

# SUSTAIN THERMAL INSULATION VACUUM OF A LIQUID NITROGEN COOLING SYSTEM FOR TPS CRYOGENIC PERMANENT UNDULATOR

F.-Z. Hsiao<sup>†</sup>, P.-S. Chuang, H.-H. Tsai, H.-Ch. Li, W.-R. Liao, Ch.-K. Yang, Ch. Shueh  
National Synchrotron Radiation Research Center, Hsinchu, Taiwan

## Abstract

At the Taiwan Photon Source (TPS) a cryogenic permanent magnet undulator, CUT18, utilizes the latent heat of vaporization of liquid nitrogen for magnet cooling. After a period of operation, some condensed water, which caused rust at the structure of CUT18, appeared at the flange connecting the cooling system and the vacuum beam chamber of CUT 18. This condensed water was mainly due to deterioration of the thermal insulation vacuum of the liquid nitrogen cooling system. Moreover, the period became much shorter after the maintenance to recover a proper vacuum under cold conditions. This paper presents the efforts to extend the period of sustaining a proper thermal insulation vacuum without the appearance of condensed water. A residual gas analyzer was used to study outgases from the insulation vacuum of the liquid nitrogen cooling system at warm and cold conditions. These efforts succeed to extend the period longer than three months, thus greatly reduced the burden from insulation vacuum maintenance.

## INTRODUCTION

A cryogenic permanent magnet undulator CUT18 was installed at the accelerator of Taiwan Photon Source (TPS) to provide a photon source for the highly brilliance micro-focus X-ray beamline TPS 15A. The coolant of CUT18 is liquid nitrogen where its latent heat of vaporization is used for cooling the terbium (Tb)-diffused neodymium-iron-boron (NdFeB) permanent magnets of CUT18 [1].

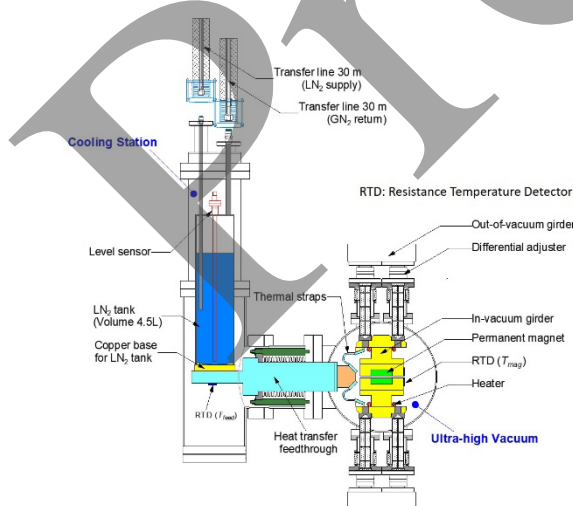


Figure 1: Cooling station with a LN2 tank.

Liquid nitrogen does not directly cool the NdFeB permanent magnet. Instead, the heat conduction mechanism is implemented via a copper bar with one end contacting a cooling station with a 4.5-liter nitrogen tank close to 77.3 K and the other end connecting to the permanent magnets through several flexible copper thermal straps, as shown in Fig. 1 [1]. Using adopted heater loads combined with the thermal load induced from the beam current 500 mA in TPS electron storage ring, the NdFeB magnets keep at 160 K to provide superior magnet properties.

Liquid nitrogen comes from the main streams of rigid cryogenic transfer pipe for TPS photon beamlines, as shown in Fig. 2 [2]. The transfer length from the source tank of volume 60 m<sup>3</sup> to the cooling station tank is more than 300 m. The pressure at the source tank varies in between 2.5 to 3.5 bar, and a valve at the exhaust line for gas nitrogen regulates the pressure at the cooling station tank in the range 1.05 to 1.1 bar.

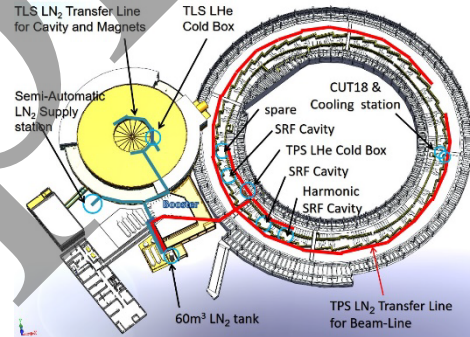


Figure 2: Infrastructure of liquid nitrogen system.

After operation a period, some condensed water appeared at the flange connecting to the vacuum beam chamber of CUT 18, dropped at the frame and caused rust. This condensed water was mainly due to deterioration of the thermal insulation vacuum of the liquid nitrogen cooling system. The period became much shorter after the maintenance to recover a proper vacuum under cold conditions. This paper presents the efforts to extend the period of sustaining a proper thermal insulation vacuum without appearance of condensed water.

## COOLING SYSTEM DETAIL

The nitrogen cooling system of CUT18 includes a valve box and a controller for the liquid level and gas pressure control, two 4.5-liter tanks as the cooling stations, and flexible cryogenic pipes for the transfer of liquid and gas nitrogen between the valve box and the cooling station, as indicated in Fig. 1. The valve box and controller are located

<sup>†</sup>fzh@nsrrc.org.tw

outside the radiation-shielding wall of the TPS accelerator for reasons of space limitation and maintenance convenience. Each flexible transfer pipe passing through the 1m thick radiation-shielding wall separates into two parts- within and outside the wall. These two parts connect in series by a couple of male and female bayonet joints with location outside and adjacent to the shielding wall. Within the shielding wall, each cooling station tank and its two connecting flexible transfer pipes- each with length of 5 m, inner pipe diameter of 21 mm, and vacuum jacket diameter of 73 mm, for the transfer of liquid nitrogen and cold nitrogen gas share the common insulation vacuum. There are two pumping ports for the insulation vacuum- one at the far end of the flexible transfer pipe for cold nitrogen gas, the other at the cooling station tank.

The cryogenic transfer pipe is thermal insulated by a static vacuum and uses multilayer insulation material with alternative layers of polyester foil and aluminum foil to reduce the heat load of thermal radiation from the outer vacuum jacket to the inner process pipe. Here 30 layers of insulation material are in the flexible pipes for the transfer of liquid nitrogen and cold nitrogen gas.

## ACTION AND RESULT

It is obvious that a vacuum pump can keep a good dynamic vacuum for the cooling system. However, this approach is the last choice as the vacuum pump increases energy consumption and needs extra efforts to keep a high reliability for uninterrupted long-term operation.

To improve the sustain period of thermal insulation vacuum lower than a target pressure of  $2.5 \times 10^{-3}$  torr, the first effort was warming up the cooling system and attaching a small amount of active charcoal at the surface of the inner pipe of the flexible transfer pipe. The active charcoal was close to entrance of the cooling station tank. The vacuum should be better as the active charcoal has the feature of high absorption rate at cryogen temperature. The cooling system was then leak checked thoroughly with helium for a leakage rate lower than  $5 \times 10^{-11}$  mbar- $\ell$ /s. After one week pumping down the insulation vacuum, we started the cooling system and recorded the vacuum pressure. The result shows the vacuum pressure kept below  $1 \times 10^{-5}$  torr in the first four weeks and increased larger than  $2.5 \times 10^{-3}$  torr at the 69th day. During a TPS short shutdown, we found the condensed water appearing again at the flange interface, which connects the heat transfer feedthrough of the copper cooling bar and the ultrahigh vacuum beam chamber of CUT 18 as Fig. 1 shows, and the pressure of insulation vacuum increased to  $5.5 \times 10^{-3}$  torr. This flange interface is at the cooling station tank near the side for entrance of the electron storage beam. After few hours pumping down the insulation vacuum to  $9 \times 10^{-5}$  torr as the cooling system in operation, we found that the vacuum pressure increased higher than  $5 \times 10^{-3}$  torr two weeks later and it needed pumping down again.

After reevaluating configuration of the insulation vacuum of the cooling system, we decided to implement the following actions during several TPS shutdown periods:

- Extend the pipe length of the existing pumping port outside the shielding wall and insert a 1.2-meter pipe with inner coating of Non Evaporable Getters (NEG) at the extending section. The homemade NEG pipe assists the active charcoal used in the first effort with additional benefit that the NEG pipe at the room-temperature section is suitable for regeneration after saturation to recover the adsorption capacity [3] during operation of the cooling system.
- Add onsite a small port of diameter 6 mm at the bayonet joint of the flexible transfer pipe for liquid nitrogen. The bayonet joint is located outside and adjacent to the radiation-shielding wall. The complex structure of the bayonet joint, the pipe size, and the available space obstruct to create a port of large diameter during the onsite work.
- Dry the common insulation vacuum by filling warm nitrogen gas from the pumping port of the flexible transfer pipe for cold nitrogen gas at the far end, passing through the insulation vacuum of the cooling station tank and that of the flexible transfer pipe for liquid nitrogen, finally leaving the port of 6 mm diameter. The room-temperature nitrogen gas is used to avoid the risk that the NdFeB permanent magnet will deteriorate its magnetic field at high temperatures.
- Increase the efficiency of vacuum evacuation by three turbomolecular vacuum pumps- two with pumping speed 300  $\ell$ /s and one 77  $\ell$ /s, to pump down the insulation vacuum at locations close to the cooling station tank and the bayonet joints of two flexible pipes for liquid nitrogen and cold nitrogen gas. Furthermore, the pumping down period is longer than two weeks.
- Use Residual Gas Analyzer (RGA) to study outgases from the insulation vacuum of the cooling station under warm and cold conditions.

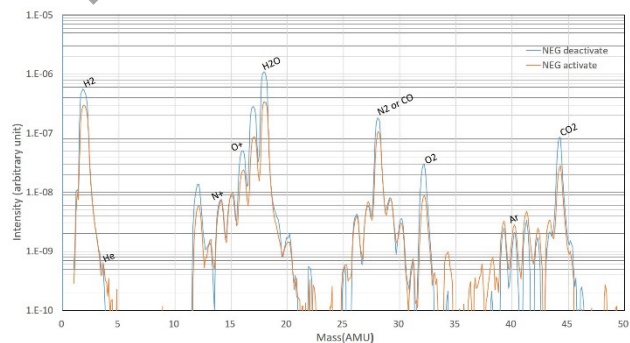


Figure 3: Outgases before and after activating the NEG.

A RGA verified the performance of NEG pipe at the extended pumping port of the flexible transfer pipe for cold nitrogen gas. Figure 3 shows the RGA measurements before and after activating the NEG film by heating the NEG coated pipe to 230 for 24 hours. The results show that the major outgases were H<sub>2</sub>, H<sub>2</sub>O, N<sub>2</sub>, O<sub>2</sub>, CO<sub>2</sub> and they reduced greatly due to the adsorption of NEG coating. Absorption capacity of the NEG coating was close to

saturation at the 11th day as the major outgases increased apparently.

During a long shutdown period of TPS, the cooling system and CUT18 warmed up to room temperature. Then the insulation vacuum of the cooling system was drying by filling nitrogen gas for six days. We remounted RGA at the pumping port of the insulation vacuum of the cooling station tank to measure outgases here before and after the drying process. The results show that moisture remained as an apparent component of the outgases and had no significant value change after the six-day drying, which indicates this drying procedure is not an effective way to remove the moisture within the multilayer insulation material for the thermal radiation.

After the drying process, we pumped down the insulation vacuum of the cooling system with three vacuum pumps for two weeks. Figure 4 shows the measurement results at the 15th day room-temperature pumping down just before activation of the NEG coating, and under 77.3 K condition as liquid nitrogen in the cooling station tank first time reached the specified level. During measurement at 77.3 K, the vacuum pressure kept below a threshold required from RGA via the cryogenic pumping effect without using the turbomolecular pump. The major outgases under room temperature are H<sub>2</sub>O, H<sub>2</sub>, N<sub>2</sub>, CO<sub>2</sub>, while H<sub>2</sub>, N<sub>2</sub>, Ar are the major outgases under 77.3 K condition. This phenomenon is due to the strong cryogenic pumping effect could significantly lower the pressure of the insulation vacuum; the gases H<sub>2</sub>, N<sub>2</sub>, Ar featured with boiling temperature equal or lower than 77.3 K do not condense and proceed phase change and thus are immune to the cryogenic pumping effect at 77.3 K.

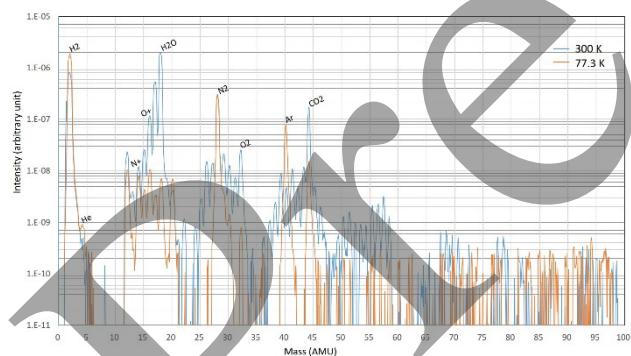


Figure 4: Outgases from the insulation vacuum of the cooling station tank under warm and cold conditions.

Figure 5 shows pressure variations of the insulation vacuum of the cooling system under cold conditions after implementing all the planned procedures. The vacuum pressure reached 1.6e-6 torr at room temperature and further down to 2e-7 torr at 77.3 K liquid nitrogen temperature. The vacuum pressure kept at the low value of 5e-7 torr for the first 14 days due to adsorption of the NEG pipe, the active charcoal and the cryogenic pumping effect. Under this good vacuum condition, we found the flange interface had cold spot temperature at its circumferential surface. Later on checking confirms that the copper cooling bar is not in the central position, which causes the cold spot

temperature due to too small clearance- requiring a lower threshold of insulation vacuum pressure to avoid the appearance of condensed water. It needs to stop this user beamline for a long period to take CUT18 out of the TPS storage ring for correction of the cooling bar position.

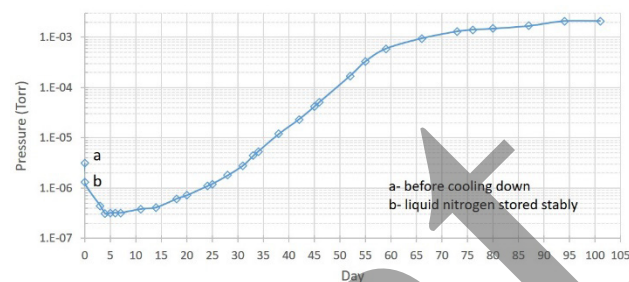


Figure 5: Pressure variation of the insulation vacuum.

The vacuum pressure increased slowly and kept below 2e-6 torr for four weeks. It took 101 days for the vacuum pressure increasing to 2.1e-3 torr, which implies the frequency to maintain the vacuum pressure could reduce significantly if the presented procedures can be repeated during each TPS long shutdown period. The record of vacuum pressure aborted after 101 days because CUT18 needed to warm up for the installation of an adjacent DCCT backup detector for measuring the beam current of TPS storage ring.

## CONCLUSION

The copper cooling bar not in the central position causes small clearance, induces the cold spot temperature at the interface flange surface, and requires a lower threshold of insulation vacuum pressure to avoid the appearance of condensed water. RGA measurements indicate the major outgases under room-temperature condition are H<sub>2</sub>, H<sub>2</sub>O, N<sub>2</sub>, CO<sub>2</sub> and that under 77.3 K condition are H<sub>2</sub>, N<sub>2</sub>, Ar. Four efforts help to extend the period of sustaining a proper thermal insulation vacuum. They are (1) attaching active charcoal at cold surface, (2) inserting NEG coated pipe at warm section, (3) increasing evacuation efficiency by vacuuming at both ends and central position of the common insulation vacuum, (4) extending evacuation time more than two weeks as the cooling station at room temperature. It takes 101 days for the vacuum pressure to reach 2.1e-3 torr without the appearance of condensed water. The 101-day period greatly reduces the frequency to maintain the insulation vacuum of the cooling station.

## REFERENCES

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