Vacuum System of Synchrotron radiation sources

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outlines

• Why do synchrotrons need vacuum?
• Vacuum system of synchrotron
• Sources of Gas in a Vacuum System
• Linear Vacuum System
• Pressure profile calculation
• Ray tracing and photon absorbers
• Examples of Vacuum system
Why do synchrotrons need vacuum?

• The main reason is beam-gas interaction (Scattering)
  – Losses accelerated particles
  – Increases beam size
  – Reduces beam lifetime
  – Increases radiation hazard

• In Beamlines
  • Hydrocarbon (carbon) contamination of x-ray optics (mirrors, gratings, crystals)
  • Some sample environments require UHV
  • Gas phase absorption and scattering
Why do synchrotrons need vacuum?

- Residual gas
  - Hydrogen usually predominant fortunately low Z, non-contaminating but can be a problem for some sample environments and cryogenic systems
  - Water and hydrocarbons need to be controlled – materials, cleaning, bakeout

- Particle-gas interaction depends on number density and nature of gas molecules (and particles)
  - Effects scale as $Z^2$ – minimise high Z gases
    \[(\Sigma Z^2 \ H_2=2, \ CO=100, \ Ar =324)\]
scattering

- Two types of scattering:
  - Elastic
    - Coulomb scattering
  - Inelastic
    - Any scattering that is not elastic
    - Electromagnetic
      - Bremsstrahlung
      - Ionisation
      - Electron capture/loss
    - Nuclear
      - Nuclear Reactions
      - Particle break up
      - Particle creation
Elastic and inelastic Scattering

- Coulomb scattering

\[
\frac{1}{\tau_{el}} = \frac{4\pi r_0^2 c}{\gamma^2} \left( \frac{\beta_y}{A_j} \right) \frac{P}{k_B T} \sum_i Z_i (Z_i + 1) N_i r_{pi}
\]

- Bremsstrahlung

\[
\frac{1}{\tau_{br}} = \frac{4r_0^2 c}{137} \left( \frac{1}{\delta_{RF}} - \frac{5}{8} \right) \frac{P}{k_B T} \sum_i \ln \left( \frac{183}{3\sqrt[3]{Z_i}} \right) Z_i \left( Z_i + \frac{\ln(1440Z_i^{-2/3})}{\ln(183Z_i^{-1/3})} \right) N_i r_{pi}
\]
To achieve beam lifetimes in the range of 10 hours a residual gas pressure in the level of 1 nTorr is required.
Beam Stability

- **Mechanical stability: as stable as possible**
  - vibration or thermal expansion of vacuum chambers
    - movement of Magnets or BPMs
    - **Beam Orbit Change**

- **Beam duct cross section: as smooth as possible**
  - abrupt change of cross section → wake field
    - Induce Beam Instability (and the lost energy could also heat up vacuum components)

- **Chamber material and thickness: Frequency Response**
  - AC or pulse magnetic field → Eddy current
    - Shielding or Changing the Original Magnetic Field and Heating the vacuum Chamber
Vacuum system of synchrotron

- Vacuum chamber
- Chamber walls
- Photon Absorber
- Photon stimulated desorption
- Thermal Desorption
- Gauge
- Pump

Conductance limited system
ILSF Vacuum System
4 fold symmetry
124 vacuum chambers in 10 different kinds
220 Ion pump
Overall pumping speed: 41000 l/s
Some challenges

• High radiation environment
  – Materials – stainless steel, copper, ceramic
  – Electronics – avoid near beam channel
  – Personnel access - remote control and monitoring
• High heat loads and power densities – up to 30kW some insertion devices
• Photon stimulated desorption – pressure can rise by orders of magnitude with beam
• Locally high magnetic fields
• Long narrow beam channels with little space for vacuum pumps: conductance limited, many pumps
• High reliability
  – 12/4 operation, 2 shutdowns a year
  – Quality control at every stage is vital
• In-situ bakeout is not possible in many sections
• More than 2km of UHV beam pipe at Low Field option
Sources of Gas in a Vacuum System

- Desorption
- Diffusion
- True Leaks
- Permeation
- Virtual Leaks
- Evaporation
- Backstreaming

Mechanical Pump
Evacuation of vacuum system

\[ P = P_0 e^{-St/V} + \frac{Q_o}{S} + \frac{Q_D}{S} + \frac{Q_k}{S} \]

Rate limiting steps during the pumping of a vacuum chamber

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Sources of Gas in a Vacuum System: Thermal Desorption

- It will define the base pressure of the system
  \[ q = \eta_t F \]
- \( F \) Vacuum chamber surface area
- \( \eta_t \) Specific desorption rate that depending on:
  - Choice of material
  - Cleaning procedure
  - History of material
  - Temperature
  - Pumping time
  (For clean stainless steel chambers \( \eta_t = 10^{-11} - 10^{-12} \text{ mbar.L/sec.cm}^2 \))
Sources of Gas in a Vacuum System: PSD

**Photon stimulated desorption (PSD)** is one of the most important sources of gas in the presence of SR.

Gas molecules may be desorbed from a surface when and where photoelectrons leave and arrive at a surface.

PSD depends on:

- Choice of material
- Cleaning procedure
- History of material
- Pumping time
- Temperature
- Energy of photons
- Photon flux
- Integral photon dose
- Temperature
Photon Stimulated Desorption (PSD)

\[ Q = \eta \gamma D \]

\[ \eta = \eta_0 \left( \frac{D_0}{D} \right)^\alpha , \quad 0.65 < \alpha < 1 \]

\( \eta \) Photodesorption yields, (molecules/photon)

Pre-baked: Pre-baked at 200°C for 24 h (but not baked in-situ).

In-situ baked: Baked in-situ at 200°C for 48 h.
Photon Stimulated Desorption (PSD)

![Graph showing Photon Stimulated Desorption (PSD) over distance from dipole (m)]
Linear Vacuum System

A = 1650 cm²/m
q = 5E-12 Torr l/s/cm²
W = 11 m l/s

Pressure distribution

\[ P(x) = Aq \left( \frac{Lx - x^2}{2w} + \frac{L}{S} \right) \]

Average pressure

\[ <P> = Aq \left( \frac{L^2}{12w} + \frac{L}{S} \right) \]
Models commonly used in the molecular gas flow regime

• Analytical 1D diffusion model (Knudsen-Clausing)
  – analytic method (Diamond)
  – Transfer matrix (SLAC)
  – finite difference (VACALC)

• Continuity principle of gas flow (CpoGF)

• Three-dimension (3D) Test Particle Monte-Carlo (TPMC)
  – The most accurate vacuum system modeling
  – MOLFLOW (R. Kersevan)
  – time consuming:
    • building the TPMC model
    • Modifying
    • calculations
Pressure profile calculation
Pressure profile calculation

Base pressure of 6m of storage ring.

Pressure profile of 6 m of storage ring, first injection
Pressure profile calculation

Pressure profile of 6 m of storage ring, (100mA, 100Ah).

Pressure profile of 6 m of storage ring, (250mA, 500Ah).
Pressure profile calculation

Final Pressure profile of 6 m of storage ring, (400mA, 1000Ah).
Pressure textures

pressure texture of dipole vacuum chamber

Pressure texture induced by ABS12
Ray tracing for SR of the bending magnets on the horizontal plane

the clearance between vacuum chamber and rays stay at least 5 mm
we use:
• two in house computer codes
• a detailed drawing
Ray tracing for SR of the bending magnets on the vertical plane

\[ P_\gamma = \frac{2}{3} r_c mc^2 \frac{c \beta^4 \gamma^4}{\rho^2}, \]

\[ P_\gamma (\text{MW}) = C_\gamma \frac{E^4 \text{(GeV)}}{\rho \text{(m)}} I(A). \]

\[ C_\gamma = \frac{4\pi}{3} \frac{r_c}{(mc^2)^3} = 8.8575 \times 10^{-5} \text{ m/GeV}^3. \]

\[ \frac{dP_\gamma}{d\Omega} = \frac{21}{32} \frac{P_\gamma}{2\pi} \frac{\gamma}{(1 + \gamma^2 \theta^2)^{5/2}} \left(1 + \frac{5}{7} \frac{\gamma^2 \theta^2}{1 + \gamma^2 \theta^2}\right). \]

**total opening angle in our case is 0.26 mrad**
Widths of collision cross section
Absorbers

3D model of lower jaw of ABS11

3D model of ABS11

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# Absorbers

<table>
<thead>
<tr>
<th>Abs.#</th>
<th>Effective length* (mm)</th>
<th>Effective angle** (mrad)</th>
<th>Total power (W)</th>
<th>Total Flux (ph/sec)</th>
<th>Minimum distance (cm)</th>
<th>Maximum power density</th>
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<tbody>
<tr>
<td>ABS11</td>
<td>173</td>
<td>61.4</td>
<td>3978</td>
<td>9.5+E18</td>
<td>117</td>
<td>183701268</td>
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<tr>
<td>ABS12</td>
<td>100</td>
<td>72</td>
<td>4679</td>
<td>1.1+E19</td>
<td>114</td>
<td>194635422</td>
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<tr>
<td>ABS13</td>
<td>117</td>
<td>43</td>
<td>2796</td>
<td>6.7+E18</td>
<td>256</td>
<td>38584724</td>
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<tr>
<td>ABS14</td>
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<td>16.2</td>
<td>1050</td>
<td>2.5+E18</td>
<td>588</td>
<td>7327407</td>
</tr>
</tbody>
</table>

* Length of absorber exposed to synchrotron radiation

** Angle of radiation fan incident absorber

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Absorbers

Real power density on ABS12
Absorbers

- Power density along absorbers of the first block
- Effective width along absorbers of the first block
Absorbers (Analysis)

FEA result for crotch absorber kind ABS11, deformation of lower jaw due to gravity

FEA result for crotch absorber kind ABS11, stress in lower jaw due to gravity
FEA result for crotch absorber kind ABS11 in lower jaw

Thermal distribution

Von Misses stress distribution

strain distribution
FEA result for crotch absorber kind ABS11 in lower jaw

Water flow in pipe of absorber ABS11

Temperature distribution in ABS11
The vacuum system of the Spanish Light source

ALBA
ALBA Vacuum system
Booster

Pressure profile for the booster

The end of RF cavity straight

5° dipole

10° dipole

Distance (cm)
Injection straight installation

Kicker magnets
Septum
Kicker magnets
Cross Sections of vacuum chambers: PETRA III

- Steel chamber w. NEG pump
- Al undulator chamber
- Cu absorber
- 2 outlets

Pumped via NEG strip
ANKA vacuum system
ASP Vacuum System
Thank for your attention