly perturbed

- Magnetic field combined with collector will “kill” locally the multipacting

Symmetric holes on top and bottom half yokes to avoid longitudinal effects
Pending Issues

Measurements with Beams

SPS HC514: a-C coated beampipes instead of magnets…

Standard bellow L1= 137

Solenoid 1a

Tubes diam 159, coated, L2+L3=6161.5

Solenoid 2a

Tubes diam 159, coated, L2+L3= 6161.5

Solenoid 1b

Solenoid 2b

present chamber L4=870

pick up to ECM electronics

Power supply

PC
SPS HC513: a-C coating magnets as from June’12...

Modifications Magnets (TS5)

Coatings
- Magnetron rectangular cathodes 2010
- Magnetron round cathodes 2011
- Magnetron rectangular cathodes 2011
- Drift tube magnetron 2012

Gauges
- New to be installed
- Already in PVSS
- PC
- TPG
• An amazing work done…
  ⇒ presented at the Electron Cloud LIU-SPS meeting (Jan’12)
• Simulations are required to assess the EC induced instability threshold in dipoles
  – Electrons in dipole field are, after some scrubbing, far away from beams
    • Faster scrubbing at the centre where high energetic electrons are concentrated
    • Lateral strips move away from beam while increasing bunch population
**Review of objectives**

*As presented in Chamonix’11*

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<th>Description</th>
<th>Deadline</th>
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## Review of objectives

*As re-evaluated for Chamonix’12*

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<td>2012</td>
<td>Define the strategy for 2013</td>
<td>2 coated half-cells coated installed <strong>Deadline: Oct’12 (Chamonix is too late)</strong></td>
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<td>Installation of the pilot sector</td>
<td>2 new coated half-cells to be installed if 2012 measurements are not conclusive <strong>During shutdown 2013</strong></td>
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<td>Validation using a pilot sector (half an arc?) as from 2014 until 2017-18 shutdown: (2 or 4 coated half-cells)</td>
<td><strong>Deadline for final decision: end 2016</strong></td>
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Conclusions

Amorphous Carbon Coatings

The guaranty of suppression…

• a-C coating technology is at the same level of validation than NEG when approved for LHC…
  – Very low SEY is compatible with ultimate bunch populations for all beampipe shapes
  – Solution of coating *in-situ* magnets is the only solution considered for the future
  – Industrialization *process* is getting *validated*, only MBA is pending
  – Long straight section beampipes will be *coated* as well (easy)
  – Reversibility is *not an issue* since coating can be remove using and oxygen glow discharge
  – Large *scale* quality is not a showstopper since *already done* for LHC NEG coated beampipes
  – Static vacuum behavior, slightly higher outgassing of the coating, *will be worked out*

• Remaining concerns essentially logistical:
  – Cost, Resources, Infrastructures, Duration, Radiation dose to personnel

ånC coating is *project baseline and presently working towards assumption that this will be needed*
The low-cost alternative…

• The ongoing simulations and Scrubbing MDs are prerequisite to decision…
  – Solutions exists on paper to enhance the multipacting close to EC threshold and thus speed up the Dose effect on SEY
  – Only MBB dipoles (1/3 of SPS) shows a very low EC multipacting threshold
  – Benefit expected on the instability threshold resulting from the non-homogeneous distribution of electrons in dipoles required to compensate for the saturation of the SEY dose effect on StSt
  – Simulations ongoing to determine required scrubbing time/feasibility - profiting from excellent LHC data and simulations

• Remaining concerns:
  – Saturation of the Dose effect on SEY of Stainless Steel beampipes is a major issue
  – Beam type required to enhance EC close to threshold
  – Unexpected limitation on beam equipments like RF, kickers due to heating
Acknowledgements

• Many thanks to all contributors: Jeremie Bauche; Mauro Taborelli; Giovanni Iadarola; Gianluigi Arduini; Elias Metral; Pedro Costa Pinto; Paolo Chiggiato; Fritz Caspers; Yannis Papaphilippou; Holger Neupert; Brennan Goddard; Roland Garoby; Elena Chapochnikova; Malika Meddahi; Hannes Bartosik; Karel Cornelis; Wolfgang Hofle; Giovanni Rumolo. (My excuses if the list is not complete)

• It was a great pleasure to lead the LIU-SPS Electron Cloud Study team and I am very happy to pass this role (as from Feb’12) to:

   Mauro TABORELLI [TE-VSC-SCC Surface, Chemistry and Coating Section Leader]