IMPROVED ANCHORING OF SSS WITH VACUUM BARRIER TO AVOID DISPLACEMENT

O. Capatina, K. Foraz, A. Foreste, V. Parma, T. Renaglia, J.-P. Quesnel
CERN, Geneva, Switzerland.

Abstract

The incident in sector 3-4 of the LHC caused a high pressure build-up inside the cryostat insulation vacuum resulting in high longitudinal forces acting on the insulation vacuum barriers. This resulted in braking floor and floor fixations of the SSS with vacuum barrier. The strategy of improving anchoring of SSS with vacuum barrier to avoid displacement is presented and discussed.

INITIAL REQUIREMENTS AND ACTUAL SSS SUPORTING SYSTEM

General description of external supporting

The Short Straight Sections in the LHC arcs are installed on three external jacks. They are used for vertical alignment; two of them are also used for transversal alignment while one jack (the closest one to the "caniveau") is used for longitudinal alignment. Thus, two jacks are block in transversal direction and one jack is blocked in longitudinal direction as shown in Figure 1.

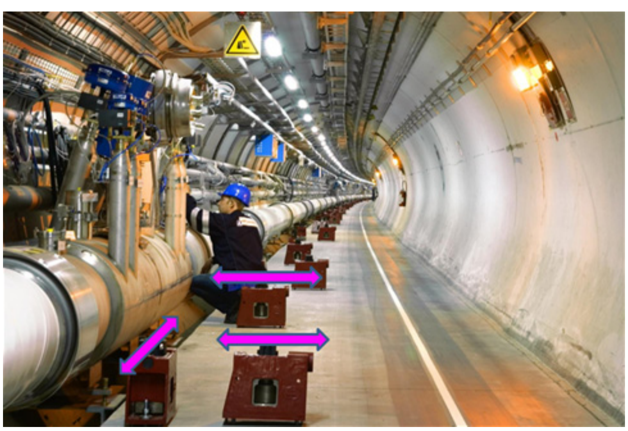

Figure 1: SSS external supporting system.

All longitudinal loads applied on the SSS are taken over by a unique external jack.

Arc vacuum sectorization

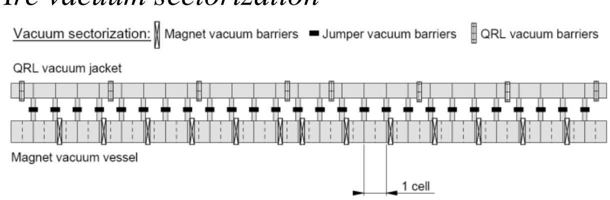

Figure 2: LHC arc vacuum sectorization.

The cryostats insulating vacuum is sectorized for each LHC arc as presented in Figure 2 (ref. [1]). The vacuum sectorization is carried out by vacuum barriers installed at some of the SSS. 13 of such SSS are installed in each arc (Q11R, Q15R, Q19R, Q23R, Q27R, Q31R, Q33R, Q31L, Q27L, Q23L, Q19L, Q15L, Q11L) resulting into a total of 104 SSS for the entire LHC that are equipped with vacuum barriers.

Initial requirements for external supporting

Figure 3 presents a cross section of an SSS with vacuum barrier.

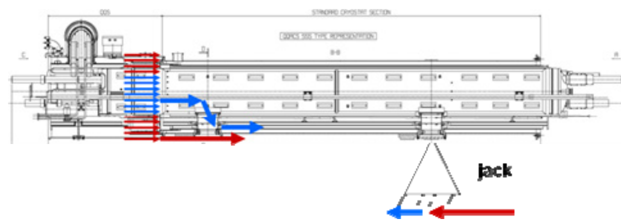

Figure 3: SSS with vacuum barrier.

The internal cold mass is supported inside the cryostat by two so-called cold supports. The cryostat itself is supported on the floor, as explained before, by three external jacks and only one of them is blocked longitudinally.

A differential pressure on each side of the vacuum barrier results into a longitudinal load applied on the external jack:

- 1/3 of the load is applied through the cold support than through the vacuum tank to the external jack.
- 2/3 of the load is applied through the vacuum tank directly to the external longitudinal jack.

The SSS vacuum tank and the vacuum barrier have been designed for an internal pressure of 0.15 MPa. During nominal operation the differential pressure on each side of the vacuum barrier can build-up to 0.1 MPa. During exceptional conditions the specified maximum pressure value was 0.15 MPa.

It has been measured that a differential pressure of 0.1 MPa results into a longitudinal load of 80 kN applied on the top of the external jack (ref. [2]).

For the installation of the external supporting jacks of the arc SSS and cryo-dipoles, the specified maximum load to be carried out by the longitudinal jack was 80 kN (ref. [2]). This value represents the equivalent load induced by only 0.1 MPa of differential pressure on the vacuum barrier.

The anchoring design of the SSS supporting system took into account only the nominal operating specifications (ref. [3]). Tests have successfully been done into the LHC tunnel up to a load of 90 MPa (ref. [3]).

An additional test up to 120 MPa has been done in a surface building but it has never been documented.

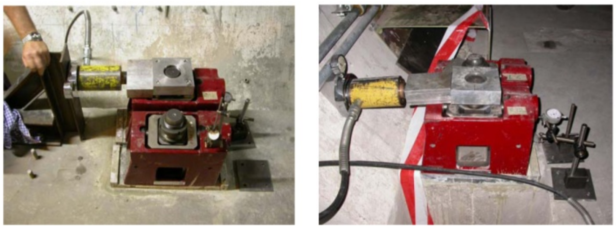

Figure 3: Jack installation tests done in the LHC tunnel.

The external supporting system of the arc SSS with vacuum barrier withstands nominal operation condition of differential pressure up to 0.1 MPa. However, it has not been demonstrated that the supporting system withstands exceptional situations resulting in a differential pressure of 0.15 MPa.

UPDATED REQUIREMENTS AND IMPROVED SUPPORTING DESIGN

Incident in sector 3-4

The incident in sector 3-4 of the LHC caused a high pressure build-up inside the cryostat insulation vacuum resulting in high longitudinal forces acting on the insulation vacuum barriers. This resulted in braking floor and floor fixations of the SSS with vacuum barrier.

Figure 4: Damaged external supporting during incident in sector 3-4.

The estimated pressure on one side of the vacuum barrier, during the incident, is 0.7 MPa. This value is 4.6 times higher than the maximum conditions defined during the LHC design phase.

Updated requirements

In order to avoid such high pressure inside the cryostats, several improvements of security relief valves have been proposed (ref. [4]).

After LHC repairing and improvement campaign this year, there will be two main configurations concerning maximum possible pressure inside the cryostats:

- Sectors that will be warmed up and on which the complete improvement campaign will be carried out. This will result in a maximum possible pressure inside the cryostats lower than 0.15 MPa as presented in Figure 5 (ref. [5]).
- Sectors that will be kept cold and on which only partial improvement campaign will be carried out. This will result in maximum possible pressure inside the cryostats higher than 0.3 MPa as presented in Figure 5 (ref. [5]).

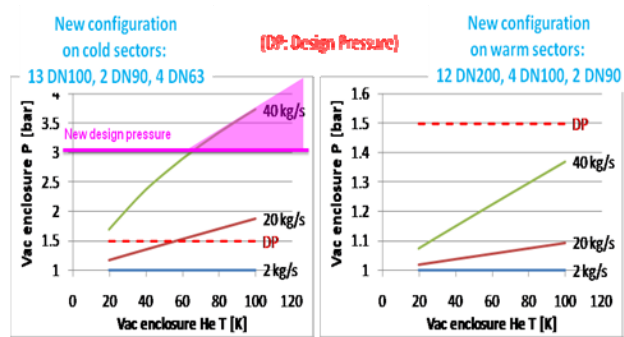

Figure 5: Updated maximum pressure inside cryostats.

Concerning the "cold sectors" configuration, it has been decided to reinforce the external supporting system in order to withstand a maximum differential pressure up to 0.3 MPa on each side of the vacuum barrier. This value is an estimate of the maximum pressure value that the vacuum barrier, as well as cold support could withstand. There is no reason to reinforce the external supporting system to withstand load values above the failure limit of the internal components.

Supporting system reinforcement

A reinforcement of the actual supporting system has been designed for the arc SSS with vacuum barrier.

The new design shall withstand a maximum longitudinal load of 240 kN, the equivalent of 0.3 MPa differential pressure on the vacuum barrier. As explained previously, this value represents the equilibrium for the chain of elements vacuum barrier / cold support / external jack.

The new system has to comply with many additional constraining due to the existing environment:

- 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

A prototype has been manufactured and installed in the LHC tunnel as presented in Figure 6 and Figure 7 (ref. [6]).

Figure 6: Reinforcement of jacks for SSS with vacuum barrier.

Figure 7: Reinforcement of jacks for SSS with vacuum barrier.

Maximum stress, deformation, stability have been numerically checked as presented in Figure 8, Figure 9 and Figure 10.

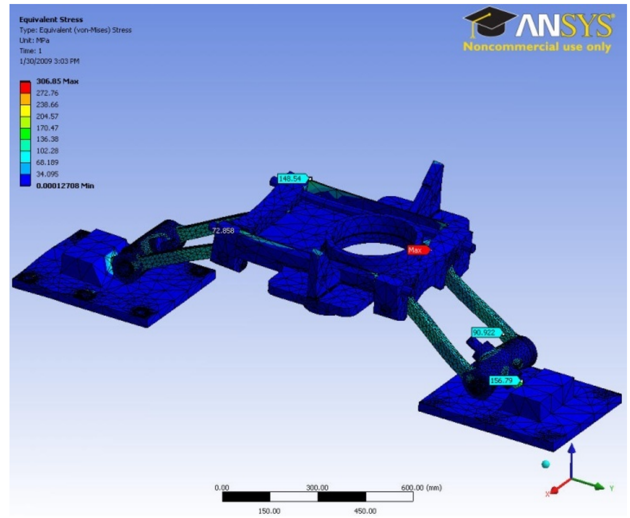

Figure 8: Maximum stress during operation.

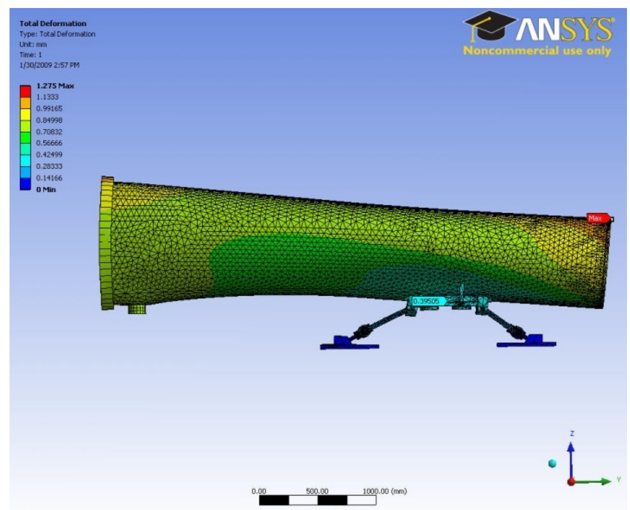

Figure 9: Maximum deformation during operation.

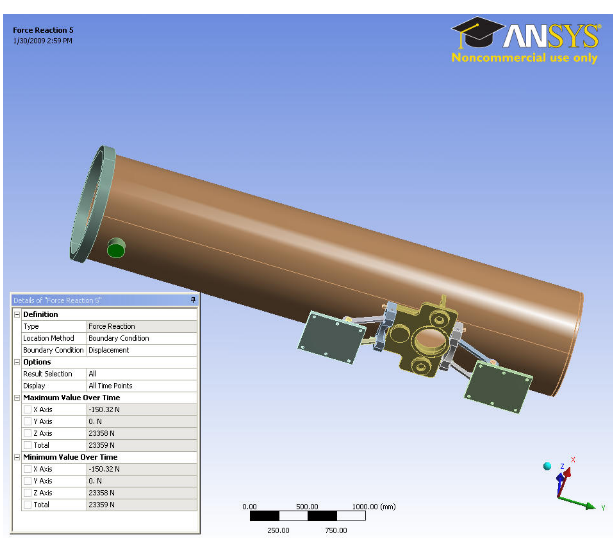

Figure 10: Vacuum tank in contact with jack for all load cases.

The floor anchoring system has been successfully tested in the LHC, in building SX4 up to a security factor of 3 (ref. [7]).

The maximum longitudinal and vertical load have been applied during 10 min and no visible damage has been observed.

Figure 11: Load test of anchoring system in SX4.

The floor strength has been tested for the test area and compared to the LHC tunnel floor. The floor in the test area is 20% stiffer than the worst case measured in the LHC tunnel (ref. [8]).

The design was thus completely validated.

PLANNING AND COSTS

It has been decided that the external supporting reinforcement will be installed on all SSS with vacuum barrier, independently of type of relief valve configuration (cold sectors as well as warm sectors).

Drilling campaign should last 2 weeks / sector; installation campaign should also last 2 weeks / sector. All the activities will be carried out within the general planning without any impact.

The cost estimate for the complete manufacturing and installation campaign is summarised in Table 1.

Table 1: Cost estimate

Activity	Quantity	Estimated total cost
System	104 x 5'000 CHF	520'000 CHF
Ground fixation		42'000 CHF
Manpower drilling	104x 4x6x62CHF	155'000 CHF
Manpower installation	104x2x8x62 CHF	103'000 CHF
Equipment for drilling and installation		27'000 CHF
Alignment		20'000 CHF
Total		867'000 CHF

The transport operations have not been taken into account since reliable value needs detailed logistics.

NEXT WEAK POINT?

The reinforcement of the external supporting system has been studied and designed for the Short Straight Sections with vacuum barrier in the arcs.

However, other equipments such cryostats in the Long Straight Sections have also to be addressed.

In particular, concerning the DFBA, many elements have to be studied and reinforced. As an example, the negative fixator has been designed for a maximum internal pressure in the shuffling box of 0.15 MPa (ref. [9]). An updated maximum pressure of 0.3 MPa inside the DFBA cryostat will result into a factor 4 for the requirements of the maximum load to be carried out by the negative fixator. If no reinforcement is installed, both the support itself as well as the anchorage to the floor would fail.

CONCLUSIONS

An improved anchoring of SSS with vacuum barrier has been designed and tested to withstand 240 kN of longitudinal load, equivalent to 0.3 MPa of differential pressure on both sides of the vacuum barrier.

The system is foreseen to be installed in both: "warm" and "cold" sectors as an additional safety device.

The installation of the equipments will be carried out without impact on the general planning. The total cost is estimated at 867'000 CHF, transport not included.

However, there are still some open questions concerning the global strategy of anchoring reinforcement:

- What happens if the differential pressure is higher than 0.3 MPa? : In particular if the cold support or the vacuum barrier are damaged first?
- We are very confident that vacuum barrier and cold foot withstand the load equivalent to 0.3 MPa but this assumption has never been demonstrated

As explained, only the arc SSS with vacuum barrier have been treated. However, all the cryostats in the LSS zone should be considered for the same analysis.

DFBA should also be studied into detail. If maximum possible internal pressure will be higher than 0.15 MPa, then reinforcement of external supports is compulsory.

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