Coupling room temperature beam vacuum system with collimators:

Gained experience & Outlook

Outline:

1) LSS Vacuum system requirements
2) Degassing rate of collimators
3) Outlook & Conclusion

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Collimation working group
08/07/0213
Vacuum Requirements for Collimators

1) Materials used in the collimators:
   a) All materials shall be qualified regarding their outgassing: $< 10^{-12} \text{ mbar} \cdot \text{l/s} \cdot \text{cm}^2$
   b) All trapped volumes shall be avoided as well as contact between large surfaces (Ferrite tiles?): Insert outgassing channels

2) Pumping Speed:
   a) Effective pumping speed is limited at 20 l·s by the space available or the conductance of the surrounding vacuum chambers
   b) In order to be able to achieve the required static pressure of $5 \cdot 10^{-9} \text{ mbar}$ the total flux of the collimator should not exceed $\approx 1 \cdot 10^{-7} \text{ mbar} \cdot \text{l/s}$

“As an indication, the allowed outgassing flux of the secondary collimator (based on the existing draft design) will be exceeded if assuming an operating temperature below 50°C and 200 cm² of graphite jaws with a local overheating (50°C < T < 100°C)”

“As any deviation from this total outgassing flux or from the operating temperature,....., imply an additional pumping speed to ensure the required gas density profile and the vacuum stability”

From EDMS 428155
Vacuum Stability: Ion Stimulated Desorption

- Observed in the ISR with high beam intensities
- Ion bombardment of the beam pipe walls desorbs gas.
- Feedback effect.
- When the beam current approach the critical current, the pressure increases to infinity.

\[ P_{eq} = \frac{Q}{S \left( 1 - \frac{\eta_{ion}}{S} \frac{\sigma}{e} I \right)} \]

\[ I_{crit} = \frac{1}{\eta_{ion} \sigma} e(S) \]

S : pumping speed
\( \sigma \) : ionization cross section
\( \eta_{ion} \) : ion induced gas desorption yield

- Beam conditioning being negligible, one must decrease the desorption yield and optimise the pumping speed.
Room temperature beam vacuum system

Ion Stimulated Desorption Stability

1. The current at which a pressure run-away occurs is directly proportional to the ion induced desorption yield for a given vacuum system.

2. An *in-situ* bake-out significantly reduced the ion induced desorption yields:
   - For a given vacuum chambers diameter the distance between lumped pumps may be increased.
   - The most critical gases are CH$_4$, CO and CO$_2$ due to the combined relatively large desorption yield and inferior molecular conductance.

<table>
<thead>
<tr>
<th>ID [mm]</th>
<th>Lmax for CH$_4$ stability [m]</th>
<th>Lmax for CO and CH$_4$ stability [m]</th>
<th>Lmax for CO$_2$, CO and CH$_4$ stability [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>93</td>
<td>15.7</td>
<td>15</td>
</tr>
</tbody>
</table>

In the LHC:
- Fixed distance for Ion Pumps ≈ 28 m
- Relaying in the NEG pumping speed for CO and CO$_2$
Vacuum Requirements for Collimators
Accepted Gases Species

Maximum total outgassing $\approx 1 \cdot 10^{-7} \text{ mbar} \cdot \text{l/s}$

- H$_2$
- CH$_4$
- CO
- CO$_2$

Affect the saturation level of NEG coating
A NEG material is a metallic alloy that can pump most of the gases present in a vacuum system after thermal dissolution of its native oxide layer (activation process).

\[ T = T_a \]

\[ T = RT \]

Native oxide layer

No pumping

Heating in vacuum

Oxide dissolution -> activation

Reactive metallic surface

Pumping

NEGs do not pump hydro-carbon at room temperature and rare gases.
NEG Pumping Mechanism

**H₂:**
- Diffuses into the getter bulk even at room temperature,
- Small quantities of H₂ do not affect the pumping of other gases.

**CO & CO₂:**
- Molecules chemically absorbed on the getter surface
- No Diffusion in the bulk and affect the pumping speed of all the other gases,
- CO capacity ≈ 5·10^{14} molecules/cm²

**N₂:**
- No Diffusion in the bulk and the absorption takes place underneath the first monolayer of the surface,
- Six adsorption sites to pump a single N₂ molecule,
- N₂ capacity ≈ about 7 times lower than for CO
- Do not affect the pumping speed of CO

**O₂ & H₂O:**
- The capacity of NEG for O₂ and H₂O is estimated around 10 times larger than for CO
Small overview of the outgassing measurements for the collimators
Phase I Tests

Averaged outgassing rate of Phase I collimators: Tests performed in Bld. 252

Considered an averaged pumping speed of 15 l/s for N₂

Acceptance limit of $10^{-7}$ [mbar·l/s]
Detailed degassing tests of a TCS: Test in Bld.113

Outlook of the TCS

- The typical collimator in LHC.
- Experiment has been performed on a spare TCS.

RF contacts along beam path

Cross section drawing

IPAC10 – J.Kamiya et al.
## Outgassing Rate

<table>
<thead>
<tr>
<th></th>
<th>Outgassing rate (N₂ equivalent) Dₓ_jaw=0mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[mbar l/s]</td>
</tr>
<tr>
<td><strong>Unbaked</strong></td>
<td>7·10⁻⁶</td>
</tr>
<tr>
<td><strong>After 1ˢᵗ bake-out</strong></td>
<td>7·10⁻⁸</td>
</tr>
<tr>
<td><strong>After 2ⁿᵈ bake-out</strong></td>
<td>5·10⁻⁸</td>
</tr>
<tr>
<td><strong>After 3ʳᵈ bake-out</strong></td>
<td>4·10⁻⁸</td>
</tr>
</tbody>
</table>
Effect of Repeated Bake-outs

Almost all gas decreases systematically by repeated bake-outs.

Third bake-out representative of the LHC machine.

Outgassing rate of each composition
Acceptance limit for the new TCTP
**TCTP Acceptance limits: Room temperature**

- Measured outgassing of materials for the prototype TCTP collimator at room temperature:
  - Tungsten bars of TCTP Jaws from Sanders: $\approx 1 \times 10^{-11}$ mbar·l/s·cm$^2$
    - **Treatments:** Chemical cleaning + Thermal treatment @ 650°C for 48h
    - **Surface:** In the TCTP: $\approx 2300$ cm$^2$: $\approx 2 \times 10^{-8}$ mbar·l/s
  - Ferrite tiles TT2-111R from Skyworks: $\approx 1 \times 10^{-12}$ mbar·l/s·cm$^2$ (RT)
    - **Treatments:** Thermal treatment in air and under vacuum @ 1000°C for 48h
    - **Surface:** In the TCTP: $\approx 1000$ cm$^2$: $\approx 1 \times 10^{-9}$ mbar·l/s (RT)
  - Stainless steel: $\approx 2 \times 10^{-12}$ mbar·l/s·cm$^2$
    - **Treatments:** Just chemical cleaning
    - **Surface:** In the TCTP: $\approx 2$ m$^2$: $\approx 4 \times 10^{-8}$ mbar·l/s (not considering the 2 edge welded bellows of the motors)
  - BPM Cable + PT100 cables: $\approx 2 \times 10^{-9}$ mbar·l/s

**Total (one collimator):** $\approx 6 \times 10^{-8}$ mbar·l/s at room temperature
Estimation of NEG life @ Room temperature

- The NEG coating capacity for CO was measured to be $5 \cdot 10^{14}$ molecules/cm$^2$ [P. Chiggiato et al., Thin Solid Films 515 (2006) 382-388].

- The outgassing rate due to CO, CO$_2$, H$_2$O in a baked system (TCS tests) is $\sim 4 \cdot 10^{-9}$ mbar l/s, corresponding to $\sim 1 \cdot 10^{11}$ molecules/s.

- For a 1 m long vacuum beam pipe with an internal diameter of 80 mm, the NEG lifetime is estimated to be $\approx 150$ days.

- In the LHC, ion pumps of about 30 l/s for N$_2$ (@ P $\approx 10^{-7}$ mbar) are installed upstream and downstream to the collimators in order to significantly decrease the gas load seen by the NEG.

All these analysis do not consider any dynamic outgassing due to possible electrons/ions/photons stimulated desorption and/or beam induced temperature increase.

These possible phenomena represent an additional outgassing rate that could increase the saturation level of the NEG coating.
TCTP Acceptance limits: Ferrite @ ≈100°C

- Ferrite tiles TT2-111R from Skyworks: ≈ 4 \cdot 10^{-12} [\text{mbar}\cdot\text{l/s}\cdot\text{cm}^2] (≈ 100°C)
  - In the TCTP: ≈ 1000 \text{ cm}^2: ≈ 4 \cdot 10^{-9} [\text{mbar}\cdot\text{l/s}\cdot\text{cm}^2] (≈ 100°C)
- The ferrite at ≈ 100 °C:
  - $\text{H}_2$: ≈ 2 \cdot 10^{-12} [\text{mbar}\cdot\text{l/s}\cdot\text{cm}^2]: $\text{Diffusion and not saturation of NEG coating}$
  - $\text{CO, CO}_2, \text{H}_2\text{O}$: ≈ 2 \cdot 10^{-12} [\text{mbar}\cdot\text{l/s}\cdot\text{cm}^2]: $\text{No diffusion and saturation of NEG coating}$

Total (one collimator): ≈ 7 \cdot 10^{-8} [\text{mbar}\cdot\text{l/s}] with ferrite at ≈ 100 °C

Estimation for NEG life with Ferrite @ ≈ 100°C

The outgassing rate with ferrite @ 100°C is ≈ 2 \cdot 10^{-9} [\text{mbar l/s}]

Total outgassing for saturation: 2 \cdot 10^{-9} + 4 \cdot 10^{-9} [\text{mbar l/s}]

NEG lifetime is estimated to be 100 days

All these analysis do not consider any dynamic outgassing (as stated in previous slide).
Outlook and Conclusion
Outlook: LS1 Activities in the LSS

During the LS1 most of the LSS sectors will be re-vacuum activated and the NEG performances re-established.
Outlook: NEG cartridges Integration in LSS3 & 7

- NEG cartridge integrated in a modified ion pump

**Ion Pumps Modification**

VPNCA Integration

**VPNCA - D-400 NEG cartridge**

**Improved pumping speed and pumping capacity**

**Limit the gas seen by the NEG coated beam pipe**
Conclusion: Outgassing rate of the TCTP

The degassing rate of the TCTP is approaching the vacuum accepted limits:

What could be improved?

- Thermal treatments (vacuum firing) of all the components especially all the stainless steels parts?

Ferrite tiles outgassing at RT are within the vacuum acceptance limit:

However:

- Ferrites could be a sort of “antenna” for HOM effects: Are we sure about the right location and the maximum possible reached temperature? What can we do in case of increase up to 200°C or even more?

- Would been necessary to think of a cooling system for the ferrite?

- Would been interesting (or better necessary) to have a reliable temperature measurements of the ferrite tiles seen the BSRT experience in 2012?
Conclusion: Increase the temperature interlock for collimators

Increase the temperature for a limited time is not a problem.
What should be considered is the integrated time of the produced outgassing.

- NEG saturation could produce an increase background:
  - Reversible just after NEG vacuum activation
    - 4 days minimum of activities
    - Re-conditioning + scrubbing of the not coated area: much faster, but must be taken in consideration

- In some area ALARA principle: not possible in a short delay of time to repeat a NEG vacuum activation if something will happen

- The sector valve interlock could and must be increased

- Production of more radiation: Impact to the R2E?

- If saturation of the NEG pumping capacity will decrease:
  - Possible limitation to the 100h of beam lifetime
  - Possible vacuum stability issues
Thanks you for your attention
Spare slides
Overview of pressure evolution in the LSS with beam
Effects of the dynamic vacuum on the saturation of
the NEG coating
LSS: Performances with Beams

- Reduction throughout the year while increasing beam intensities from 200 to 400 mA:
  - Scrubbing and cleaning effects
- $<P_{\text{LSS}}> \sim 7 \times 10^{-10}$ mbar
LSS3: Normalized pressure profile for the 2012 for “no collimators” vacuum sectors
LSS3: Normalized pressure profile for the 2012 “with collimators” vacuum sectors

Normalized Pressure [mbar/mA]

Pressure increase each time the beam current is increased

Some conditioning when beam current kept stable
TCP in A6L7.B: Temperature increase

BLM and Pressure have the same patterns.

Bunch length effect

No more losses: No more “fake” pressure spikes.
Pressure reading limitation: Ionization of cables

Data: 13/12/2012 04:05:59
Pressure reading limitation: Ionization of cables

Data taken during the scrubbing run at 25 ns

Data: 13/12/2012 04:05:59
Effects of the dynamic vacuum outgassing on the NEG saturation level
Base pressure evolution without beams in 2010-2012

Evolution of pressure [mbar]

<table>
<thead>
<tr>
<th>Year</th>
<th>≈ 0</th>
<th>&gt; 1E-12</th>
<th>&gt; 1E-11</th>
<th>&gt; 1E-10</th>
<th>&gt; 1E-9</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>72 %</td>
<td>13 %</td>
<td>15 %</td>
<td>1 %</td>
<td>0 %</td>
</tr>
<tr>
<td>2011</td>
<td>39 %</td>
<td>32 %</td>
<td>17 %</td>
<td>11 %</td>
<td>1 %</td>
</tr>
<tr>
<td>2012</td>
<td>25 %</td>
<td>40 %</td>
<td>18 %</td>
<td>14 %</td>
<td>3 %</td>
</tr>
</tbody>
</table>

28 vacuum sectors
Mainly in LSS4 and LSS7

G.Bregliozzi et al., IPAC13
Example of base pressure evolution: A6R7.B

[Graph showing pressure evolution over time with labels for 2009, 2011, and 2012.]

Without beams
Composition of outgassing before and after bake-out

Each composition is estimated by the measured cracking pattern of the RGA.
The RGA is calibrated for H₂, CH₄, CO, N₂, CO₂.
This data is obtained in the case of two SVT off.

- H₂O is the main component (~65%) before the bakeout.
- H₂ is the main component (~85%) after the bakeout.

Ref: IPAC10 – J.Kamiya et al.
Examples of beam induced temperature increase in the LSS: BSRT

Bunch length effect

Beam 2, Probes in Vacuum
- Shaft 1
- Mirror 1
- Mirror 2
- Ferrite 1
- Shaft 2
- Ferrite 2

Beam Intensity [1e12 p]
Min Bunch Length [1e-11 s]
Location of the 28 sectors: To be finished

The main two areas interested in this saturation phenomena are the LSS4 and LSS7:

![Bar chart showing the number of LSS Vacuum Sectors for different LSS values.]
Degassing Ferrite TT2-111R Skyworks

Thermal treatment: 400°C Air for 24h + 400°C under vacuum + 1000°C under vacuum