CLSI BMIT'S SUPER-CONDUCTING WIGGLER CRYOGENIC SAFETY IMPROVEMENTS*

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Abstract

4.1 T superconducting (SC) wiggler on CLS Biomedical Imaging and Therapy (BMIT) beamline [1-4] developed a critical problem in the cryogenic safety relief and refill paths. Ice blockage formed and prevented helium gas from relieving during liquid helium (LHe) refill. This resulted in an internal pressure built up, which caused expelling of the LHe and cold gas helium (GHe) from the wiggler cryostat. Several improvements were performed over the years including replacement of the original rupture disk, the pressure relief valves and installation of metal O-ring seals at external ports. Following these improvements, a major upgrade on the wiggler safety relief path was implemented by adding a new vent pipe directly connected to the cryostat for safety exhaust. The LHe refill path was also modified to eliminate possibility of ice blockage. During initial tests after the upgrades, we experienced significant heat load increase which was linked to the thermal acoustic oscillations in the LHe transfer line. The problem was resolved by improving the insulation vacuum in the transfer line and adding a super insulation assembly into the direct vent pipe along with a plug at the refill path.

BACKGROUND

BMIT's 05ID-2 beamline 4.1-Tesla, 25+2 pole wiggler was designed and constructed by Budker Institute of Nuclear Physics (BINP) [3]. The wiggler is equipped with Sumitomo cryo-coolers. During normal operation, the wiggler runs at sub-atmospheric pressure ~50 mbar below zero gauge-pressure with temperature range of 3.1-3.5 K at the second stage of the top cryo-coolers. The minimal no-load pressure recorder during the SR shutdown was –162 mbar. In case of the single quench, the boil-off gas is usually contained within the cryostat with a pressure rise to below 300-400 mbar activation pressure of the two pressure relief valves. There is a rupture disk with activating pressure of 1.7 bar (gauge) in case of further pressure rise for machine safety protection.

During LHe refilling procedure it was observed that the LHe transfer was blocked. Pressure was building up inside the cryostat with no sings and indications from the external pressure gauges. A large amount of cold helium gas was expelled from the cryostat through the refill port when the refill tube was removed.

The ice blockage was experienced several times over the 2-3 years of operation. The wiggler had to be warmed up to about 100 K in order to enable a LHe refill.

INVESTIGATIONS

The following areas were investigated for the refill and pressure built up problems:

1. Air leaks.
2. Vent path
3. LHe refill path

Air Leak Problems

Air leaks were discovered at the followings:

- Air leaked through the pressure relief valves which were not able to seal-back tight after gas release during quench, especially when a large amount of cold helium gas was passing through the seal surface.
- Air also leaked through the mechanical and electrical connection ports that had Buna O-ring seals.
- There was a small leak through the pinhole in the rupture disk.

Vent Path Problem

The air leaking into the cold space eventually froze at the wiggler's vent path – see Figure 1, separating the cold space from the room temperature gas space. The vent path was made of a spiral channel cut in a foam insulation installed in wiggler's central throat. The vent path/channel was about 15 mm wide and 10 mm deep, connecting dewar with the top casing where the vent outlet was located. The pressure relief valves and the rupture disk were both connected to this vent outlet. As a result of the blockage, the helium gas was not able to relief through this vent path during liquid helium refilling procedure, at the same time the pressure gauges were not showing properly the cold space pressure - a safety concern was raised.

Figure 1 Spiral vent path cut in the insulation foam.

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LHe Refill Path Problem

The wiggler refill path is constructed with three-sections: external LHe transfer line is inserted into the wiggler through the top section and sits on the first funnel. The middle section is made of an internal LHe transfer tube that leads LHe to the second funnel located on the top of the magnets. The bottom section is a bended LHe transfer tube built around the magnets that discharges the LHe to the bottom of the cryostat (see Figure 2). Ice has formed at all three refilling path sections. A heated copper pipe was used to successfully remove the ice at the top and the middle sections. However, if ice-block formed at the second funnel or the bottom section it was not removable without the warmup. When attempting to refill with vent path blocked, LHe would boil-off at the transfer line sections and at the top section of the cryostat. Pressure therefore would build up until refill tube was removed. A large amount of cold helium gas came out from the cryostat at high pressure at this point, cryogenic hazard occurred.

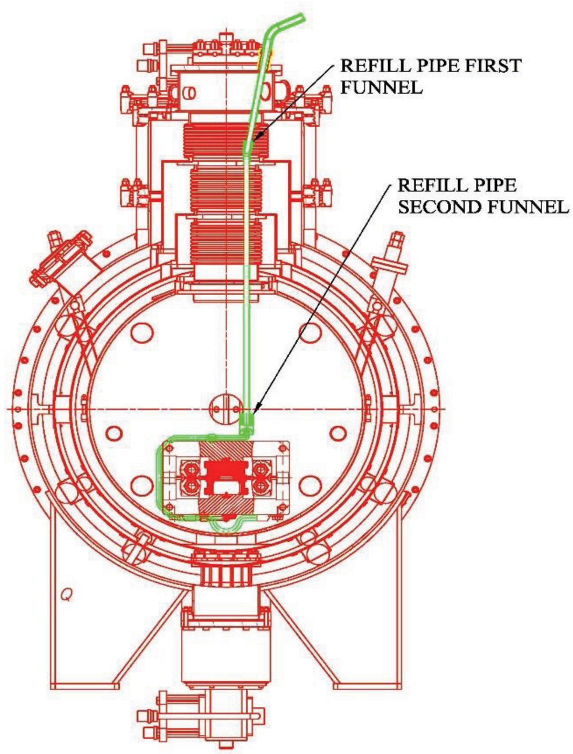

Figure 2 BMIT's wiggler initial refill path.

SOLUTIONS

1. Fix the leaks – the source of the ice blockage

- Pressure relief valves were replaced with the type equipped with zero leak seals at reset pressure. Valves were piped about 450 mm away from the vent outlet port and connected with a 300 mm straight pipe downstream to prevent from ice and condensations forming at valve seal surface.
- All Buna O-ring seals were replaced with aluminium O-rings providing leak free operation.
- Rupture disk was replaced with the new one and equipped with rupture indication signal.

2. Major modifications at the wiggler vent path and refill path – made by BINP group.

- A separate and direct vent path was added - 1.5" DIA pipe connected the wiggler cryostat cold and warm space through the central throat. This hollow pipe runs from the top of the cryostat to the new rapture disk located on the top of the wiggler and provides a barrier free direct exhaust for emergency pressure relief.
- The vent path for the pressure relief valves uses improved spiral channel at the foam insulation.

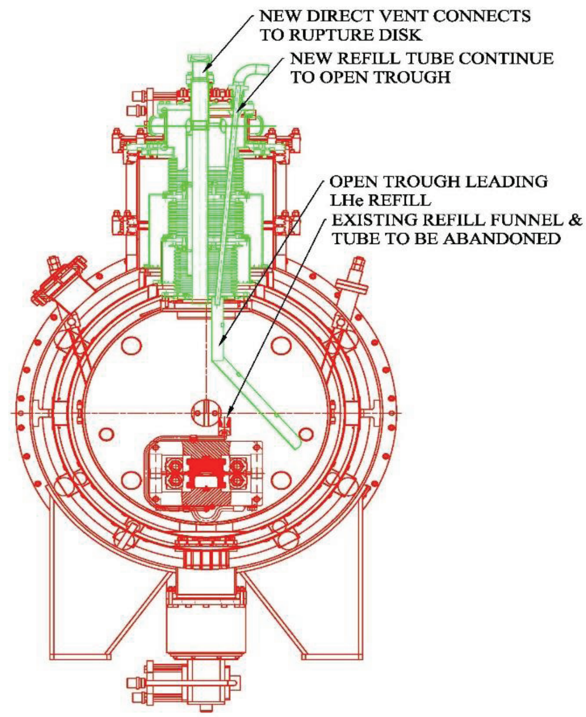

Figure 3 A new vent path & refill path.

- Two heaters were added into the pressure relief vent path to the two narrow points of the central throat - at the two copper flange plates (20 K & 60 K) to mitigate potential ice built up.
- A new LHe refill path was constructed to replace the existing one with two sections. The top section is a single tube runs straight into the bottom section - an open trough that leads the LHe to the lower side of the wiggler cryostat (Figure 3). This change is to eliminate potential ice blockage at the bends.
- Liquid helium transfer line was permanently connected to the wiggler – This became a huge problem as discovered later.

OUTCOMES

1. The wiggler experienced thermal acoustic oscillation problems at refill after the upgrades [4]

- The problem was discovered at the first refill: pressure at the cryostat built up to 350 mbar two hours after the refill was completed and stabilised for about 5 hours then started oscillated. The LHe started evaporating right after and the LHe level in the cryostat dropped from 43% to 0 in less than 2 hours (see Figure 4).

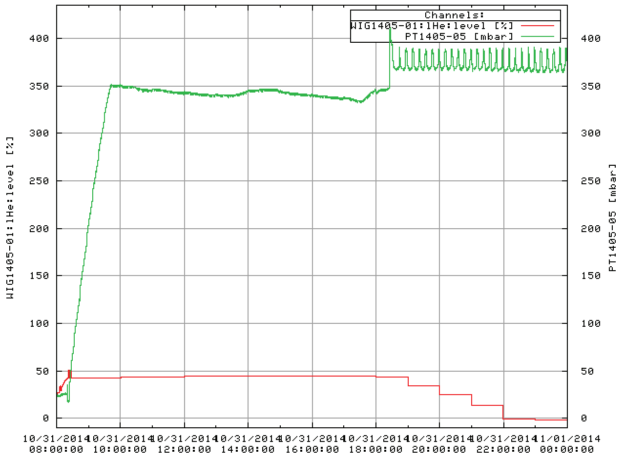

Figure 4 Pressure & level changes at oscillation.

- The second refill repeated and confirmed the same problem: 7 hours after the refill, pressure built up to 350 mbar and stabilised for about 4 hours then started oscillations again.
- BINP indicated that the thermal acoustic oscillation was most likely caused from the long, warm, LHe transfer line that was connected to the cryostat.

2. Several steps performed to fix the thermal acoustic oscillation problem

- LHe transfer line was removed. Pressure at cryostat built up to below pressure relief pressure (350 mbar) and was able to drop and stabilized. Small osculation was still shown (see Figure 5). The above atmosphere pressure at no load condition indicated that heat load increased at this new configuration.

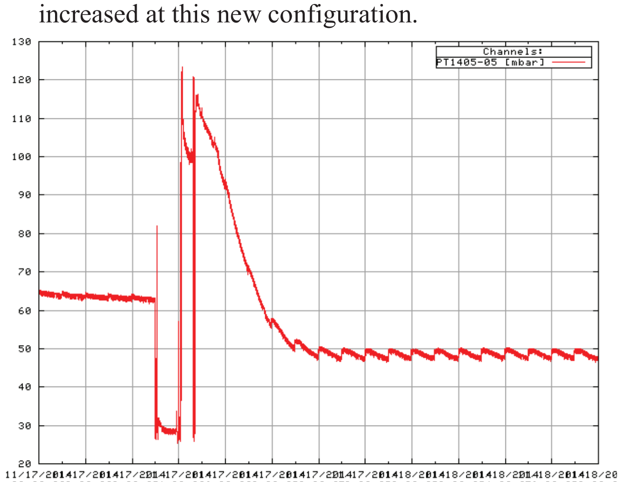

Figure 5 pressure change at LHe transfer line removed.

- A dummy plug made of G-10 FR4 (epoxy the surface) installed at the LHe refill tube to close the opening in the central throat insulation.
- Supper insulation disks designed and installed inside of the 1.5" DIA exhaust pipe using multilayer insulation to reduce radiative and convention heat-loads.

3. End results

- The secondary vent path provides a barrier free safety relief to the wiggler cryostat with super-insulation disks to reduce the heat leaks.
- Pressure at the wiggler cryostat is able to run back to sub-atmosphere to about -160 mbar after the upgrades with no SR heat-load.

CONCLUSIONS

BMIT SC wiggler has performed very well since from the initial installation in 2007. However due to air leaks, ice blockages have formed both at vent and refill path which prevented the refilling process and also isolated the cold space from the safety relief system. Pressure was building up within the cryostat causing cold GHe expelled from the top sections of the refill path when LHe transfer line was removed.

Several improvements were performed over the years trying to resolve this cryogenic safety problem. All air leak sources were removed via replacing the original rupture disk, pressure relief valves and installing metal O-ring seals at external ports. A major upgrade on the wiggler was performed by BINP group in 2014. A new barrier free safety vent pipe that is directly connected to the cryostat was added along with a significant change on LHe refill path to eliminate possibility of ice blockage. Serious heat load increase which was linked to the thermal acoustic oscillations in the LHe transfer line and direct vent path was observed through LHe refill after the upgrade. This heat load was minimised when the LHe transfer line was disconnected, a super-insulation assembly installed within the direct vent pipe and a plug installed at the refill path.

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