Multi-refrigerators system integrated into the superconducting accelerating cavity cryostat

N. Kikuzawa, E. Minehara*, R. Nagai*, M. Sawamura*, J. Sasabe**,
M. Sugimoto*, M. Ohkubo*, Y. Suzuki* and Y. Kawarasaki*

Department of Nuclear Engineering, Kyushu University

*Linac Laboratory, Department of Physics, Tokai Research Establishment,
Japan Atomic Energy Research Institute

**Hamamatu Photonics Co., Research Center

Abstract

A linear accelerator system for a free electron laser (FEL) has been constructed by using superconducting RF cavities at Japan Atomic Energy Research Institute(JAERI). We have newly developed a multi-refrigerators system integrated into a superconducting linear accelerator module cryostat containing accelerating cavities to realize the highly-efficient .

A finite element method(FEM) calculation code has been used to evaluate temperature distribution of heat shields, and other major components of the cryostat. Thermal design for the cryostat has been performed to optimize heat loads to the major components of the cryostat by utilizing the calculational and experimental results. The design of the cryostat for JAERI FEL accelerator modules is reported in details in this report.

1. Introduction

A linear accelerator system for a free electron laser (FEL) has been constructed by using superconducting RF cavities at Japan Atomic Energy Research Institute(JAERI). We have newly developed a multi-refrigerators system integrated into a superconducting linear accelerator module cryostat containing accelerating cavities to realize the highly-efficient. The superconducting linear accelerator consists of two modules of single-cell cavity and two modules of 5-cell cavity.

A 4K closed-loop He gas refrigerator mounted just above a liquid He supply tower of the module was adopted to cool down and to recondense cold vapour of liquid He around a heat exchanger in a liquid He vessel. A 20K/80K two- stage closed-loop He gas refrigerator, which mounted in a vacuum vessel of the module, 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 multi-refrigerators system and the accelerator module cryostat is shown in fig. 1. The 4K refrigerator suspended in a stainless-steel 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.

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 loop 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.

2. Heat Load

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.

Major components in the cryostat are shown fig. 2. In the figures, we can see the 80K and 40K heat shields. Major heat inflow sections are beam tubes, outer conductor of the RF coupler and liquid He transport pipes. The problem has been solved with a representation of the metal heat 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 plate, the end plates 3mm thick copper plate, and the 40K shield 2mm thick copper plate.

The components of the cryostat are modeled using the element of 2-dimensional isoparametric thermal solid model. This element only represents a bidimensional thermal conduction. We can define this element with four nodal points, and the temperature is the only degree of freedom. Thermal properties of component materials were introduced by thermal conductivity as a function of temperature.

3. Finite Element Method Calculation

A finite element method(FEM) calculation code(ANSYS Rev.4.4A) has been used to evaluate temperature distribution of the heat shields, and other major components of the cryostat. First, we calculated temperature distribution of the 80K shield. The temperature of cold head in the refrigerator is fixed at 80K. Temperature distribution of the 80K shield is shown in fig. 3a. The calculated static heat load to the 80K shield is 39W. Temperatures of connecting parts from the shield to beam tubes is about 120K.

Then, we calculated temperature distribution of the 40K shield by using results of the calculation of the 80K shield as a boundary condition. Temperature distribution of 40K shield is shown in fig. 3b. The calculated static heat load to the 40K shield is 10W. Temperatures of connecting parts from the 40K shield to the beam tubes is about 43K.

Concerning about a copper plated outer conductor of the RF coupler, stainless steel parts of the coupler are represented by the 2-dimensional isoparametric thermal solid in axically-symmetric geometry. When thermal anchors are installed in positions illustrated in the figures, the calculated static heat load to liquid He vessel is about 1W . A half of them is due to the copper plated outer conductor of the RF coupler.

4. Conclusion

The multi-refrigerators system used to cool down superconducting accelerating cavities has been designed in detail. It should be concluded that 5-cell accelerator modules cryostat installed in JAERI FEL would be cooled down successfully by the multi-refrigerators system. The static heat load for the 80K shield is 39W, and that for the 40K shields 10W. When thermal anchors are installed in these positions, the calculated static heat load to L.He vessel is about 1W.

Acknowledgment

We would like to thank Drs. N. Shikazono, M.Ishii of JAERI for their continuous encouragement and interests on this work.

Reference

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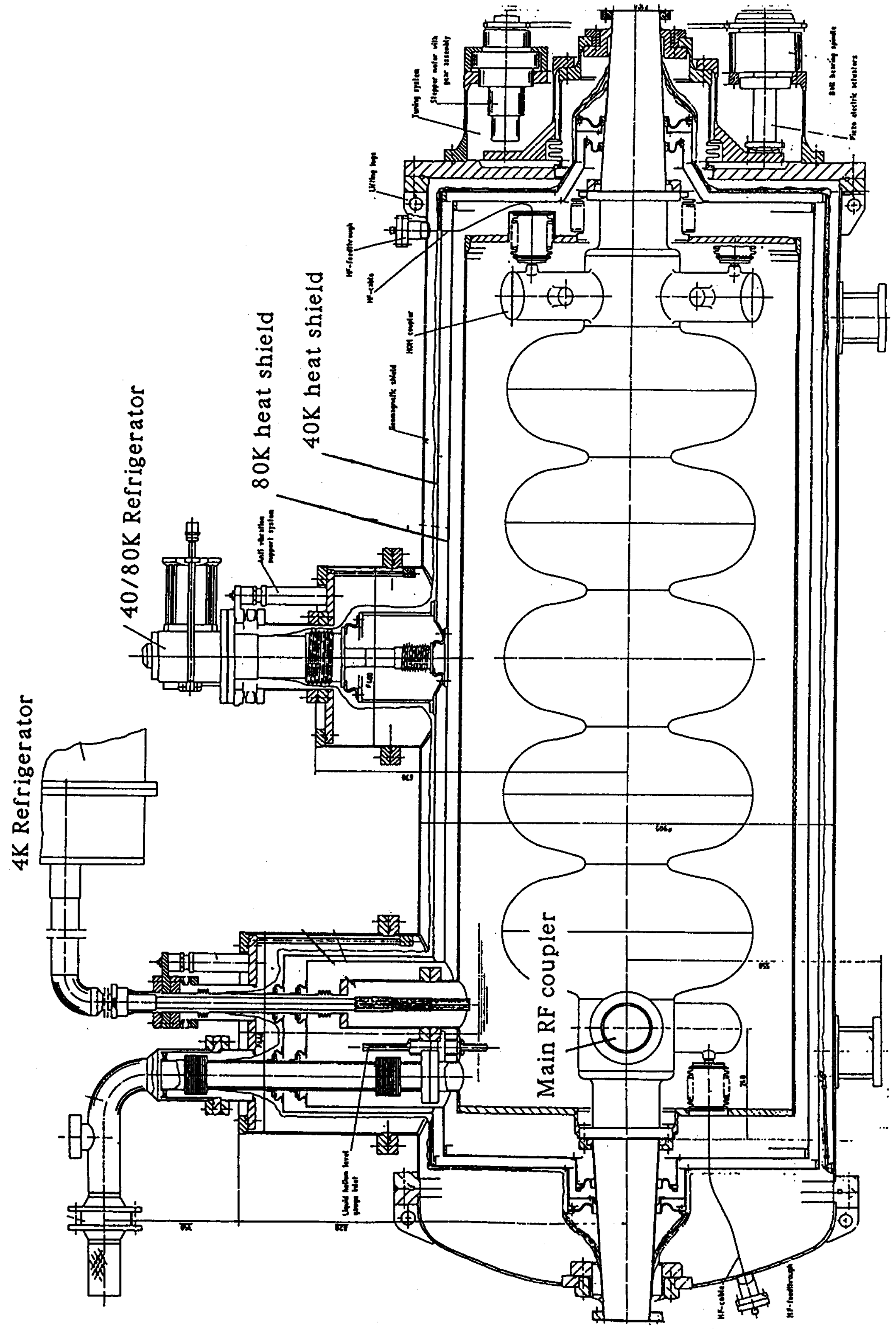

Fig. 1 Structure of the superconducting accelerating cryostat.

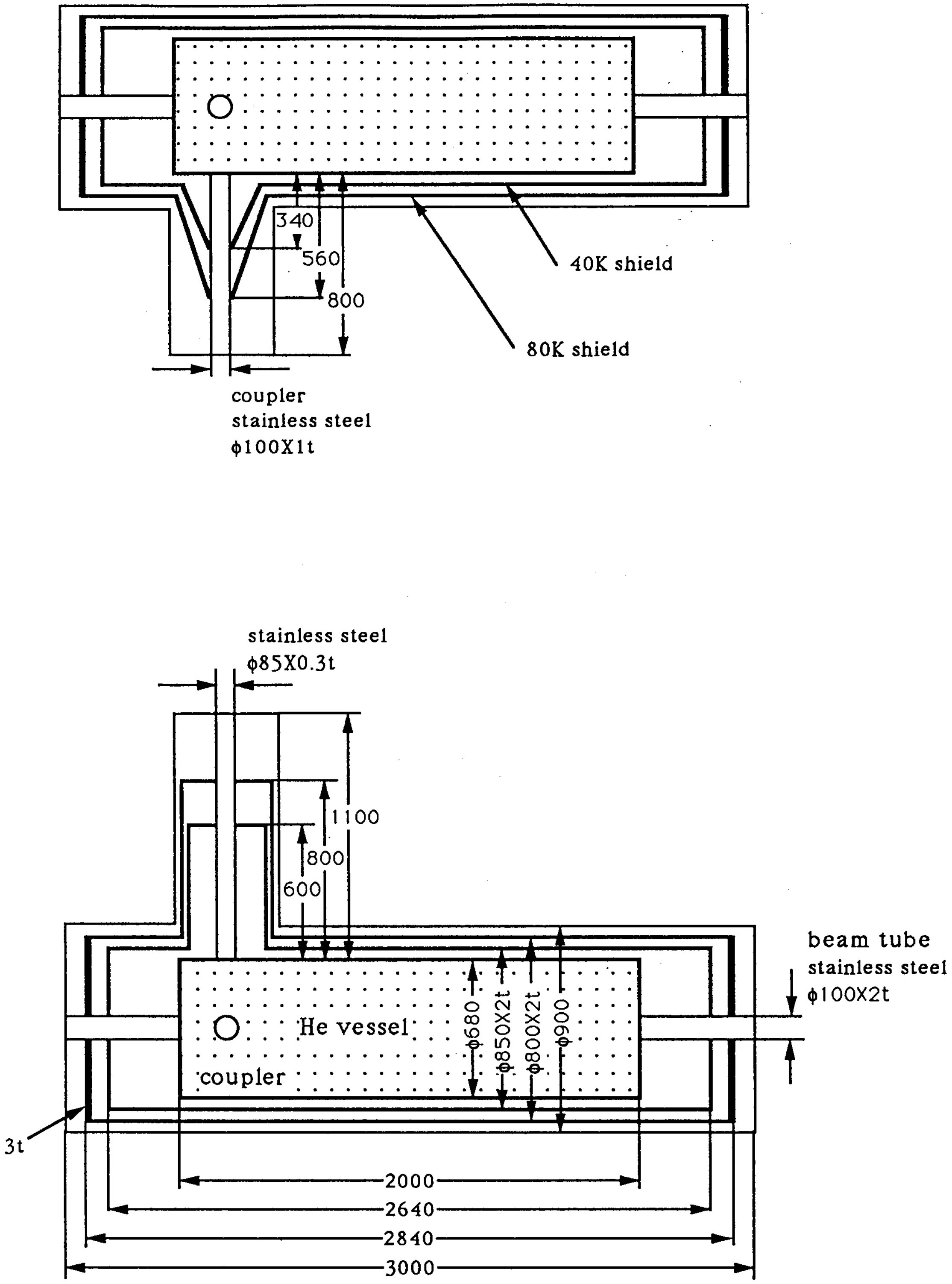

Fig. 2 Component geometry.

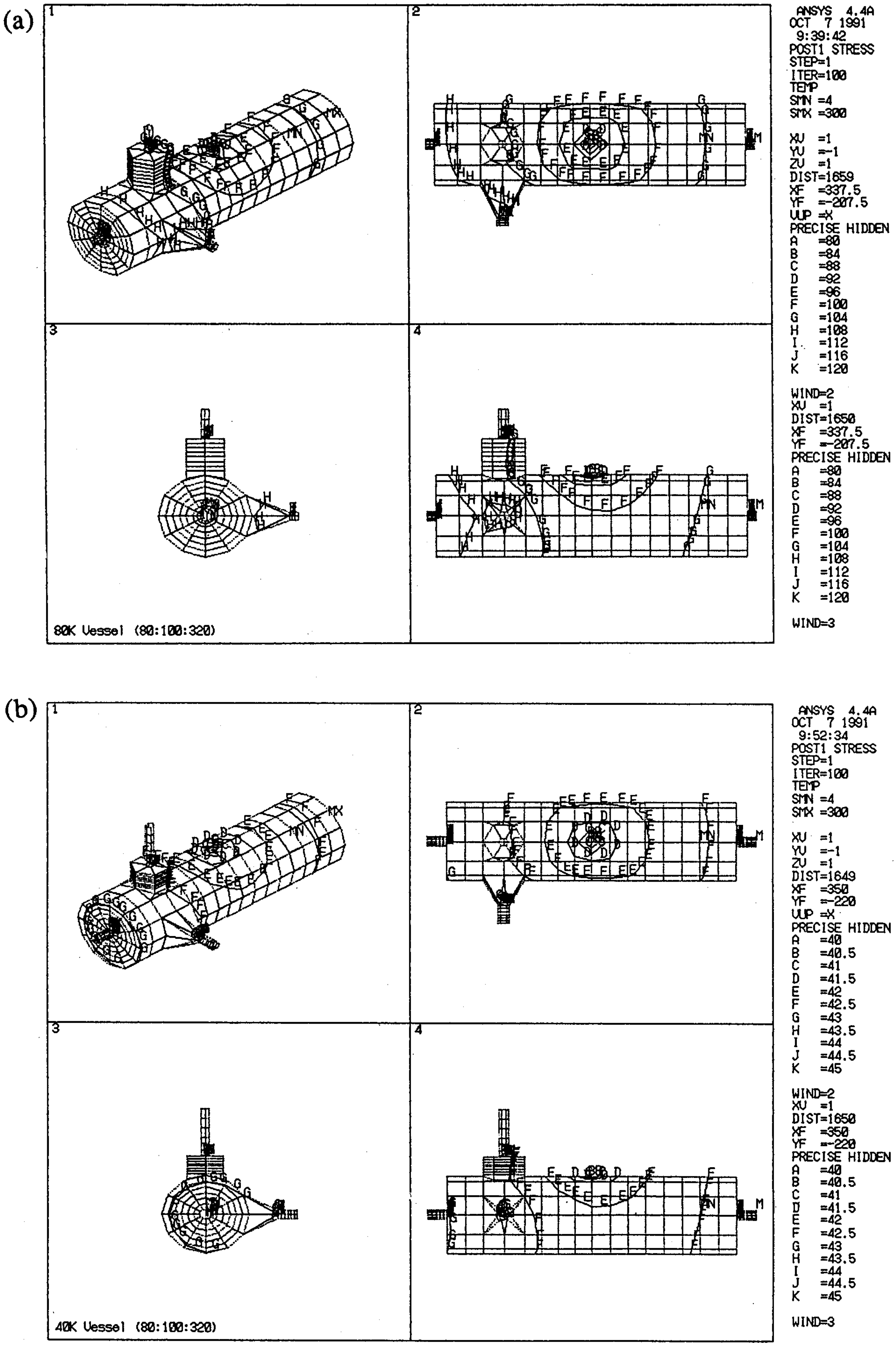

Fig. 3 (a) Profile of temperature distribution on the 80K heat shield.
(b) Profile of temperature distribution on the 40K heat shield.