Development of a China test cryomodule for ILC*

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Abstract Research and development of a 1.3 GHz 9-cell cavity test cryomodule were carried out by a collaboration group between IHEP (Institute of High Energy Physics) and TIPC (Technical Institute of Physics and Chemistry) in China. The cryomodule is a “test model” for the ILC cryomodule, and a key component of a superconducting accelerator test unit which will be built in the near future, also can be used as a horizontal test facility for 1.3 GHz 9-cell cavities. This paper presents the development status of the cryomodule, including structure design, cryogenic flow diagram, thermal and mechanical simulations, heat load estimation and etc.

Key words cryomodule, 1.3 GHz cavity, ILC, test model

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1 Introduction

The International Linear Collider (ILC) is a proposed electron-positron collider, which will be the world’s largest research center in the field of high energy physics. The superconducting accelerator technology was chosen for the main linac of the ILC in 2004[1]. As an important part of the R&D activities for ILC in China, a SRF cryomodule collaboration group between IHEP (Institute of High Energy Physics, Chinese Academy of Sciences) and TIPC (Technical Institute of Physics and Chemistry, Chinese Academy of Sciences) was set up in Oct. 2006. Research and development of a 1.3 GHz 9-cell cavity cryomodule is their first task. The cryomodule is a “test model” for the ILC cryomodule[2—4], and a key component of a superconducting accelerator test unit which will be built in the near future. It also can be used as a horizontal test facility for 9-cell cavities. The structure design, thermal and mechanical simulations, 3D modeling, cryogenic flow diagram, manufacturing process, cost estimation and etc were carried out for this cryomodule.

2 Structure of the test cryomodule

As a “test model” for the ILC cryomodule, the main structure of the cryomodule is similar to the ILC cryomodule, as shown in Fig. 1. There are in total four temperature regions in the cryomodule: room temperature for the vacuum vessel; 80 K for the nitrogen cooled radiation shield; 5 K for the helium cooled radiation shield and 2 K for the cavity and superfluid helium system. The cryogenic pipes were connected with the cryogenic system through a valve box on the top of the cryomodule. There are in total 7 cryogenic pipes in the cryomodule: inlet and outlet for the 2 K, 5 K, 80 K and a pre-cooling pipe. The helium gas return pipe (GRP) is the backbone of the module. Two epoxy posts support the GRP; the cavity and the superfluid helium vessel suspend under the GRP through sliding supports.

At one end of the two-phase helium pipe, a helium vessel is added and a level meter is inside，so that the liquid surface of the 2 K helium can easily be controlled. At the other end, the two-phase helium pipe is connected to the GRP. The helium gas in the

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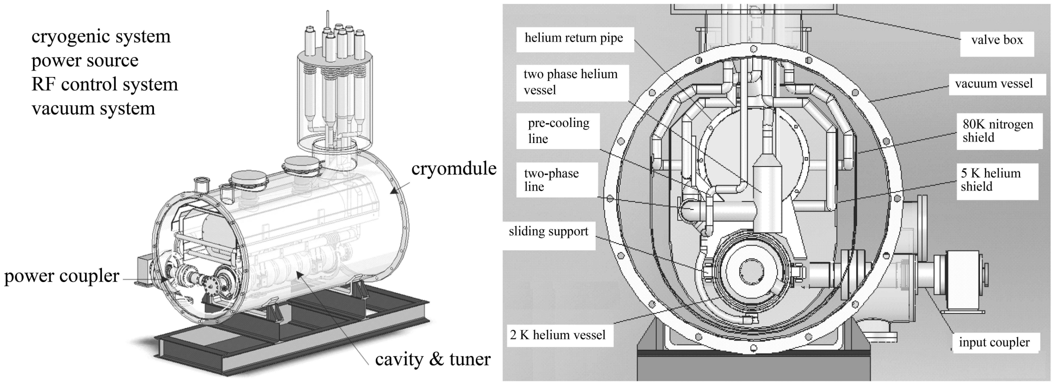

Fig. 1. Structure of the China test cryomodule for ILC.

two-phase helium pipe is pumped to the GRP and the liquid helium flows to the 2 K vessel. Due to the high heat transfer efficiency and capacity of the superfluid helium, the static and dynamic heat load of the 2 K system is transferred to the helium surface in a very short time, and vaporizes the liquid helium to vapor.

The 5 K and 80 K radiation shields minimize the radiation heat load of the 2 K system. Simultaneously, the support posts and power couplers are connected to the two shields in their mid parts. Most of the heat conducted from room temperature flows to the 80 K and 5 K shields. The 2 K conduction heat load was also minimized.

The material of the 2 K helium vessel is titanium, whose thermal expansion coefficient is similar to that of niobium, to decrease the thermal stress between cavity and helium vessel (The tuner system makes up the final difference of the thermal expansion coefficient between the two materials). The two materials are also easy to be welded. The material of the 5 K and 80 K shields is aluminum alloy 5083, whose heat conduction coefficient is high and its mechanical behavior is satisfying. The material of the vacuum vessel is iron, acting as the first magnetic shield of the cryomodule simultaneously. The second magnetic shield is usually a layer of pamalloy inside 2 K helium vessel with thickness of 1 mm.

3 Cryogenic flow diagram

The cryomodule provides a static 2 K operation environment for the SRF cavity. The 2 K heat load of the module is absorbed by the superfluid helium flow. The 5 K shield is cooled by helium. The 80 K shield is cooled by nitrogen.

At the static condition, the heat loads are from thermal radiation, support posts, power coupler, beam pipe of the cavity, instrumentation cables and etc. The estimated 80 K, 5 K and 2 K heat loads are 16.7 W, 2.55 W and 0.6 W respectively. At the dynamic condition, the input coupler and the cavity will cause more heat loads. The detail is shown in Table 1.

Table 1. Estimated heat load of the test cryomodule.

heat source	static(W)			dynamic(W)		
	80 K	5 K	2 K	80 K	5 K	2 K
radiation	4	0.15				
support posts	3	0.4	0.05			
input coupler	3	1.2	0.04	3	0.2	0.05
cavity	0.5	0.2	0.1			0.4
instrumentation cables	1	0.3	0.2			
other	1	0.3	0.2			0.1
sum	12.5	2.55	0.59	3	0.2	0.55

Figure 2 shows the cryogenic flow diagram. The cryogenic system provides 4.5 K liquid helium to the helium dewar. The pressure in the dewar is 1.2 bar. From the 4.5 K dewar, the liquid helium is pre-cooled and throttled to 2 K. The 2 K two-phase helium flows to a phase-separate vessel. In this vessel the helium gas is pumped to the GRP and the liquid helium flows to the 2 K superfluid helium vessel to cool the cavity. The pressure in the phase-separate vessel is 16 mbar. The liquid surface of the helium in the vessel is controlled to a stable value by adjusting the power of a heater in this vessel.

The mixture of 300 K and 80 K helium gas precool the cryomodule to 80 K, and then the liquid helium is used to cool the module to 4.5 K. After the precooling is finished, the 4.5 K helium is throttled to 2 K and provided to the module.

4 Thermal and mechanical simulation

Thermal and mechanical behaviors of the test cryomodule were simulated with the FEM software ANSYS, including the temperature distributions of the 5 K and 80 K shields with the varied mass flow of the cooling gas, the thermal stress distributions and deformation of the radiation shields, 2 K system and the support posts and etc.

The maximum temperature difference of the 80 K shield is limited to 10 K, and that of the 5 K shield to 5 K. The maximum deformation of the two shields is limited to 10 mm. Fig. 3 shows the temperature distribution and deformation along the horizontal & axial direction of the 5 K shield with a helium flow of 0.08 g/s. It shows that the maximum temperature of the shield is about 8.7 K, occurring around the support posts, and the maximum deformation is about 7.7 mm along the horizontal & transverse direction, occurring at the center of one side of the shield.

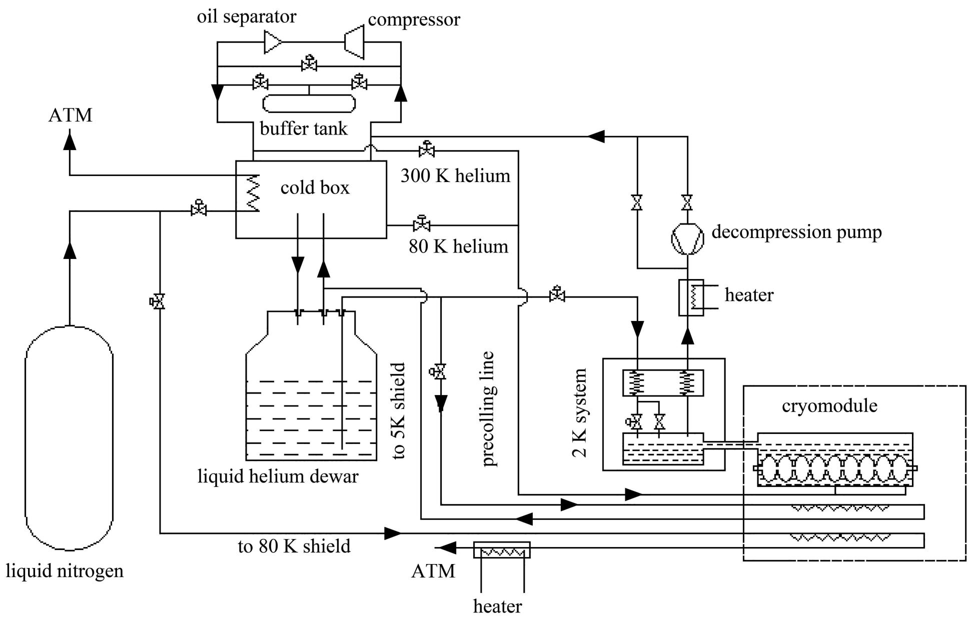

Fig. 2. Cryogenic flow diagram of the test cryomodule.

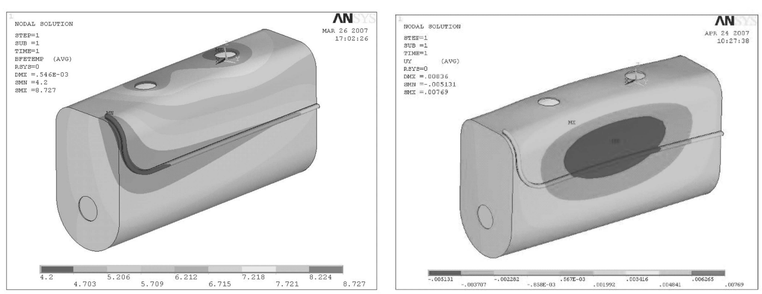

Fig. 3. Temperature distribution and deformation along the horizontal & axial direction of the 5 K shield with a helium flow of 0.08 g/s (Unit: temperature—K, deformation—m).

Figure 4 shows the variation of the outlet temperature of the cooling helium, the average and maximum temperature of the 5 K shield with the different mass flow of the cooling gas. It shows that no big variations occur to the maximum and average temperatures of the 5 K shield with mass flow of the cooling helium, even if it is increased several times.

Figure 5 shows the horizontal deformation of the 2 K system after being cooled down. For the horizontal axial direction, the 2 K system shrinks from the two ends to the fixed support post. The deformations of the two ends are 2.6 mm and 1.1 mm, respectively. For the horizontal transverse direction, the 2 K system shrinks from the two sides to the support line of the cryomodule. The maximum deformation is about 0.5 mm.

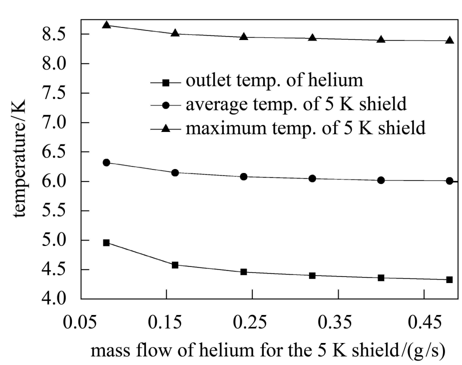

Fig. 4. Variation of outlet temperature of the cooling helium, average and maximum temperature of the 5 K shield with the different mass flow of the cooling gas.

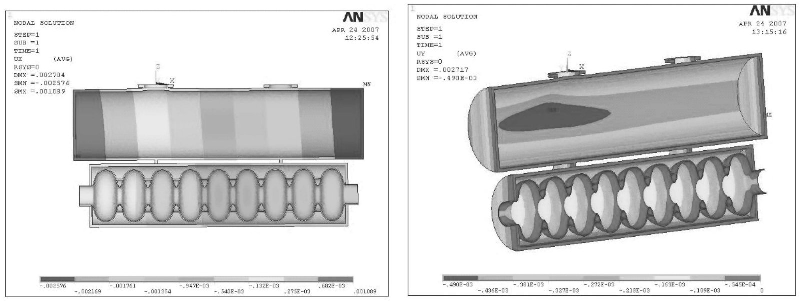

Fig. 5. Horizontal deformation of the 2 K system after being cooled down (Unit: m).

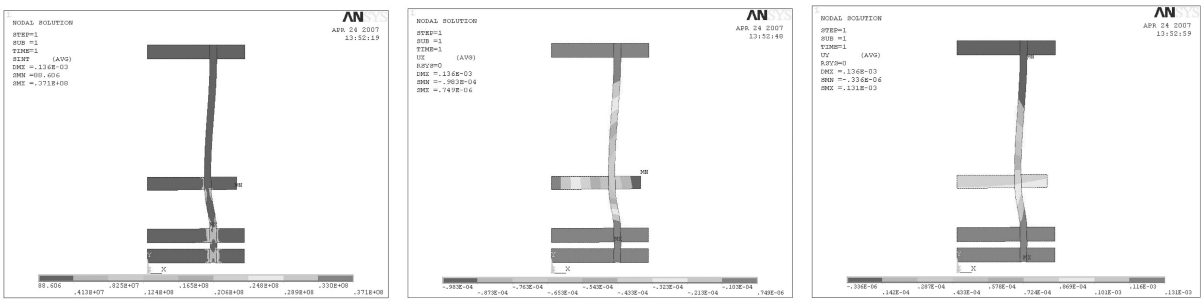

Fig. 6. Stress distribution, horizontal and vertical displacements of the support post after being cooled down (Unit: stress—Pa, deformation—m).

Figure 6 shows stress distribution, horizontal and vertical displacements of the support posts after being cooled down. The maximum stress occurs at around the 5 K and 2 K region. The stainless steel rings and G10 pipe move obviously to the inner side at the 80 K region. The maximum deformations are 0.1 mm at the outer side of 80 K region along the horizontal direction, and 0.13 mm at the 2 K region along the vertical direction.

5 Summary

As a part of R&D work for ILC in China, a test model for the ILC cryomodule was developed. The structure design, thermal and mechanical simulation, 3D modeling, cryogenic flow diagram, fabrication process and the cost estimation were carried out for this cryomodule. A scaled model has been fabricated for this test cryomodule system, as shown in Fig. 7.

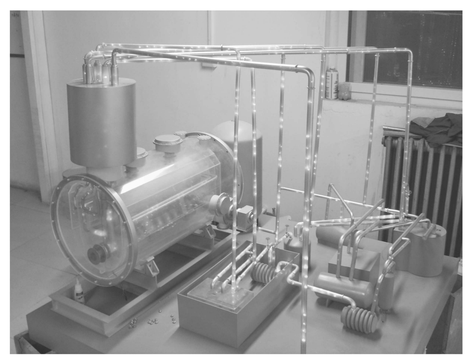

Fig. 7. A scaled model for the China test cryomodule system.

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