E-cloud Remedies and PS2 Vacuum Design

J.M. Jimenez

Main Topics

- Introduction
- PS2 Vacuum Design
  - Main parameters & Vacuum implications
  - Revue of technical solutions
  - Layout & 3D Integration
- E-cloud Remedies
  - Electron cloud build up
  - Remedies validated in existing accelerators
  - On going investigations

Introduction

- The Vacuum System of the PS2 accelerator shall be designed to ensure:
  - The required beam lifetime is equivalent to PS
  - A limited effect of the beam-gas scattering
    - Dose rate induced by lost particles to the tunnel environment e.g. activation of components, damages on cables and electronics…
    - Emittance preservation
  - Dynamic Vacuum stability i.e. Ion instability
  - Beam stability
    - Low Impedance (image beam current)
    - RF shielding to avoid HOM induced heat loads and beam induced instabilities
    - Low Electron Cloud density

PS2 vacuum design

Main parameters & Vacuum implications

- Machine parameters
  - Beam Parameters
    - Energy: 4 Gev @ inj., 50 GeV @ extract.
    - 8×10^{11} p/bunch, 170 bunches (~5 A)
      - 25 ns bunch spacing
      - 20 ns bunch length @ injection
      - 4 ns bunch length @ before extraction
  - Dynamic pressure : $<10^{-9}$ mbar
  - Average radius: 214.3 m
  - Circumference: 1346.4 m
  - Bending radius: 99.9 m
  - Integrated dipole length: 627.9 m ⇨ 200 dip., L= 3 m, V=70 mm, H=250 mm
  - Integrated quadrupole length:174 m ⇨ 120 quad., L= 1.75 m - Pole radius 75 mm
  - “Free” straight section: 545 m
    - Kickers & Septa (x18): 123 m
    - Auxiliary magnets (~170): 70 m
    - Interconnecting bellows: ~150 m
    - Space left for other items: ~200 m

Low photon flux
High conductance on beam pipes
Critical bunch intensity for E-cloud
UHV dynamic pressure

Design of the vacuum chamber is
critical if a bake out is required
5 mm for vacuum chamber thickness,
bake out and alignment

PS2 vacuum design

Mechanical Design (1)

- Mechanical issues
  - UHV standards based on Conflat® flanges
  - Magnet chambers
    - Magnet chamber shall provide the maximum aperture while allowing:
      - Manufacturing tolerances: straightness 0.2 mm/m
      - Complex shape: quasi-rectangular shape
      - Space for bake out if required: 5 mm minimum on radius
    - ☞ Extruded chambers instead of welded chambers ⇨ Aluminium and copper easier to extrude
    - ☞ Surface treatment/coating required for electron cloud issues ⇨ Supply the chambers to the magnet factory to avoid later problems of insertion
  - Short & Long straight sections
    - Cylindrical chambers in copper ID130 mm to stay compatible with DN150CF flanges
- Impedance
  - Copper or Aluminium chambers instead of Stainless steel with copper coating
  - ☞ Conductibility is a factor 7000 lower in copper than in stainless steel
  - ☞ ~0.8 mm copper coating required for a 70 mm height stainless steel vacuum pipe (dipole magnets)

PS2 vacuum design

Mechanical Design (2)

- RF Shielding
  - Expensive ⇨ reduce the number of variants
- Aperture issues
  - Smooth transition between diameters ⇨ space requirements / Costs (2.5 kCHF/unit)
  - Define a limited number standard apertures

☞At the design stage, the standardisation of the vacuum components is essential since it will have an impact during the future operation of the accelerator: availability of spares !

PS2 vacuum design

Layout & 3D integration

- Shown to be essential in the LHC
- Absolutely required in more compact accelerators
  - Start as soon as possible
  - Set a Layout and Integration Committee
  - Define the equipment owners responsibility and the objectives for the Integration Team
  - The Layout is required to fill the Database which define the vacuum components to be manufactured
- Vacuum sectorisation
  - Vacuum requirements
  - In situ conditioning requirements
  - Exploitation requirements
  - Radiation and safety aspects

☞ The 3D integration aims to ensure that the vacuum system - which is used to be installed while all other equipments are in place - can be installed as initially foreseen i.e. avoiding compromises on pumping, bake out and vacuum instrumentations.

E-cloud Remedies

Electron Cloud built up – Review of the main parameters (1)

The Electron Cloud build up depends on:

- Beam parameters
  - Bunch intensity ⇨ Threshold effect: SPS case: 2-3×10^{10} p/bunch in dipoles
    5.0×10^{10}p/bunch in field free
  - Bunch spacing ⇨ Threshold effect: SPS case: Build up occurs for bunch spacing < 75 ns
  - Bunch pattern ⇨ Surviving electrons i.e. low energy electrons (<5 eV) are lost in missing bunches (gaps). SPS case: >225 ns required between bunch trains (batches)
  - ☞ Playing with these parameters reduces the total beam intensity…
- Surface characteristics
  - Secondary Electron Yield Characteristics

    The SEY i.e. number of secondary electrons emitted by a primary electron depends on:
    - Material and/or coating [talk S. Calatroni @ al. – Friday a.m.]
    - The surface characteristics e.g. oxide thickness, roughness, surface contamination…
    - The primary electron energy
    - The angle of incidence of the primary electron
    - ☞ Does not depend on the existence of a strong magnetic field
  - How can the SEY be reduced?
    - Appropriate choice of the material and/or coating
    - Surface treatment by glow discharge
    - Bake out
    - Geometrical effects
      - Grooves reduced the apparent SEY and the build up ⇨ the groove's effect could be reduced by a dipole field

E-cloud Remedies

Electron Cloud built up – Review of the main parameters (2)

The Electron Cloud build up depends on:

- Surface characteristics
  - Beam Conditioning and Vacuum Cleaning (physics aspects)
    - Beam conditioning is characterized by a decrease of the SEY resulting from the bombardment of the electrons from the cloud
    - Vacuum cleaning is characterized by the removal of the gases physisorbed and chemisorbed on the surface resulting from the bombardment of the electrons from the cloud (electron stimulated desorption).
  - ☞ The vacuum cleaning will improve the dynamic pressure (in presence of beam) but will not affect the electron cloud density which will only decrease with the beam conditioning.
  - ☞ Their rates of reduction are different
- Alternative to the reduction of the SEY
  - Clearing electrodes
    - Collect the emitted electrons before they start contributing to the build up [talk F. Caspers – Friday a.m.]
- Detrimental effect of the magnetic field
  - Field free regions ⇨ Higher build up threshold
  - Bending dipole fields enhance the electron cloud in the vertical plane ⇨ Build up threshold is reduced
  - Quadrupole fields trap the electrons along the poles ⇨ Heat load limitation for the superconducting quadrupole (not applicable in PS2)

E-cloud remedies

Remedies validated in existing accelerators

- Right choice of vacuum chamber material
    - Copper and stainless steel have a SEY as received around 2.3 to be compared with the 2.7 of aluminum
- Coating of the inner surface
    - NEG coating
        - Used as baseline for the LHC long straight sections. After activation, SEY decreases down to 1.1 and increases up to 1.3 when saturated.
    - TiN coating
        - Values measured on samples provided by RHIC and measured by
          N. Hilleret showed SEY values ranging from 1.5 to 1.7 after air exposure.
          [talk S. Calatroni @ al. – Friday a.m.]
- Glow discharge
    - Ar, Ar/O_2, N_2 glow discharge decrease the SEY but the effect is reset after a venting to air.
    - ☞ A "memory" effect is still visible and the beam conditioning is faster
- In situ bake out
    - In situ bake out reduces the SEY e.g. for copper from 2.3 down to 1.7
    - ☞ After a venting to air, the SEY is back to 2.3
- Beam conditioning
    - Beam conditioning is being successfully used in the SPS since 2002 prior to operation with LHC type beam.
    - ☞ The beam conditioning efficiency depends on the electron bombardment intensity which decreases while the SEY decreases

E-cloud remedies

On going investigations

- Low SEY coatings which :
  - Do not require an in situ bake out
  - Do not suffer from an air exposure
- In situ / ex-situ glow discharge
  - Ar/O_2 and CH4
- Clearing electrodes
- Grooves and nanostructures

Conclusions

- The PS2 Vacuum System will have:
  - The complexity of the PS accelerator in term of integration and space available for vacuum components,
  - The complexity of the LHC LSS for the impedance and HOM issues,
  - The requirements of LHC LSS for the dynamic vacuum,
  - The radiation issues comparable to the SPS extraction areas.
- Based on today’s knowledge, the electron cloud suppression & vacuum requirement imply a UHV design i.e. baked vacuum system with NEG coatings to ensure vacuum stability