INSULATION VACUUM AND BEAM VACUUM OVERPRESSURE RELEASE

V.Parma, CERN, Geneva, Switzerland

Abstract

The incident of 19th September 2008 caused a high pressure build-up inside the cryostat insulation vacuum despite the presence of the baseline pressure relief valves. As a result, high longitudinal forces acted on the insulation vacuum barriers and broke the floor and the floor fixations of the SSS with vacuum barriers. The consequent large longitudinal displacements of the SSS damaged chains of adjacent dipole cryo-magnets. Estimates of the helium mass flow and the pressure build-up experienced in the incident are presented together with the pressure build-up for an even more hazardous event, the Maximum Credible Incident (MCI). The strategy of limiting the maximum pressure by the installation of addition pressure relief devices on the insulation vacuum envelope is presented and discussed.

Both beam vacuum lines were ruptured during the incident in sector 3-4 giving rise to both mechanical damage and pollution of the system. The sequence, causes and effects of this damage will be briefly reviewed. We will then analyze possible actions that could be taken to minimize the impact of a similar incident on the operation of the LHC.

PRESENT OVERPRESSURE RELEASE SCHEME IN THE ARCS AND EVIDENCE OF DAMAGE IN SECT.3-4

Present overpressure release schemes

The present protection scheme of the arc cryostats against overpressure in the vacuum vessels (Figure 2.), features the use of 2 DN90 equivalent spring loaded valves on every vacuum subsector (~200m long sectors between two adjacent vacuum barriers). These valves were designed to start opening at a 70 mbar pressure difference and achieve full opening at 140 mbar pressure difference. This scheme was supposed to protect the cryostat vessel and cryostat components from overpressure forces resulting from a maximum helium release rate from the cold mass circuit of ≤2 kg/s.

Cryostat design features

The cryostat vessels and components were designed for an internal design pressure of 1.5 bar, limiting the pressure difference to ≤ 0.5 bar w.r.t. to atmospheric pressure. Therefore, the vacuum vessel is not considered as a pressure vessel according to the European Directives in force. Only the vacuum barrier, which can experience a pressure difference of up to 1.5 bar, was tested, according to the code for pressure vessels, up to 1.87 bar.

In case of a pressure build-up up to 1.5 bars in an vacuum sub-sector, the vacuum barriers at each extremity will load the SSS with a longitudinal load of 240 kN which have to be taken by the jacks and their anchoring to ground.

Evidence of damage in sect.3-4.

In the incident in sect.3-4, the pressure build-up largely exceeded the design pressure of 1.5 bar. In the absence of pressure measurements, only an indirect estimate of the maximum pressure could be made through the mechanical damage observed on the interconnection bellows. By this approach a pressure of 8 bar was estimated. Due to the large longitudinal forces, collateral damage was caused by up-rooting of the jacks of the SSS with vacuum barriers, resulting in large longitudinal displacements and chain collision to the adjacent magnets also resulting in secondary electrical arcs. Up to 39 dipole magnets and 14 SSS were involved in the damaged zone, and a number of the dipole cryostats suffered the rupture of their internal supports. It is evident that if the pressure build-up would have been limited to within 1.5 bars, the collateral damage in the cryostats could have been limited to the contamination of the Multilayer Insulation (MLI).

MAXIMUM CREDIBLE INCIDENT (MCI) AND NEW OVERPRESSURE RELEASE SCHEMES

Maximum Credible Incident (MCI)

Helium mass flow estimates for the incident in sect.3-4 yielded peak flow rates of 20 kg/s, resulting essentially from the rupture of one interconnection line (M3). However, for a similar event, in case of puncturing of the 3 interconnect lines (M1, M2, M3), a larger flow rate could be expected. Due to the internal impedance limitations inside the cold masses, it is believed that the maximum flow rate could be only twice as high, i.e. yielding a maximum flow rate of 40 kg/s. This is today the value retained for the risk analysis for a new Maximum Credible Incident (MCI).

New overpressure release schemes

The pressure build-up inside the cryostats, The pressure build-up inside the cryostats, in case of an incident similar to the one which occurred in sect.3-4, will be limited by equipping the vacuum vessels of the magnet cryostats with additional overpressure relief devices (SV).

In the case of machine sectors which have been warmed up, SV devices can be added by drilling the vessels and installing new DN200 ports carrying pop-off flanges. The installation can be carried out on the cryo-magnets in the tunnel. For those sectors which are meant to remain cold (and with vessels under vacuum), a temporary solution is adopted, consisting in the replacement of the vacuum clamps of the flanges on the existing ports of the SSS with Pressure Relief Springs (PRS), thus allowing these ports to act as SV devices. The two types of SV devices are illustrated in Figure1. However, this second solution enables only a limited increase of the cross sectional area of the SV devices in one vacuum sub-sector; for this reason, when these sectors will be warmed up, the final SV scheme will be implemented.

The following figure gives the schematic of the protection devices of the present scheme (A), the final scheme (B), and the temporary scheme for cold sectors (C) with their equivalent cross sectional discharge areas.

A complementary check of the radial conductance from the magnet cold mass, through the thermal shielding, to the vacuum vessel was made to ensure that there is no restriction to the helium flow to the SV devices. Figure 5 summarizes the distribution of the cross sectional areas through the thermal shield, essentially resulting from slots in the aluminium sheets of the thermal shielding, yielding a total area of 12’900 cm2 per vacuum sub-sector. This value is 3 times the cross section area of the SV scheme (B) and 10 times the cross section area of the SV scheme (C). With the final SV scheme (B) in place, which will be implemented in 4 sectors of the machine in the shut-down 2008-2009 and in the remaining 4 sectors in the forthcoming shutdowns, in case of an event equivalent to the new MCI (40 kg/s helium release, assuming a temperature of helium vapors at about 60-80 K), the pressure in the cryostats will remain below the design pressure of the cryostats, namely 1.5 bar (Figure 6).

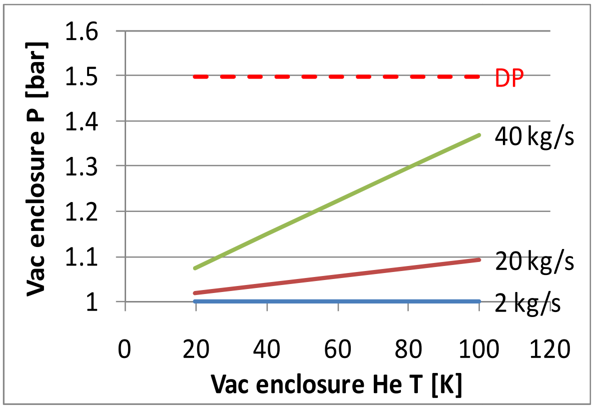

Figure 6. Pressure rise with final SV scheme (B).

In the case of the temporary SV scheme (C), an event equivalent to the new MCI will still cause an increase of pressure to about 2.8-3.3 bar, therefore largely exceeding the 1.5 bars design pressure of the cryostats (Figure 7).

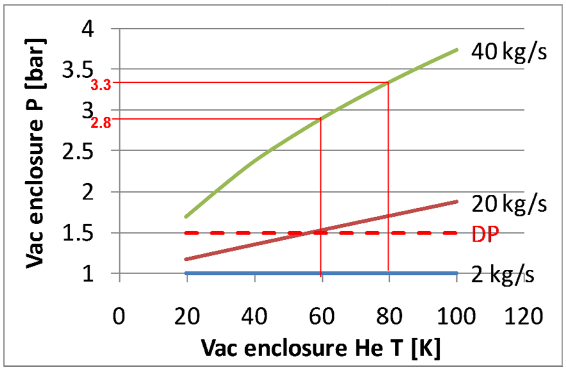

Figure 7. Pressure rise with temporary SV scheme (C).

The resulting forces on the cryostats equipment, in particular on vacuum barriers, internal magnet supports, and external jacks and ground anchoring, will exceed their design values. For an internal pressure of 3 bar, the external jacks and anchoring will have to carry an equivalent force of 240 kN, out of which about 1/3 (80 kN) will be carried through the internal magnet supports, and the remaining 160 kN will be taken by the vacuum barrier.

The external jacks and anchoring of the SSS mounting vacuum barriers (about 100 units in the machine), need to be reinforced to avoid lifting off of the SSS from the jacks heads and breaking of the ground anchoring and floor.

The internal magnet supports and vacuum barriers should be able to carry the forces equivalent to a 3 bar pressure but this assumption will be confirmed by complementary testing of these components.

Reinforcement of external jacks and ground anchoring

The incident in Sect.3-4 showed that, as a consequence of the large pressure forces on the SSS with vacuum barriers, the jacks anchoring to ground and/or the floor broke.

For those sectors which are meant to remain cold, and for which the temporary SV scheme (C) is adopted, in the case of an MCI, the jacks and floor anchoring will need to carry a longitudinal force of 240 kN. A reinforcement of the external jacks taking the longitudinal forces was therefore being designed and tested and will be installed on all the SSS carrying a vacuum barrier in these sectors (a dedicated paper covering this subject is presented in this workshop).

Considering that a weakness in the floor was observed in the sect.3-4 incident, where the floor under a jack was up-rooted without breaking of the anchoring studs, the reinforcement of the jacks of all SSS with a vacuum barrier will be extended to all the machine as a measure of precaution.

BEAM VACUUM OVERPRESSURE RELEASE

Though this paper was supposed to cover this issue too, at the time of this workshop work was still in progress so no conclusive statements could be presented.

The present protection scheme makes use of 2 burst disk per beam line, positioned at the extremities of every arc (mounted on the beam line manifolds of the Q8 SSS). If proven to be of any technical interest for protecting the beam tubes from propagation of a pressure wave of contaminated helium, every SSS being equipped with beam line manifolds, these could be easily equipped with overpressure devices (burst disks for example).

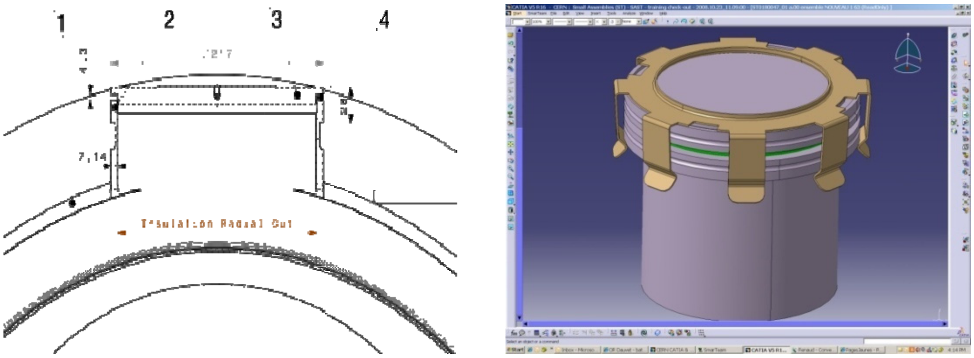

Figure 1. New DN200 SV (left), and Pressure Relief Springs (right).

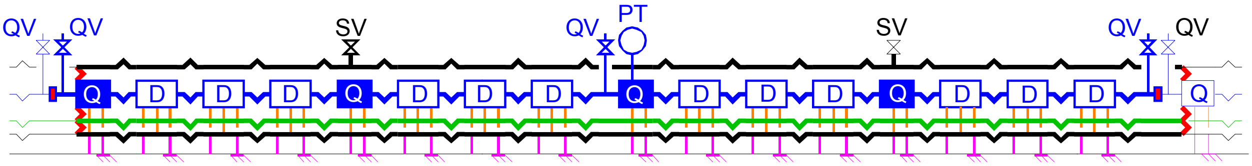

Figure 2. Scheme A. Present SV scheme: 2 DN90 SV. Discharge cross section: 127 cm^2

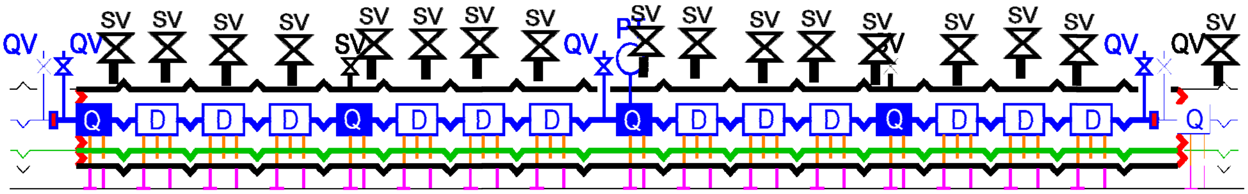

Figure 3. Scheme B. Final SV scheme: 1 added DN200 SV on each dipole, 4 added DN100 SV with SLD. Discharge cross section: 4190 cm^2.

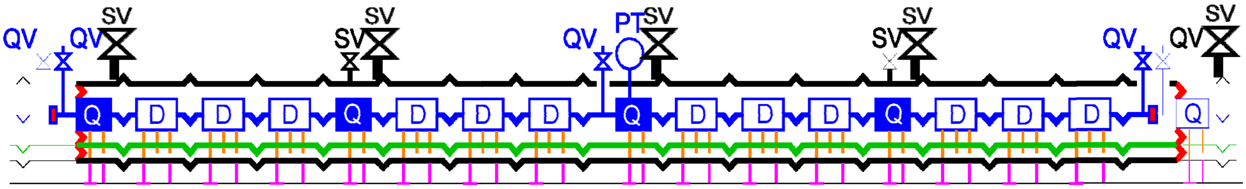

Figure 4. Scheme C. Temporary SV scheme for cold sectors, using SLD: 2 DN90 SV, 13 DN100 SV, 4 DN63 SV. Discharge cross section: 1270 cm^2.

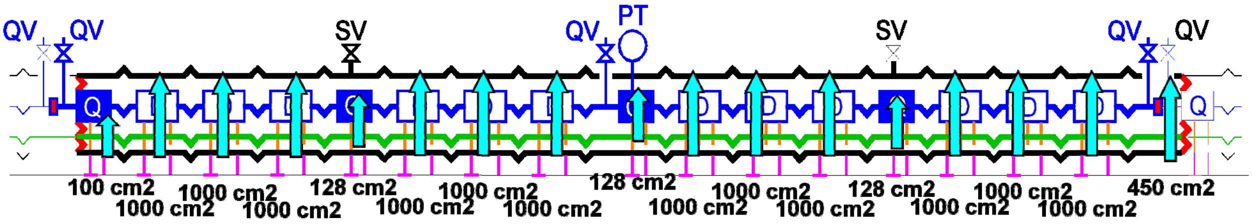

Figure 5. Radial conductance through the thermal shield. Total cross section area: 12’900 cm^2.

SUMMARY

There is evidence that the incident in sect.3-4 has caused a pressure build-up inside the cryostat largely above the 1.5 bar design pressure and that this was the cause of the collateral damage caused by up-rooting the jacks fixing to ground the SSS mounting vacuum barriers.

The present cryostat overpressure protection scheme was not adequate to release the peak helium flow rate of 20 kg/s. Considering that a new MCI foresees a maximum flow rate of 40 kg/s, a new protection scheme is proposed for the cryostats, requiring the installation of 1 DN200 overpressure relief device on each dipole cryostat. This is presently being implemented on the 4 out of 8 warm sectors of the machine. For the 4 sectors foreseen to remain cold, a temporary solution is proposed by making use of the existing ports on the SSS which can be used as overpressure devices by replacing their clamps with pressure relief springs. For these sectors, in the case of an MCI, the overpressure in the vacuum vessels will be of about 3 bar; despite being still beyond the 1.5 bar design pressure, the resulting forces would be within the structural limits for supports and vacuum barriers. Nevertheless, it is recommended that a testing campaign on these components confirms their robustness. The jacks fixations to ground for the SSS with vacuum barriers are being studied to be able to resist the longitudinal forces resulting from a 3 bar pressure.

The means of protecting the beam vacuum is still being studied but if technically of interest additional burst disks could be added on the beam lines on the existing manifolds of every SSS.

ACKNOWLEDGEMENTS

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