Cryomodule Test Bunker for the ILC Technology Network

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Abstract. "ILC Technology Network" (ITN) is an international framework for the technological development outlined in the time-critical Work Package (WP). The focus of WP1 and 2 are cavity production and cryomodule design, respectively. The High Energy Accelerator Research Organization known as KEK plans to produce one cryomodule equipped with eight superconducting 9-cell cavities for WP1 and 2 from FY2023 and conduct measurements by FY2027. To do that, a test facility will be required to perform the measurements. This test facility was named "Cryomodule Test Bunker" (CTB). The refrigerator (Linde LR280) currently operating at KEK will be used for CTB. The helium transfer line has been designed based on KEKB's transport line design; however, it was slightly modified because the International Linear Collider (ILC) does not use liquefied nitrogen for the thermal radiation shield. It is planned to install a 2K refrigerator, a purification filter, etc. The construction of the CTB will enable us to measure the performance of the cryomodules which are the main components of the ILC. This indicates that it will be possible to verify various aspects of the fabrication and inspection of cryomodules for the ILC, and is a very important technological step towards the construction of the ILC. It can also be used as a general-purpose test stand for superconducting accelerators, which will be useful in developing future superconducting accelerators.

1 Introduction

As part of the ILC Technology Network (ITN) project, construction of an International Linear Collider (ILC) -type cryomodule and measurement of its performance has been planned over a five-year period starting in April 2023. To measure the performance of the cryomodule, the cavity should be cooled to 2 K; therefore, a cryogenic system using liquid helium is required. This measurement facility is called the Cryomodule Test Bunker (CTB) for ITN. The CTB will be built in the Center Of Innovation (COI) building in the KEK Tsukuba campus. To conduct measurements by March 2028, installation of the cryogenic system must be completed by mid-2027.

2 Helium refrigerator

An existing helium liquefier (Linde LR280) will be used for the CTB to reduce the construction cost. The liquefier is already installed in the COI building. The ILC cryomodule has a

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40–80 K radiation shield, a 5–8 K thermal anchor, and a 2 K region for the superconducting cavities (Figure 1). The refrigerator has a capacity of 250 L/h in liquefier mode or 600 W in refrigerator mode at 4.4 K. In addition, it can be supplied with helium gas at 40 K. The use of 40 K helium gas results in a decrease in liquefaction capacity. However, the effect is not linear; The behavior of the refrigerator is complex, such as an increase in the temperature of the supplied gas. Here, the impact on the refrigeration capacity is extrapolated from the impact observed with a significantly small amount of supply gas. The capacity at 40 K is estimated at 40 g/s. Considering the heat capacity of helium gas, the cooling capacity of the 40–80 K region is 8 kW.

In particular, 40 K helium gas is supplied from a branch of the supply pipe to the expansion turbine. After reducing the pressure at a control valve, the helium gas cools the radiation shield. Finally, the gas is sent to the low-pressure port of the liquefier. In design for ILC refrigerator, 80 K gas returns to the turbine inlet; however such a design is not possible in this project because the existing liquefier would need to be reused [1]. According to the TDR, the heat load of the radiation shield is approximately 134 W. Even if it is assumed that the heat load is greater than in the previous facility, the allocation of 200 W is sufficient. The helium gas used to cool the radiation shield is expected to have a temperature rise of 40 K; thus its cooling capacity is approximately 200 W per g/s. A flow rate of 3 g/s will be assumed for the CTB to provide an ample margin. Therefore, 8% of the refrigeration capacity is used to cool the radiation shield.

The 5–8 K thermal anchor is cooled by liquid helium. In the ILC, liquid helium is sent directly from the refrigerator; however, in the CTB, it is first stored in a Dewar and then supplied; thus, the pressure in the cooling pipes is low. The evaporated gas returns to the liquefier as low-temperature gas; thus, it is operated in refrigerator mode. The heat load in this region is estimated to be approximately 16 W; whereas, the heat load of the transfer line is approximately 10 W. The cooling capacity in the refrigerator mode is 600 W. Therefore, 4% of the cooling capacity of the refrigerator mode will be used.

The 2 K region is cooled by reducing the pressure of the supplied liquid helium using a vacuum pump. As the vacuum pump operates at room temperature, cooling in the 2 K range is performed in liquefier mode. The capacity of the liquefier mode is 250 L/h; hence, when evaluated in terms of latent heat of liquid helium, it is 175 W. The expected heat load is approximately 11 W. The capacity of the vacuum pump was determined to ensure that it could handle a heat load of approximately 100 W. Therefore, the 2 K heat load uses approximately 6.3% of the liquefier mode. The pump capacity is set to handle up to approximately 57%.

3 Transfer line

The CTB will be constructed in the COI building, an existing building at the KEK Tsukuba campus. The heavy radiation shield must be constructed around the cryomodule; thus it should be built on a reinforced floor. There is a reinforced floor in the COI building; hence, it was decided to establish the CTB in the COI building. The helium refrigerator is already in operation; thus, its location is decided. These devices are separated by approximately 100 m. Because liquefied helium must be transported between these instruments, high-performance insulated piping, the transfer line, is required. At KEK, a high-performance transfer line is already in operation: details on their designs have been described in a previous study [2]. Transfer lines with thermal radiation shields cooled by liquid nitrogen are already installed at SuperKEKB, STF, and cERL. The transfer line (Figure 2) for CTB employs the radiation shield cooled by helium gas. Because the 80 K gas is returned to the low-pressure port of the refrigerator, the gas pressure in the transfer line can be reduced. Low-gas pressure prevents the flow velocity in the cooling pipes from being too slow, making the pipes thinner and

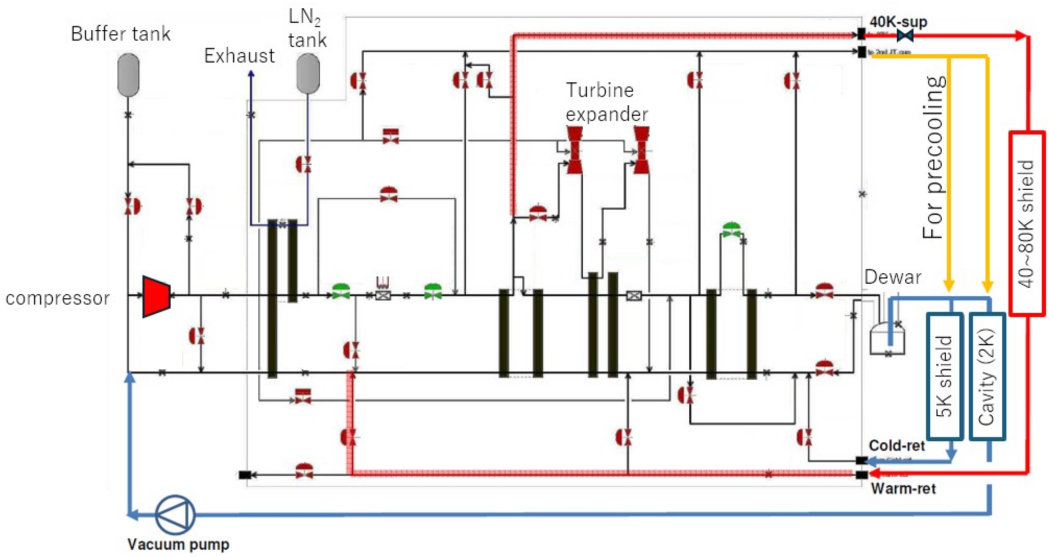

Figure 1. Flow diagram of the CTB refrigerator. The control valve colors are green for normally open and red for normally closed.

reducing the cold mass. The flow rate required to cool the radiation shield is approximately 1 g/s; however, to be on the safe side, we calculated the pressure loss and gas velocity when the flow rate was 3 g/s, and found that a maximum flow velocity of 40 m/s and pressure loss of approximately 30 kPa were acceptable. Assuming that the temperature of the radiation shield is 40 K and that 10 or more layers of SI are installed, the heat load to the radiation shield is approximately 70 W. Because the radiation shield is cooled to a temperature lower than the liquid nitrogen temperature, it is assumed that the heat input to the liquid helium supply pipe will be smaller than that in the KEKB case. The heat load to the liquefied helium supply pipe is approximately 0.05 W/m; thus, we calculate it to be 0.1 W/m to be on the safe side. Specifically, the assumed heat load on the liquefied helium supply pipe is 10 W.

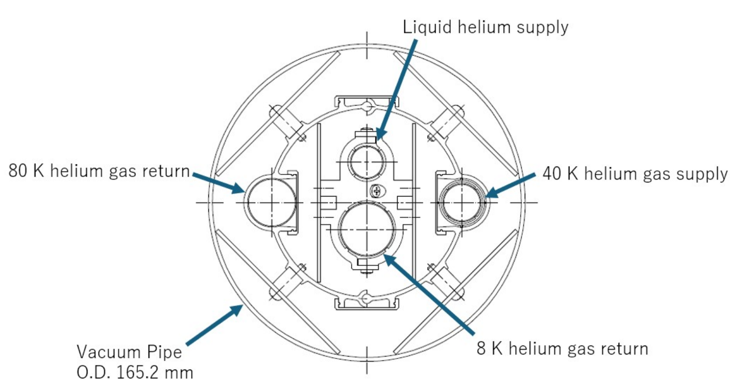

Figure 2. Cross section of the high-performance transfer line

4 2 K refrigerator

The cryomodule is cooled via a 2 K refrigerator installed in the CTB. The conceptual diagram of a 2K refrigerator is shown in Figure 3. KEK has experience in designing and operating 2K refrigerators at STF and cERL.Therefore, these designs were used as references to optimize the ILC cryomodule for measurements. One of the important purposes of the CTB is to measure the heat load at each temperature region in the cryomodule. This is a different objective than that of existing 2K refrigerators, which are intended to operate at high heat load. The heat load of the 80 K shield can be calculated by measuring the temperature of helium gas at the supply and return ports of the radiation shield of the cryomodule and the mass flow. To measure the heat load of the 5K anchor, the liquefied helium supplied from the transfer line is separated into gas and liquid and only the liquefied helium is sent to the 5K shield. By measuring the temperature and mass flow of the returning gas, the heat load can be determined from the enthalpy difference. The 5K shield is cooled by refrigerator mode; thus, the flow rate must be measured at low temperatures. The pressure of the 2K region is reduced to approximately 3 kPa of absolute pressure using a vacuum pump. Liquefied helium is supplied to the 2K region through a heat exchanger to cool the 2K region. The heat exchanger is cooled by helium gas evaporated from the 2K region. When measuring the heat load in the 2K region, the supply of liquid helium to the 2K region is stopped. As the amount of liquefied helium evaporated corresponds to the heat load, the heat load can be calculated by measuring the mass flow. The mass flow may be measured at low temperature or at room temperature.

By expanding the interface section, the 2K refrigerator can cool various cryomodules, including those that operate the cavity at 4.2K.

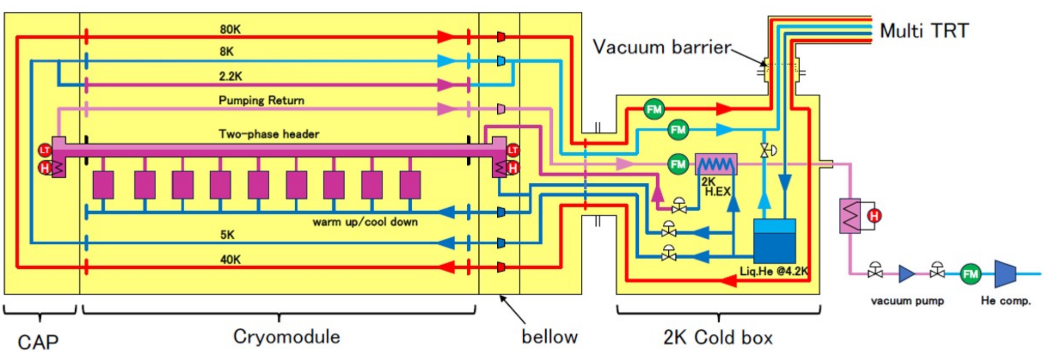

Figure 3. Conceptual diagram of the 2K refrigerator for CTB. FM:flow meter, LT:helium level meter, H:heater. TRT:transfer line

5 Conclusion

A CTB facility capable of measuring cryomodules for the ILC is currently under construction, with completion scheduled for mid-2027. The transfer line and 2K refrigerator for the CTB were optimized for this facility, considering the existing equipment. The planned cryogenic facility is designed for general purpose, it can be used to test cryomodules for other projects as well. The layout and detailed design of the transfer line for the CTB is mostly complete. The conceptual design of the 2K refrigerator has been completed, and detailed design is underway.

6 Acknowledgment

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References

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