Vacuum Systems for Storage Rings with High Current

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References

New generation light source: “High current & low emittance”

Vacuum system should accommodate:

- High gas load
- High heat load
- High impedance
- Small aperture
- Tight space
- Small beam size (submicron stability)
- Photon absorber
- Damage protection
- BPM support
- Pumping system
1. Pumping system

❖ Conventional pumping with ante-chamber

**PLS-II**\(^1\)
- 22 mm V-aperture with ante-chamber
- Machined & welded Al chamber (or SST chamber)
- NEG strip/cartridge + SIP

**NSLS-II**\(^2\)
- 25 mm V-aperture with ante-chamber
- Extruded & bent Al chamber (or SST chamber)
- NEG strip/cartridge + SIP + TSP + NEG coated chamber

**ESRF EBS**\(^3\)
- 13 mm V-aperture with ante-chamber
- Deep drawing & welded SST chamber (or Al chamber)
- Thick ante-chamber as a stiffener
- NEG cartridge + SIP

**Spring-8-II**\(^4\)
- 16 mm V-aperture with ante-chamber
- Roll forming & LBW SST chamber
- 100 um copper coated on inner surface
- NEG cartridge + SIP
1. Pumping system

- **NEG coated chamber**
  - **SOLEIL** [5]
    - 56% of the ring is NEG coated
  - **MAX-IV** [6]
    - 100% of the ring is NEG coated

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**SOLEIL**

- Thickness distribution of NEG coating: 0.5 to 1.5μm
- The roughness depends on the use of one of the substrates: \( R_a < 0.3 \) μm
- Compromise between low roughness and pumping speed

**NEG activation with a stored e-beam**

- Start heating
- 100% activation
- Cooling down
- Beam loss monitor signal

**Number of activations**

- After 10 years of operation:
  - The maximum of venting and reactivation of NEG coating: 6 times including the first test in lab
  - Quantities of reactivation after partial saturation: 10 (due to a periodical warm-up of a cryogenic in-vacuum undulator closed to a NEG coated vacuum chamber)
  - 7 sections of the ring with NEG coated vacuum chamber have never been reactivated since the first installation: no difference with an equivalent section which have been reactivated several times (not better, not worst)

**MAX-IV**

- Dipole
- Sextupole
- Magnet apertures Ø25mm

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**Coating non-conformities**

- All the chambers were inspected at site before installation.
  - Observed peeling-off: All RF fingers Cu-Be insert and Cu end piece, RF fingers and Cu end were not shielded properly during coating. Solution: new pieces ordered and replaced (without coating).
  - Severe peeling off at RF fingers and Cu end piece
  - Peeling-off at the edge of stainless VC. Chamber not approved for installation.
  - Uncoated areas: Porcelain uncured, in complex chambers
  - Uncoated areas
1. Pumping system

- Conventional pumping + NEG coated chamber

**APS-U**[^7]

![Diagram of APS-U chamber and APS chamber](image)

### Vacuum chambers

- **Aluminum at multiplets and quad doublets**
  - 22 mm ID, ~0.3 to 0.8 m lengths

- **Aluminum bonded to Inconel segment for fast corrector magnets**
  - 22 mm ID, ~0.5 m lengths

- **NEG-coated OFE copper at FODO section**
  - 22 mm ID, ~0.8 to 1.6 m lengths

- **Extruded aluminum with antechamber at L-bends**
  - 22 mm I.D. beam aperture
  - 2.1 m length

[^7]: Source citation [7]
1. Pumping system

- **NEG coated chamber (new technique)**

ALS-U[8]

**Neg Coatings in Very Narrow Chambers**

- Use twisted wires
- Coating ~ 1 μm thick
- No adhesion issues on Al and Cu chambers
- We find some local composition variations

**Optimal parameter set:**
- 1000 V, 50 mA
- Pulsed (10 μs on/50 μs off)
- Mag. coil current 20 A dc
- Original base pressure in low 10⁻⁸ Torr range
- 0.54 Torr (72 Pa) pure Ar, no flow to get uniformity

CERN[9]

**Procedure: Cu/NEG/Cu/Al sequence**

Step 1: Aluminium degreasing  
Step 2: Sputtering Cu-NEG-Cu on mandrel  
Step 3: Cu on Cu Electroforming  
Step 4: Al dissolution NaOH 5M

Copper tube is EB welded to the SS flanges

Al removal NaOH 5M  
Cu removal

80th IUVSTA Workshop  
25.10.2016  
Lucia Lain Amador
1. Pumping system

❖ Pill type NEG (low-cost option)

### PLS-II

- **Type**
  - NEG Film (~ 1 μm)
- **Pill NEG**
  - Activation
    - 200°C, 1 d
    - 180°C, 1 ~ 2 d
  - Pumping Speed / length
    - Low (< 1/5)
  - Sticking probability (α)
    - 0.015 (200°C, 24 h)
    - 0.003 ~ 0.0037 (180°C, 48 h)
  - α (after two additional venting)
    - 0.015 → 0.008
  - Capacity (H₂)
    - 1000×
  - Disadvantages
    - Aging after venting
  - Particle

### KEK

- **Titanium rods**
- **Alumina tube**
- **Stacked NEG pills**
- **Titanium screws**
- **Tantalum wire**

<table>
<thead>
<tr>
<th>Gases</th>
<th>H₂</th>
<th>CO</th>
<th>CO₂</th>
<th>N₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumping speed (L/s)</td>
<td>140–130</td>
<td>200–140</td>
<td>190–130</td>
<td>35–17</td>
</tr>
</tbody>
</table>

- Vacuum chamber with the pill NEG is being used since 2015
- Do not experience particular issue in a storage ring for a year
2. Photon absorber

❖ Materials for high-heat-load photon absorber

❖ OFHC Copper
✓ Commonly used for photon absorption (easily available)
✓ Excellent thermal conductivity
✓ Very low outgassing rate
✓ Need bi-metal joint with stainless steel flange (brazing, EBW, ...)
✓ Softened after exposure to high temperature for brazing

❖ Glidcop
✓ Good thermal conductivity & high strength
✓ Resistance to thermal softening
✓ UHV compatible
✓ Widely used for high-heat-load vacuum components
✓ Difficult to optimize brazing condition
✓ Limited supplier (cost, delivery)
2. Photon absorber

- **Materials for high-heat-load photon absorber**

- **Cold forged OFHC Copper**
  - Excellent thermal conductivity
  - Easily available
  - E-beam weld to prevent softening from brazing (shorter exposure to high temperature than brazing)

- **CuCrZr**
  - Good thermal conductivity
  - UHV compatible
  - Conflat flange integrated to absorber
  - Widely available

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“Cold forged OFHC absorber at PLS-II”[1]

“CuCrZr flange at NSLS-II”[13]  “CuCrZr absorber at TPS”[14]
3. Damage protection

3.1 Cu/Ni foil damage in IVUs at PLS-II

Possible causes of damage:
- MPS malfunction
- Beam miss-steering
  - 28 mW/mm² → surface
  - 28 W/mm² → side clamp
- Local foil bump
- Gap btw foil & magnet

SR from bending magnet

Poor thermal contact
Avalanche meltdown

Image current + SR (BM)
SR from vertical corrector (?)

- Image current
- 0.6 mW/mm²
- SR from vertical corrector
- 2 mW/mm²

Center line damages (B2)

Outer side damages (A, B1, C, D)

Abnormal pressure change before beam dump

P [kW] = \frac{E(GeV)^4}{\rho [m]} \cdot I[A]

\rho = \frac{L}{2 \sin(\theta/2)}

\theta = 0.17 \text{ mrad (0.65 mm @2.5 m)}

If \theta = 1.2 \text{ mrad (=3/2.5)}:
- \rho = 166.6 \text{ m, heat flux = 2 mW/mm², foot print = 0.65 mm wide}
- Foot print is sharper than image current effect
- Heat flux is larger than image current effect
- But the power is too low to fuse the foil
3. Damage protection

3.1 Cu/Ni foil damage in IVUs at PLS-II

- Improvements

1. Hardware
   - Removed all side clamps
   - Increased the thickness of the Cu/Ni foil from 50/20 μm to 50/50 μm

2. Orbit control
   - Apply a fast beam orbit interlock
     - 200 ms (already implemented)
     - → 10 ms (goal)

3. Heat load reduction (to be done)
   - Bunch length ↑
     - RF gap voltage ↓ by Ext. Q adjustment
     - 3rd harmonic cavity
   - Bunch current ↓: 400 → 430 bunch (10% ↓)
3. Damage protection

3.2 RF-shielding failures

- PLS-II
- PEP-II
- NSLS-II
- SOLEIL
3. Damage protection

3.2 Designs for robust RF-shielding

SuperKEK\(^{[15]}\)

Mo-type flange

Comb type

RF-shielding

SS Flange

Vacuum

Cu Gasket

1.5 mm

1.0 mm

NSLS-II\(^{[2]}\)

Wide thick fingers

ESRF EBS\(^{[3]}\)

Sliding fingers

Gate valve with wide fingers
3. Damage protection

3.3 Analyze of failures

- Vacuum chamber heating in NSLS-II
  - Transition behavior of pressure
    - PSD (Photon Stimulated Desorption): \( P_{\text{PSD}} = \eta \times I \)
    - TD (Thermal Desorption): \( P_{\text{TD}} = P_0 \exp(-E_d/kT) \)

\[ P_{\text{TD}} = P_{\text{tot}} - P_{\text{PSD}} = P_0 \exp(-E_d/kT) \]

\[ \ln (P_{\text{TD}}) = A + B(E_d)^* \frac{1}{T} \]

- Transition behavior of pressure after beam storage:
  \[ P_{\text{tot}} = \eta \times I + P_0 \exp(-E_d/kT) \]

- The linear relation between \( P_{\text{TD}} \) (C16G1C2) and \( 1/T \) (C16RTD08) means that the pressure evolution of C16G1C2 is strongly related to the thermal desorption around C16RTD08.

[cf. foil damage in PLS-II]
3. Damage protection

3.3 Analyze of failures

- Vacuum chamber heating in NSLS-II
  - Transition behavior of temperature

- In principle, it is possible to find heat source with transient data of temperature at several points.

- Different transient behavior between T1 & T2? → Case study is needed

- In principle, it is possible to find heat source with transient data of temperature at several points.
4. BPM support

4.1 Improvement in BPM position stability in PLS-II

- Effect of BPM displacement to photon beam stability
  - Orbit feedback system intends that the electron beam pass through the center of the BPMs
  - Position of BPM could be changed by ground motion, thermal load change, etc., then the electron beam orbit can be changed

  Beam dump $\rightarrow$ Δtemperature $\rightarrow$ Δe-BPM position $\rightarrow$ Δphoton beam position

- New design of BPM chamber & support
  - Balance in thermal expansion
  - Enhanced cooling

![Diagram showing the comparison between existing and improved designs of BPM chamber and support.]

- Graph showing the change in beam current and temperature over time.
4. BPM support

4.1 Improvement in BPM position stability in PLS-II

- Improvement of new BPM chamber & support
  - (a) Reduction of BPM displacement
    - 25 µm $\rightarrow$ 5 µm.
  - (b) Fast recovery after beam abort & restoration
    - 3 h $\rightarrow$ 1 h
4. BPM support

4.2 Improvement in BPM position stability in PLS-II

- Water cooling jacket for BPM chambers
4. BPM support

4.2 Improvement in BPM position stability in PLS-II

- Need more careful design of support to keep the center of the BPMs still
Summary

- **Pumping system**
  - Conventional pumping
    - Antechamber, NEG strip, NEG cartridge, SIP, TSP, …
  - NEG coated chamber
  - Combination of conventional pumping and NEG coated chamber

- **High heat load photon absorber**
  - More options in material choice rather than Glidcop
    - Cold forged OFHC copper with EBW or LW
    - CuCrZr absorber integrated with flange (no bi-metal joint)

- **Damage protection**
  - Need fast orbit interlock (< 10 um) to prevent damage in IVU
  - Various shielding mechanisms are studied

- **Need high mechanical stability (< 1 um)**
  - Water cooling is very effective
  - Need careful design of BPM support
I would like to close my talk by introducing a great description by Ben Stillwell in vacuum group of APS-U.

We need a Ferrarabu!

High performance modifications to an otherwise conservative design.

Thank you!