Improved anchoring of SSS with vacuum barrier to avoid displacement

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### Overview

- Introduction
- Initial requirements and actual SSS supporting
- Updated requirements and improved supporting design
- Planning and costs
- Next weak point?
- Conclusion
Introduction

• Incident on 19th of September 2008 => failure of some supports of SSS in sector 3-4 due to longitudinal loads
Initial requirements and actual SSS supporting

- Each SSS is installed on 1 jacks for longitudinal alignment + 2 for transversal alignment; The 3 jacks are used for vertical alignment.
Initial requirements and actual SSS supporting

- Alignment done by geometers after installation
Initial requirements and actual SSS supporting

- Each SSS is installed on 1 jacks for longitudinal alignment + 2 for transversal alignment; The 3 jacks are used for vertical alignment.
Initial requirements and actual SSS supporting

• Vacuum sectorisation for one LHC sector

Vacuum sectorization: Magnet vacuum barriers □ Jumper vacuum barriers □ QRL vacuum barriers

QRL vacuum jacket

Magnet vacuum vessel

• Vacuum barrier in 13 SSS / sector (Q11R&L, Q15R&L, Q19R&L, Q23R&L, Q27R&L, Q31R&L, Q33R)
• A total of 104 SSS with vacuum barrier

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Initial requirements and actual SSS supporting

- Vacuum vessel/vacuum barrier designed for 0.15 MPa internal pressure
- Supporting system should withstand loads induced by differential pressure on both sides of vacuum barrier:
  - Nominal operation: up to $\Delta p = 0.1$ MPa
  - Exceptional: up to $\Delta p = 0.15$ MPa
- $\Delta p = 0.1$ MPa across vac. Barrier $\rightarrow$ 80 kN at the jacks (tested value)
Initial requirements and actual SSS supporting

• Supporting system should withstand
  – Nominal operation up to 80 kN longitudinally ($\equiv 0.1$ MPa)
  – Exceptional operation up to 120 kN longitudinally ($\equiv 0.15$ MPa)

• Actual SSS supporting system:
  – Designed for 80 kN and tested in the tunnel for a longitudinal load up to 90 kN
  – Test done once in surface building up to 120 kN (not documented)

Sonia Bartolome et al., tests done in the LHC tunnel, June 2003

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Initial requirements and actual SSS supporting

- Actual SSS supporting system:
  - Tested failure tensile loads of anchors **120 kN to 150 kN**
  - Ok for nominal operation
  - Failure limit for exceptional conditions (~ 150 kN)
  - No concrete damage observed

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Sonia Bartolome et al., tests done in the LHC tunnel, June 2003

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Updated requirements and improved SSS supporting

- Sect.3-4 incident: estimate (see pres. Ph. Lebrun session 01) pressure inside vessels (on one side of vacuum barrier): 0.7 MPa (x 4.6 design pressure)

 => Improvements of security relief valves proposed (see pres. V. Parma session 04) different form warm / cold sectors

- Updated design pressure (see pres. V. Parma session 04)

**New configuration on cold sectors:**
13 DN100, 2 DN90, 4 DN63

**New configuration on warm sectors:**
12 DN200, 4 DN100, 2 DN90

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Updated requirements and improved SSS supporting

- Updated design pressure **0.3 MPa** for SSS anchoring. Why?
  - Covers an important area of possible events
  - Very high but feasible value of longitudinal loads to be considered for the new anchor design - **240 kN**;
  - The chain of elements **vacuum barrier / cold foot / jack** should be equilibrated
    - Design of vacuum barrier for **0.15 MPa** with security factor **3** => confident that it withstands **0.3 MPa**
    - Cold foot tests showed no failure up to **70 kN** equivalent to **0.3 MPa**

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Updated requirements and improved SSS supporting

- Requirements for the design of the improved SSS anchors
  - Withstand longitudinal load of 240 kN
  - Possibility to install the system on SSS already on jacks
    - Reduced space under the SSS – very difficult for drilling
    - Accessibility for alignment
  - Estimation of realignment every year
  - Allow thermal contraction of vacuum tank in case of accident
  - Allow space for other foreseen equipment under the SSS
  - Uninstalling the system should allow SSS removal if needed
    - Transport / installation zones to be taken into account
  - Optimize price
  - Feasibility within general planning
Updated requirements and improved SSS supporting

• Several solutions have been studied
  – 1st solution – distribution of the longitudinal load among the 3 jacks
Updated requirements and improved SSS supporting

- Several solutions have been studied
  - 1st solution – distribution of the longitudinal load among the 3 jacks
  - No cryostat thermal contraction allowed
Updated requirements and improved SSS supporting

- 2nd solution – bloc additional fixation to the ground – only shear loads transmitted to the floor
- Poor accessibility to jacks for alignment
Updated requirements and improved SSS supporting

– 3rd solution – bloc additional fixation to the ground and to the cryostat – only shear loads transmitted to the floor

– Necessitates special installation procedure (monitored by geometers) to avoid vacuum tank deformation
Updated requirements and improved SSS supporting

– 4\textsuperscript{rd} solution – the final one
Updated requirements and improved SSS supporting

– Final solution – equivalent stress

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- Final solution – deformation
Updated requirements and improved SSS supporting

- Final solution – reaction loads

- Contact on single jack guaranteed

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- Final solution – reaction loads

- Ground fixation system tested this morning in SX4

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Updated requirements and improved SSS supporting

- Final solution – one ground fixation system tested in SX4
- Up to 380 kN applied longitudinally and 230 kN applied vertically (traction) during 10 min (1.5 x design load if only one side charged)
=> no visible damage observed

M. Guinchard and A. Foreste, tests done in SX4, February 2009
Planning considerations

• Prototype
  – Manufacturing complete prototype w7-8
  – Test prototype w9

• LHC installation
  – Hypothesis
    • Conservative hypothesis that drilling not allowed when liquid helium
    • Installation = same risk as alignment operations (ok with liquid helium)
  – Drilling 2 weeks / sector starting in week 11 for sector 2-3
  – Overall installation 2 weeks / sector within the general planning
  – Alignment check of SSS after system installation: a total of 25 days
    ok with general planning
## Costs

- **104 systems to be manufactured and installed**
  - System: $104 \times 5'000$ CHF = 520’000 CHF
  - Ground fixation: 42’000 CHF
  - Manpower
    - Drilling: $104 \times 4 \times 6 \times 62$ CHF = 155’000 CHF
    - Installation: $104 \times 2 \times 8 \times 62$ CHF = 103’000 CHF
  - Equipment for drilling and installation: 27’000 CHF
  - Alignment: 20’000 CHF

- Total for 8 sectors: 867’000 CHF

- **Rmq transport operations not included**
Next weak point?

- The anchoring of SSS with vacuum barrier have been discussed
- If new cryostat design pressure 0.3 MPa instead of 0.15 MPa, what about the other equipments?
- DFBA
Next weak point?

- **DFBA**
  - Calculations done by A. Bertarelli in 2006 for a vessel design pressure of 0.15 MPa absolute (0.05 MPa relative)
  - The new design pressure of 0.3 MPa (0.2 MPa relative) multiplies the applied loads by a factor 4

- Shuffling module vacuum vessel – with the new design pressure the tank will plastify locally but should not get to failure
- The “negative fixator” (external support) will fail
- Fixation very difficult to improve due to lack of space

Alessandro Bertarelli
DFBA calculations done in 2006

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Conclusions

- The design of the improved anchoring of SSS with vacuum barrier has been presented.
- It was designed to withstand 240 kN longitudinally, equivalent to 0.3 MPa of differential pressure on both sides of the vacuum barrier.
- The system is foreseen to be installed in “warm” sectors too as an additional safety device.
- The installation of the equipments will be within the global planning.
- The total cost will be of about 867’000 CHF, transport not included.
- Open questions:
  - What happens if Δp > 0.3 MPa? : cold foot, vacuum barrier damaged before external anchoring damage…
  - We are very confident that vacuum barrier and cold foot withstand the load equivalent to 0.3 MPa but it has never been demonstrated.
  - Next week point could be the DFBA…
  - What about other elements (such as all “special” cryostats of the LSS, jumper vacuum barrier …)?

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Thank you!

… in particular Lucio for his patience and advices