LEP2 synchrotron-radiation issues

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Main Topics

- Introduction
- Vacuum requirements
- Vacuum engineering considerations
- What was learnt?
- Closing Remarks
Introduction

Accelerator vacuum requirements

• LEP particle beams were travelling under vacuum to reduce beam-gas interaction which was responsible for:
  – Machine performance limitations
    • reduction of beam lifetime (nuclear scattering),
    • machine luminosity (multiple coulomb scattering),
    • intensity limitation by pressure instabilities (ionization) and
  heavy gases were the most dangerous because of their higher ionisation cross-sections Argon from welds…

• Beam-gas scattering frequently induced background to the Detectors
  – Non-captured particles which interact with the detectors
  – Nuclear cascade generated by the lost particles upstream the detectors.

• Beam-gas scattering was responsible for the increase of the radiations
  – High dose rates lead to material activation (personnel safety issues), premature degradation of tunnel infrastructures like cables and electronics
  – Higher probability of single events (induced by neutrons) which destroyed the electronics in the tunnel
Introduction
Accelerator vacuum requirements [cont.]

• Vacuum system obeyed to severe additional constraints which had to be considered at the design stage since retrofitting mitigation solutions is often impossible or very expensive

  – Minimise beam impedance and HOM generation
  
  – Optimise beam aperture in particular in the magnets
  
  – Intercept the huge SR power deposited in the vacuum beampipes
  
  – Specific shielding against radiation to protect magnet coils and tunnel infrastructures
Vacuum requirements
Beam Lifetime Considerations

• Beam-gas scattering dominated by bremsstrahlung on the nuclei of gas molecules. Therefore, depends on:
  – Partial pressure
  – Weight M of the gas species
  – Radiation length [g/cm²]

Typical composition of photon-stimulated desorption: 75% H₂, 24% CO/CO₂, 1% CH₄

☞ Ar is 67 times more harmful than hydrogen (H₂)
☞ CO₂, CO and N₂ are about 30 times worst compared to hydrogen (H₂)
☞ CH₄ is 10 times worst

☞ Gas density requirements are more stringent in colliders than in Linacs
  ☞ Bake out was the baseline
Vacuum requirements
Vacuum Cleaning

- **Vacuum Cleaning**
  - Characterize the reduction of the desorption yields ($\eta$) of a surface resulting from the bombardment of the surface by electrons, photons, ions.

  \[ \eta = \text{Number of gas molecules desorbed from the surface/bulk by a primary electron, photon, ion.} \]

- **Accelerator vacuum system cannot be designed for nominal performances on “day 1”, LEP relied on:**
  - Vacuum cleaning
    - Reduction of the desorption yields ($\eta$) by photon, e- and ions bombardments

  \[ \text{Necessitate accepting a shorter beam lifetime or reduced beam current during initial phase, about 500 h for LEP} \]
  - Could be significantly decreased by using NEG coatings (see end of the talk)
Vacuum engineering considerations
SR Issues

- **Power deposition**
  - 50% of the radiation power hitting the vacuum chamber was absorbed in the aluminum chamber
  - Remainder 50% (high-energy part of the spectrum) escaped into the tunnel and created severe problems:
    - Degradation of organic material and electronics due to high dose rates
    - Formation of ozone and nitric acid leading to severe corrosion problems in particular for aluminum materials

- **Lead Shielding**
  - Lead shielding of 3 to 8 mm soldered directly on the vacuum chamber were used at LEP

- **Heat load extraction**
  - Evacuation of SR induced heat load on vacuum pipe wall and on lead shielding was a critical issue. Water circulation was used
    - Critical and required heavy maintenance

- **Material fatigue**
  - The induced thermal stress was studied for LEP and had an impact on the material choice
Vacuum engineering considerations
Materials

• Extruded aluminum beam pipes were used since:
  – Cheap and easy to extrude complex shapes
  – High thermal conductivity optimum for SR cooling issues

☞ But was a limitation for:
  – Bake out temperature pressurised hot water limited to 150°C
  – Reliability of vacuum interconnection based on aluminum flanges is a concern at high temperature (>150°C)
  – Corrosion problems
  – Larger thickness for the beampipe wall since bake out was required

• Stainless steel
  – Was more difficult and costly to get machined and shaped
  – Has poor heat conductivity

☞ But has higher resistance to corrosion and more reliable vacuum connections
Vacuum engineering considerations
Pumping Scheme

- Pumping scheme based on:
  - Mobile turbomolecular pumping stations for roughing
  - UHV was ensured by NEG strips heated by current circulations (40 A)
    - Activation of the strips only possible during long technical stops
  …combined with ion pumps
    - Pumping of noble gasses and methane
  - Use of superconducting RF structures and magnets implied Cold/Warm transitions
    - Needed special attention in particular for NEG strips
What was learnt?
Injection areas & Arc to LSS transitions

• Higher SR power resulted in local pressure and temperature rise
  – Local pressure bumps
  – Local lead melting $\not\Rightarrow$ not enough power evacuation capacity
  – Heating of the vacuum flanges to very high temperature (400-700°C) and transition pieces (aperture change) which resulted in failures on:
    • Transitions pieces by fatigue of the material
    • Flanges, each time beam was lost or dumped $\not\Rightarrow$ too fast cool down!
      – Problem enhanced in presence of steel material (vacuum components and flanges)

$\not\Rightarrow$ Localised in the double bending dipoles at the injection in LEP ring

$\not\Rightarrow$ AT the transition from the arc vacuum beampipes in dipole magnets and the long straight sections

• Other observations
  $\not\Rightarrow$ HOM escaping from the 2 GHz cavities were burning the RF fingers upstream/downstream the cavity
  $\not\Rightarrow$ cycle heating up to 750°C!

**Figure 1**
Leak at a stainless steel transition in HC 632

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What was learnt?
Long straight sections

• Any unexpected SR heat power deposited in the LSS was creating a vacuum issue since most of the LSS vacuum system was made out of stainless steel
  – Higher power deposition in components and flanges
• Problems were observed:
  – Downstream the wigglers of IR7, in particular when they were used during the ramp in energy with the collimation settings changed during the ramp (more opened)
    • Several leaks despite the consolidation of the cooldown
• SR generated by the Q0 of the Detectors
  – Tiny high power irradiation creating a temperature transient of up to 350°C for few seconds!
• RF fingers heated and melted when they were in direct view of the SR generated by the quadrupoles of the LSS or of the Experimental areas
  – Several consolidation required
Closing Remarks
Aspects to be addressed in details

• Vacuum engineering issues
  – HOM and Impedance implications
    • Use the engineering design of the SR facilities instead of simple LEP design!
      – Cost increase!
    – Bake-out of vacuum system use NEG coatings instead of strips
      • Activation of NEG coatings and compatibility with Al chambers approach…
  – Heat loads induced by synchrotron radiation
    • More shielding issues due to existing infrastructures more lead thickness (weight / cost)
      – Heat load evacuation to avoid lead melting
      – Water cooling and compatibility with NEG coating activations
    • Bellows and flanges shall be optimised: HOM and transparency to SR
    • Unexpected SR heat loads generated by orbit displacements resulting from:
      – Adjustments of quadrupoles and wiggler magnets
      – Collimator settings during the ramp in energy
    Were degrading LEP performances by inducing leaks
  – Corrosion issues
Closing Remarks
Aspects to be addressed in details [cont.]

• **Experimental areas**
  – SR induced pressure rise
  ₱ Heat load evacuation if using photon absorbers

• **LEP required long maintenance and consolidations periods**
  – Impact on the LHC siting below shall not be neglected

 ₱ Safety aspects for Helium release
Closing Remarks
NEG coatings: THE baseline...

Pumping Speed

![Graph showing pumping speed vs. CO surface coverage](image)

CO surface coverage [Torr ℓ cm\(^{-2}\)]

ESD Yields

![Graph showing ESD yields vs. heating temperature](image)

Secondary Electron Yield

![Graph showing secondary electron yield vs. PE energy](image)

PSD Yields

![Graph showing PSD yields vs. dose](image)

Table 2: Summary of results from the activated test chamber

<table>
<thead>
<tr>
<th>Gas</th>
<th>Sticking probability</th>
<th>Photodesorption yield (molecules/photon)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H(_2)</td>
<td>~0.007</td>
<td>~1.2 × 10(^{-5})</td>
</tr>
<tr>
<td>CH(_4)</td>
<td>0</td>
<td>2 × 10(^{-7})</td>
</tr>
<tr>
<td>CO (28)</td>
<td>0.5</td>
<td>&lt;1 × 10(^{-5})</td>
</tr>
<tr>
<td>C(_2)H(_2) (28)</td>
<td>0</td>
<td>&lt;3 × 10(^{-8})</td>
</tr>
<tr>
<td>CO(_2)</td>
<td>0.5</td>
<td>&lt;2 × 10(^{-6})</td>
</tr>
</tbody>
</table>

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...being successfully used in SR facilities
Closing Remarks
NEG coatings: THE baseline... [cont.]

Some evidences exist that a large part of the remaining desorption after activation could be due to a small fraction of the photons flux striking outside the chamber.

CH$_4$ desorption yield reduced by a factor of at least 200 after activation, no Kr degassing detected.

Courtesy of P. Chiggiato
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