THERMAL DESIGN FOR THE JAERI FEL SUPERCONDUCTING LINEAR ACCELERATOR MODULE

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Abstract

An electron linear accelerator driver for a free electron laser (FEL) system has been built utilizing superconducting RF cavities at Japan Atomic Energy Research Institute, Tokai. We have newly developed a multi-refrigerators system integrated into a superconducting linear accelerator module cryostat containing the cavities to realize the highly-efficient without any liquid coolant.

A finite element method (FEM) calculation code (ANSYS Rev. 4.4A) has been used to evaluate temperature distribution of heat shields, and other major components of the cryostat. Thermal design for the cryostat is performed to optimize heat loads to the major components of the cryostat by utilizing the calculated and experimental results.

A design goal and some optimization of the cryostat for the JAERI FEL accelerator module are reported,and discussed in detail in this report.

1. Introduction

An electron linear accelerator driver for a free electron laser (FEL) system has been built utilizing superconducting RF cavities at Japan Atomic Energy Research Institute, Tokai. We have newly developed a multi-refrigerators system integrated into a superconducting linear accelerator module cryostat containing the cavities to realize the highly-efficient without any liquid coolant.

A 4K closed-cycle He gas refrigerator mounted just above a chimney of the module was adopted to cool down and to recondense cold vapour of liquid He around a heat exchanger in the liquid He vessel. A 20K/80K two- stage closed-cycle He gas refrigerator, which mounted in a vacuum vessel of the module like a piggy back, was adopted to cool down 40K and 80K heat shields and other major components of the cryostat. These two kinds of the He-gas refrigerators have been available commercially recently. Layout of the refrigeration system for the accelerator module is shown in fig. 1. The 4K refrigerator suspended in a frame can be lifted up and down to remove the heat exchanger out of the liquid He vessel, and to insert the exchanger into the vessel. Cooling capacity of the refrigerator is 9.6W at 4.5K and 60Hz.

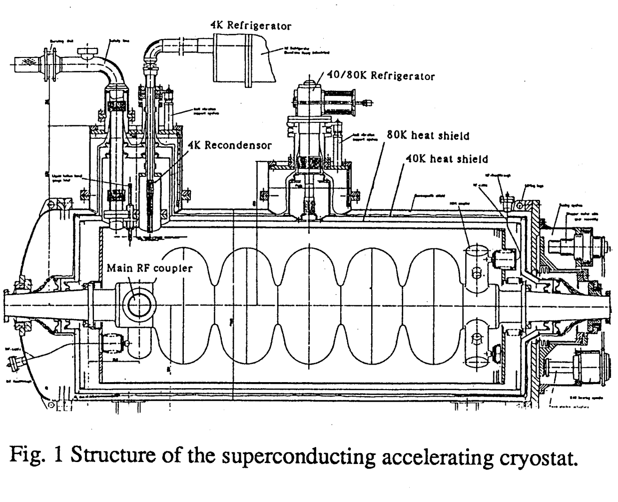

Fig. 1 Structure of the superconducting accelerating cryostat.

The 40K and 80K heat shields are used to prevent heat invasion from outside into the liquid He vessel. These heat shields make the return route with a temperature higher than 4K for all heat bridges from the outside to prevent heat invasion into the vessel. These shields are cooled down to work as a thermal anchor by a closed cycle He gas refrigerator. The 20K/80K refrigerator used here provides two cooling stages with a typical pair of temperature of 40K and 80K and heat load capacities of 120W and 40W, respectively.

A goal of the thermal design is the optimization of the heat shields and other major components being cooled by the multi-refrigerators.

2. Thermal model

Radio frequency loss in the superconducting cavity was estimated to be 90W per 5-cell in the condition of $Q_0 = 1.0 \times 10^9$ and Eacc = 5MV/m[1]. Because of 1% pulse mode operation, the loss was reduced down to 0.9W. Therefore, we assumed that the heat generation by the loss could be ignored in the consideration. Heat load for the 80K shield is assumed to be 40W, and the load for the 40K shield 10W.

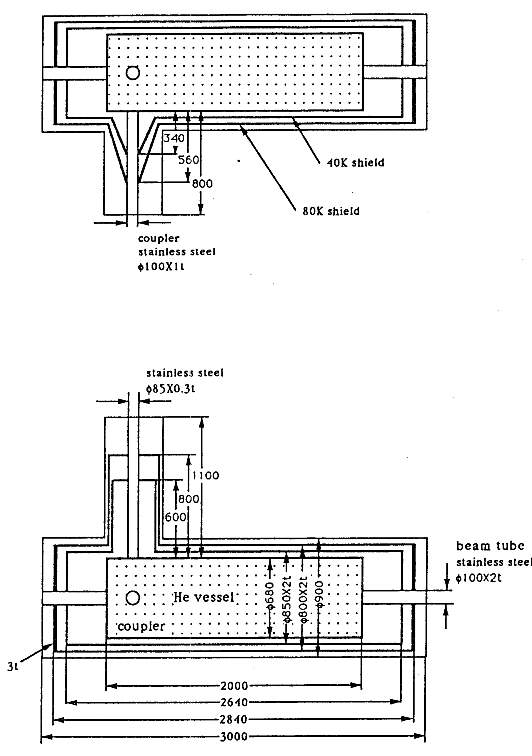

Fig. 2 Component geometry.

Major components in the cryostat are shown fig. 2. In the figures, we can see the 80K and 40K heat shields. Major components of heat inflow are located around beam tubes, outer conductor of the RF coupler and liquid He transport pipes. Thermal model to be solved here is mainly governed by a physical phenomenon of heat conduction. As there should be some contributions from two other physical phenomena of heat radiation and convection, we calculated to estimate the contributions independently in the same condition with the conduction.

The beam tubes are assumed to be made of 2mm thick stainless steel, and the liquid He transport pipes thin stainless steel in the calculation. The outer conductor of the RF coupler is assumed to be made of 1mm thick stainless steel tube having 10 μm copper-plated inner surface. The 80K shield cylinder is assumed to be made of 2mm thick copper, the end plates 3mm thick copper, and the 40K shield 2mm thick copper.

These components are modeled using a FEM element of 2-dimensional isoparametric thermal solid model. The element is only usable for a 2-dimensional thermal conduction in the code. The element with four nodal points was applied to construct the components and cryosat in the thermal model. As the temperature is only one degree of freedom here, properties of the materials used to fabricate the components were introduced by thermal conductivity as a function of temperature.

3. Calculated results

At a beginning phase, we first calculated temperature distribution of the 80K shield. Temperature of the first stage in the two stage refrigerator is assumed to be fixed at 80K. Typical distribution of temperature on the 80K shield is calculated and shown in fig. 3a. Summed static heat load to the 80K shield is calculated to be about 39W. Temperature of connection between the shield and beam tube is calculated to be around 120K.

Then, we calculated further temperature distribution of the 40K shield in using the calculated results of the 80K shield as boundary conditions. Typical distribution of temperature on the 40K shield is shown in fig. 3b. Summed static heat load to the 40K shield is calculated to be about 10W. Temperature of connection between the shield and beam tube is calculated to be around 43K.

The next largest heat inflow is known to be copper-plated stainless steel outer-conductor in the main RF coupler. The stainless steel tube is constructed by the 2-dimensional isoparametric thermal solid element in an axial-symmetric condition. As there are several other connecting parts as a heat inflow to the 4K stage of the cryostat, their contributions to total heat load are calculated in similar manner..

When the two heat shields thermally anchor all connecting parts between 4K and 300K stages, the static heat load to the liquid He vessel is calculated to be about 1 W. A half of the load comes from the RF coupler, because a thin copper layer of higher thermal conductivity can not be anchored by the heat shields.

4. Conclusion

The thermal design of the superconducting linear accelerator module cryostat with the multi-refrigerators system has been successfully optimized by using the FEM calculation code ANSYS for the JAERI FEL system. As shown in fig. 4, the results of the calculation shows that 5-cell accelerator modules cryostat can be cooled down satisfactorily by the multi-refrigerators system. The static heat load for the 80K shield without radiation is 39W, and the load for the 40K shield 10W. When the two heat shields thermally anchor each heat bridge between 4K and 300K stages, the static heat load to the liquid He vessel is calculated to be about 1 W.

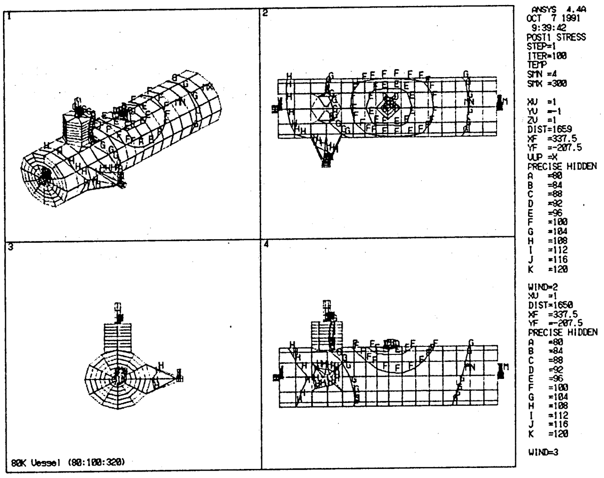

Fig. 3a Profile of temperature distribution on the 80K heat shield.

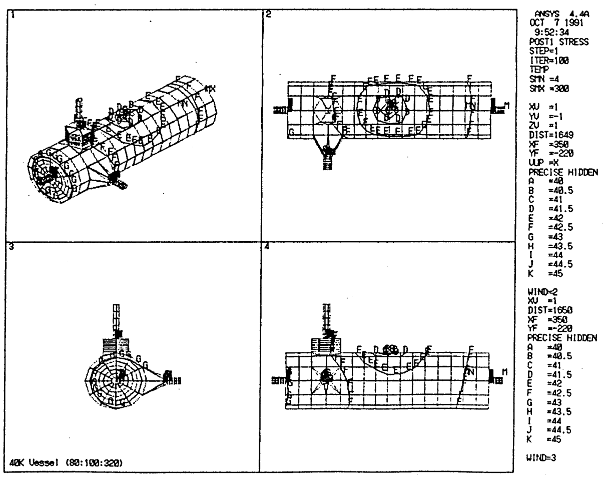

Fig. 3b Profile of temperature distribution on the 40K heat shield.

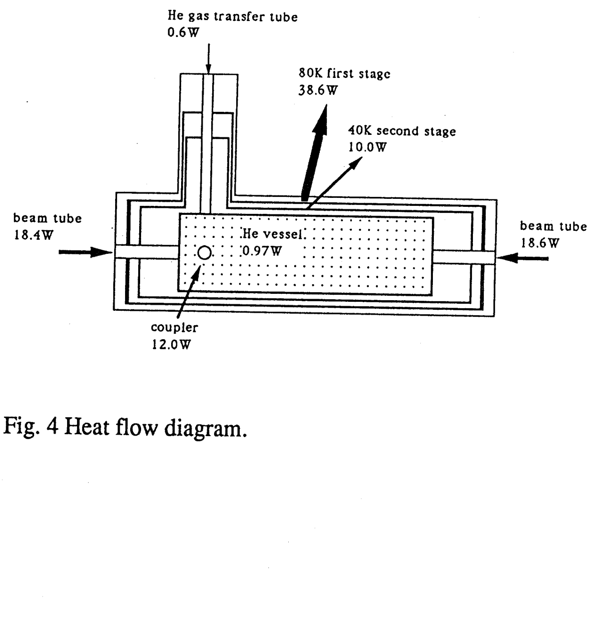

Fig. 4 Heat flow diagram.

Acknowledgment

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Reference

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