Heat Load Estimation of the Cryomodule for 200-MeV Energy Upgrade at KOMAC

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1. Introduction

A 200-MeV energy upgrade is planned based on the existing 100-MeV proton linear accelerator (linac) at Korea Multi-purpose Accelerator Complex (KOMAC) [1]. The main goal of the energy upgrade is to provide a test platform of the atmospheric and space radiation environment to the users related with the semiconductor industry. A half-wave resonator (HWR) based on the superconducting radiofrequency technology will be used to accelerate 100-MeV proton beam to 200-MeV. The operating temperature of the HWR is 2K and four HWR cavities will be installed in one cryomodule. Total number of 36 HWR cavities will be used and 9 cryomodules are needed. A doublet lattice based on the normal conducting quadrupole magnet is used for transverse beam focusing, which is installed between cryomodules [2]. In this paper, heat load of the cryomodule is estimated in order to decide the capacity of the cryoplant. The heat load estimation will be divided into static heat load and dynamic heat load. And the static heat load is estimated from the radiation heat transfer and conduction heat transfer. Heat transfer from the convection is not considered in this estimation, which is negligible when the insulation vacuum inside the cryomodule is kept below 10^{-6} Torr [3].

2. HWR Cavity and Cryomodule

In this section, an introduction of the HWR cavity and cryomodule is described. The design parameters presented in this section are used for the heat load calculation in the following section.

2.1 HWR Cavity

The design parameters of the HWR cavity is shown in Table 1 [4]. It uses 350 MHz RF frequency which is the same with the existing 100-MeV linac. The E_{acc} is 7.5 MV/m with which the phase advance per period can be kept less than 90 degrees. When we optimize cavity structure, we maintain the V_{acc} to be 3.6 MV which produces consistent results between cavity optimization and beam dynamic calculation. The optimization process of the cavity was conducted with aiming at decreasing the peak electric field less than 35 MV/m and peak magnetic field less than 70 mT. The surface resistance which determines the cavity quality factor is 20 nohm which results from BCS resistance, trapped magnetic field effect and residual resistance. The designed HWR is shown in Fig. 1.

Table I: HWR Cavity Parameters

Parameters	Values
Frequency	350 MHz
Optimum beta (β_{opt})	0.56
V_{acc}	3.61 MV
E_{acc}	7.53 MV/m
E_p	29.08 MV/m
B_p	61.66 mT
R/Q	256.6
G	116.1
Q0 (Rs=20nohm)	5.8E9
Aperture diameter	40 mm
L_{eff} ($\beta_{opt}\ \lambda$)	0.480 m

Fig. 1. HWR cavity designed for 200-MeV energy upgrade of KOMAC 100-MeV linac.

2.2 Cryomodule

The dimensional characteristic of the designed HWR is that both the height and diameter of the cylindrical shape cavity have similar dimensions, which is not usual case for HWR cavity. Therefore, a cylindrical shape cryomodule, not rectangular box type cryomodule, is designed, which is supported by the proven technology through active research and development through accelerator society. The designed cryomodule is shown in Fig. 2 [1]. The cavity made by the niobium sheet is surrounded by the titanium helium vessel and cold magnetic shield. A heat shield is installed to reduce the radiation heat from ambient temperature. Two sets of Multi-layer Insulation (MLI) are installed both inside and outside of the heat shield. A warm magnetic shield is installed outside the heat shield and cold mass is installed in the space frame. And finally, the space frame is installed inside the vacuum vessel.

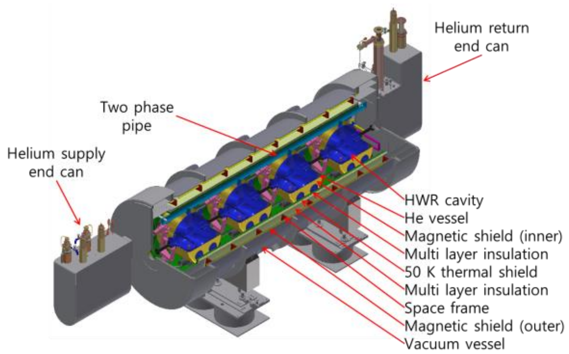

Fig. 2. Cryomodule including 4 HWR cavities for 200-MeV energy upgrade of KOMAC 100-MeV linac.

3. Heat Load of the Cryomodule

There are two kinds of heat load. A static heat load is one occurred without RF whereas a dynamic heat load is one due to the RF operation of the cavity. The major sources of the static heat load are the radiation and conduction heat transfer.

3.1 Radiation Heat Transfer and Thermal Shield

The radiation heat from the ambient temperature is reduced if the thermal shield is installed between ambient and cold temperature. The heat loads into the 2K helium bath and thermal shield are calculated with respect to the thermal shield temperature to decide the working temperature of the thermal shield. For the comparison, the total heat loads are normalized to the heat load at 4.5K and plotted in Fig. 3. It is well known in radiation heat transfer that it is difficult to know the exact emissivity of the material, which is depending on the surface condition of the material, temperature and so on. Therefore it becomes major error source. Also it is known that the radiation heat is reduced proportional to the inverse the number of MLI. But it is not applicable for the low temperature case. Therefore, we use an effective total emissivity to decide the heat shield temperature [5]. The heat load to heat shield is decreasing with respect to the heat shield temperature whereas the heat load to 2 K is increasing as shown in Fig. 3. The total heat load converted to 4.5K is global minimum between 50K and 70K in the designed cryomodule geometry. And we decided the working temperature of the heat shield to be 50K, with which we can make use of much experience of the existing cylindrical cryomodule technology [3]. In estimating heat loads, we used conservative values for heat loads, 2.5W/m^2 for 300K to heat shield temperature and 0.1W/m^2 for heat shield temperature to 2K, which include the MLI effects [3]. The heat load from radiation is 18.0W at 4.5K equivalent.

3.2 Conduction Heat Transfer

The 2K system is connected to ambient temperature by beam pipes to the warm sections in axial direction and nitronic rods to the space frame. The heat load due to the conduction heat transfer was calculated using the thermal conductivity integrals in order to take into account the temperature effect of the thermal conductivity. The heat load from conduction is 10.8W at 4.5K equivalent.

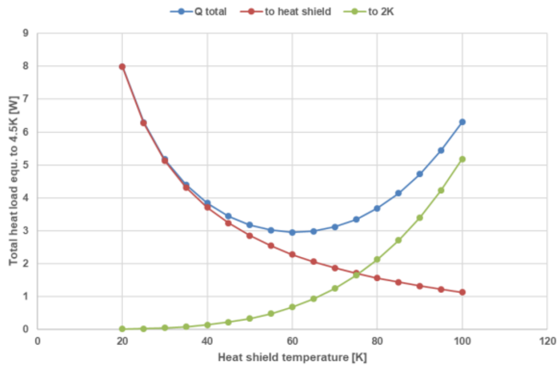

Fig. 3. Radiation heat load depending on the heat shield temperature, which is normalized to 4.5K.

3.3 Dynamic Heat Load of the Cavity

The dynamic heat load due to the RF power inside the cavity is calculated by using the cavity parameter [6]. The calculated value was 0.87W per cavity with 10% duty factor and 3.5W per cryomodule. A disc type window and probe antenna is being currently designed as a RF coupler for HWR. In order to estimate the dynamic heat load from the coupler, we scaled the heat load from the data of Spallation Neutron Source (SNS) coupler [3]. And the result is the 0.15W per coupler and 0.6W per cryomodule.

3.4 Heat Load Summary

The heat load of the cryomodule is estimated. The static heat load of the cryomodule is 7W at 2K and 77W at 50K heat shield. The dynamic heat load of the cryomodule is 8W at 2K. The total heat load per cryomodule is 52.7W at 4.5K equivalent.

3. Conclusions

The heat load in the cryomodule was estimated. The temperature of the heat shield was decided and the static heat load was calculated. Also the dynamic heat load was calculated from the cavity design parameters. The heat load at both supply and return end can will be analyzed.

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