DEVELOPMENT OF MULTI-CHANNEL LINE FOR NSRRC CRYOGENIC SYSTEM

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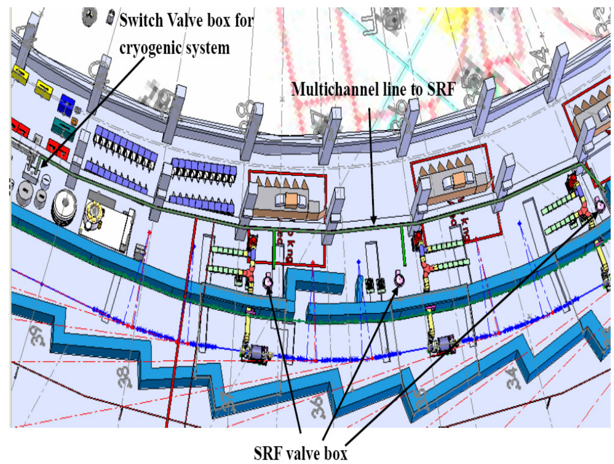
Abstract

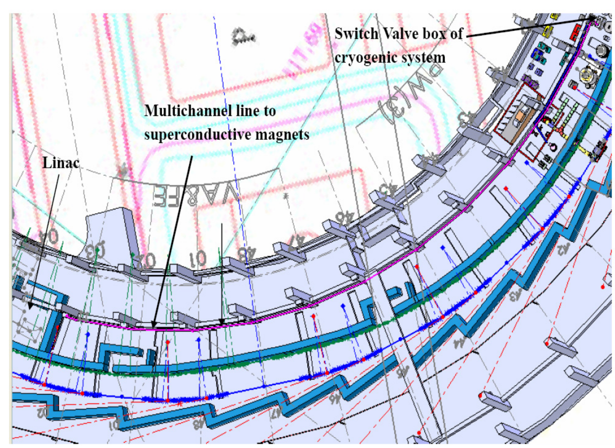
For the past few years, the technology of X-ray photon source is getting more and more advanced, more and more countries are now striving to build the biggest synchrotron facility to meet its' need. The construction of an electron accelerator with the energy of up to 3.5 GeV is constructed to fulfil the strong demands for an X-ray photon source with high brilliance and flux for Taiwan photon source (TPS) project at NSRRC. Thus, to let the TPS be under stable operation, the cryogenic system is therefore very important. The refrigerant of the TPS cryogenic system is liquid helium, to maintain liquid helium in its state, the temperature has to be maintained under 4.5 K, however to let liquid helium turn into gas helium, only 20 W is needed. Therefore, the Multi-Channel Line is developed in our system to prevent heat from conduction in and letting liquid helium vaporize. Several mechanical parts have been designed to reduce heat loss and meet its needs, for example the Spacer. The paper presents a design methodology of long multi-channel helium cryogenic transfer lines. It describes some aspects heat transfer calculation, supporting structure and contraction protection.

INTRODUCTION

The refrigerant of the TPS cryogenic system is liquid helium, to maintain liquid helium in its state, the temperature has to be maintained under 4.5 K, however to let liquid helium turn into gas helium, only 20 W is needed. Therefore, the Multichannel transfer line (MCL) was installed in our system to prevent heat from conducting in and letting liquid helium vaporize. Figure 1 (a) and (b) shows the layout of multichannel line and distribution valve boxes. The multichannel transfer line has thermal shielding at 77 K by using liquid nitrogen. The vacuum pipe of the multichannel transfer line has a diameter of 10 inches. Inside the vacuum pipe are a line for liquid helium of diameter 0.75 inch, a line for liquid nitrogen of diameter 0.5 inch, and a return line for helium gas of diameter 2 inch. The 1 inch GN2 return line was included to reserve the possibility to recover the enthalpy of GN2 in the future. The total length of liquid helium transfer lines was about 124 m. One distribution valve box and four control valve boxes were installed and commissioned in 2015 to distribute the liquid helium from the dewar to four SRF cavities [1]. The total heat load of 124 m helium transfer lines and the valve boxes is about 87 W. The MCL may extended in the future, since the new superconducting devices may installed and located far away from the cryogenic system in the future. The estimate length of MCL is about 178 m. The low heat load MCL was then to develop in house to connect from the end of current MCL. This paper aimed to present the design of the MCL. The mechanical design and heat transfer mechanism was also presented and discussed.



(a)



(b)

Figure 1: (a) Multichannel line to SRF valve box, (b) Multichannel line to superconductive radio frequency cavities.

DESIGN

The multichannel transfer lines consists of Helium supply, return line, and liquid nitrogen supply, return line. Main transfer line is multichannel type. The most important part of the multichannel line is the spacer, with a good spacer design, loads of heat loss could be reduced [2]. Knowing that Liquid Helium is very expensive, thus,

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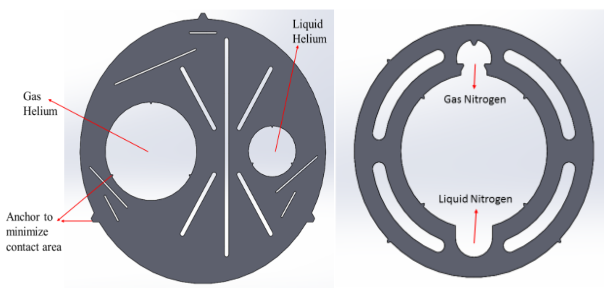
the main goal is to design a spacer for which liquid Helium and gas helium pipes cold be in contact with the spacer and still have heat loss of under 0.1 W per meter, Fig. 2 (a) is the spacer design for liquid helium and gas helium, whereas Fig. 2 (b) is the spacer design for liquid nitrogen and gas nitrogen. Figure 3 shows that helium lines have been protected by a shield to prevent thermal radiation, and the shield is also in contact with the liquid nitrogen piping letting shield temperature to cool down to 80K reducing direct thermal radiation to the Helium piping's [3].



(a) (b)

Figure 2: (a) Helium Spacer, (b) Nitrogen Spacer.

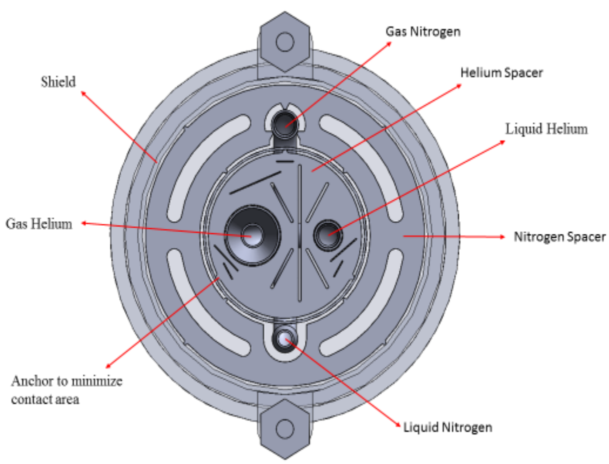


Figure 3: A Sectional View of NSRRC Multichannel line.

Figure 4 shows the experimental MCL developed in NSRRC could be detached. The purpose of the detachment makes it easier do change different types of spacer designs throughout the experiment. As can see in Fig. 4, a pumping port is installed at the front end of the multichannel line allowing to pump down the vacuum barrier to keep it vacuum. The main reason is to prevent heat from convecting, in order to let liquid helium evaporate, only 20 W is needed, thus, preventing heat convection is very important. At the front, middle and end, there would be feedthroughs placed to measure physical properties.

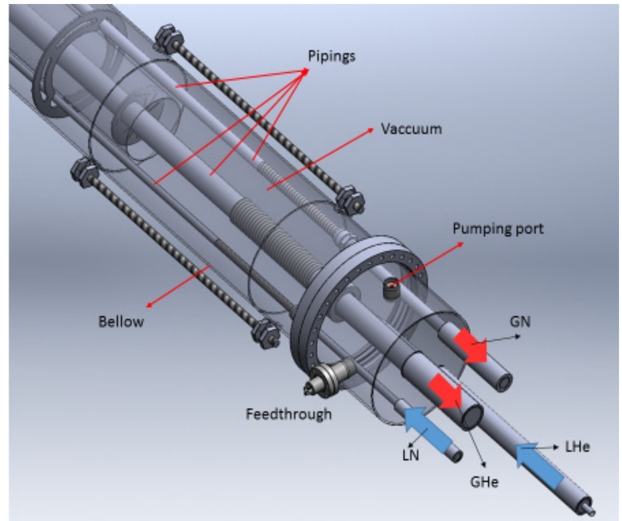


Figure 4: Detachable Multichannel line.

There is an estimated total length of 178 m liquid helium transfer lines in NSRRC. As we all know that the steel expands when heated and contracts when cooled. The 178 m steel contracting when liquid Helium passes through would be a big risk of damaging the pipes. To prevent pipes from damaging when contracting and expanding, a bellow is specifically designed and built to meet its end, in the multichannel line. We want to prevent the pipelines bending at the joint, however, we also want it to bear the margins that is caused by thermal contraction [4]. For reducing the thermo-mechanical stresses and mechanical forces acting on multichannel line, the specific bellow is design to move only in the horizontal direction as shown in Fig. 5.

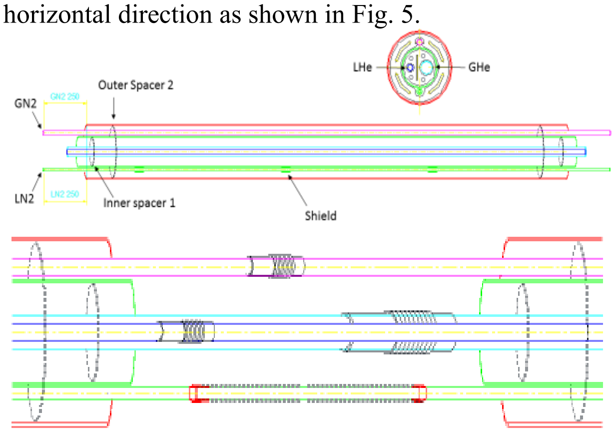


Figure 5: Connecting pipes with Anti-Torque Bellow.

SIMULATION

The problem of heat transfer is of important in mechanic and engineering field, in the past decade, it has been encountered in many applications of engineering. Helium cryogenics has become a key technology in many big scientific facilities for example NSRRC for making extensive use of superconducting magnets, cavities, high speed vacuum cryopumps and other devices. For the multichannel line, heat transfer passing through the spacer will affect liquid helium to heat up and cause phase change. The main purpose of designing the spacer is to

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solve heat from conducting from 80K to 4K, therefore, liquid helium can be maintained in its state. Many attempts were made to solve the problem. As shown in Fig. 6, the outer cusps of the spacer are the points that are in contact with the liquid nitrogen shield, therefore the temperature would be around 80 K, the inner cusps of the spacer is in contact with liquid helium which is around 4 K. As seen that the heat will travel in the shortest route to transfer from high to low temperature, therefore, attempts were made to cut the heat off from conducting effectively while still maintaining the structural strength of the spacer. Many trials were made, and finally, the preliminary design has been completed. As can see in Fig. 7, only a minor of heat will conduct through the cusps and into helium, the average ΔT from the contact surface of the cusp to the contact surface of helium is only about 0.4 K.

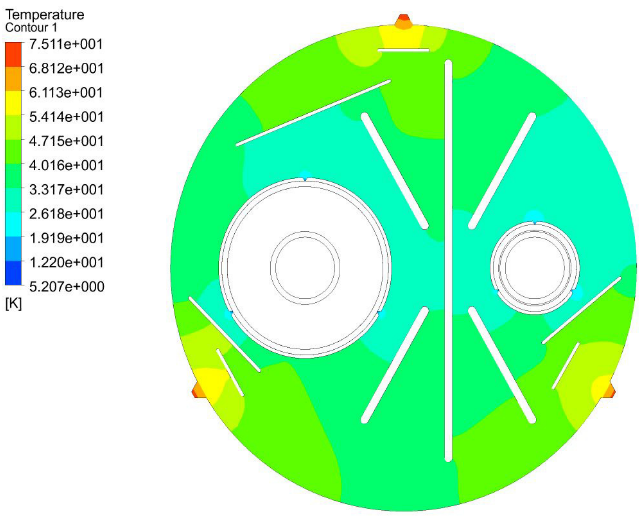

Figure 6: Temperature distribution of spacer.

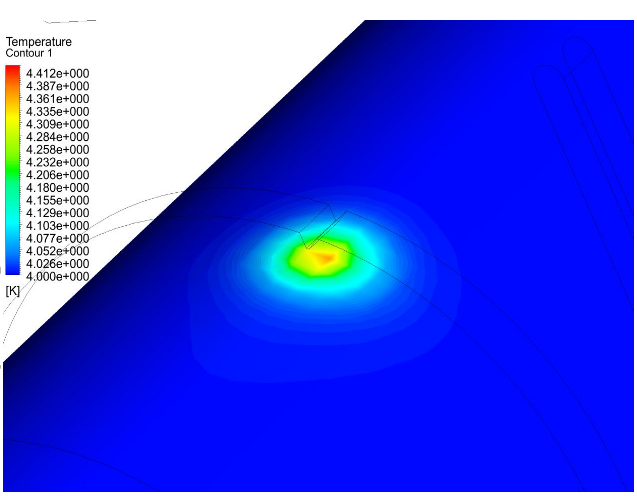

Figure 7: Temperature distribution of helium at point which is in contact of cusp.

Simulating and analysing the test section of the multichannel line leads to the result of 0.02088 W of heat loss per meter for liquid Helium pipeline and 0.0006 W of heat loss per meter for gas Helium pipeline. This result is much better than the 0.1 W per meter goal set at first.

CONCLUSION

Although the multichannel line doesn't seem as important as other parts in the entire cryogenic system, it is still a very complex heat transfer mechanism objects requiring careful design. Simulating the test section of the multichannel line leads to the result of 0.02088 W of heat loss per meter for liquid Helium pipeline and 0.0006 W of heat loss per meter for gas Helium pipeline, this result is much better than the 0.1 W per meter goal set at first. The MCL test section line is now under construction, we expect to fish testing it at the end of next year.

ACKNOWLEDGEMENT

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REFERENCE

[1] H. H. Tsai, F. Z. Hsiao, H. C. Li, S. H. Chang, T. F. Lin, W. S. Chiou, C. P. Liu, "Commissioning of the Helium Cryogenic System and LN_2 Transfer System in the TPS Ring," presented in ICEC/ICMC 25 conference, Netherlands, July 7-11, 2014.

[2] Jun Yoshida *et al.*, "Development of STF Cryogenic System in KEK," *in Proc. of PAC'07*, Albuquerque, New Mexico, USA, 2007, paper THICKI04, pp. 2701-2703.

[3] Erdt W. *et al.*, "The Cryogenic Distribution Line for the LHC: Functional Specification and Conceptual Design," in Advances in Cryogenic Engineering 45, pp 1387-1394 (2000).

[4] J. Fydrych *et al.* "Design Methodology of Long Complex Helium Cryogenic Transfer Lines."

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