A NEW C-BAND 50-MW CLASS SiC RF LOAD

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Abstract

A new high power rf dummy-load is being developed in this year as part of the R&D for the e^+e^- linear collider (GLC). In this rf dummy-load, sintered ceramic Silicon Carbide (SiC) is used as the microwave absorbing material. Each SiC disk is 8-mm in diameter, and 3.3-mm high. A total of 40 pieces of SiC per dummy-load can absorb enough microwave power to meet the requirements needed in a system with 50-MW of peak rf power at a pulse width of 1-µsec and pulse repetition rate of 50-pps.

The main body of the load will be composed of cylindrical TM_{011} mode chained cavities for the ease of manufacturing. Simulating at 50-MW, 1-µsec and 100-pps, (the required specification of the 500-GeV C.M. energy e^+e^- linear collider), the calculated steady state temperature rise of the SiC is only ~90 °C when the load is cooled with 30 °C water.

1 INTRODUCTION

The first SiC-dummy-load, which was originally developed for the KEK 2.5-GeV injector linac at an S-band (2856-MHz) frequency in 1980, used direct water-cooling method [1]. Thermally this was very efficient, but corrosion problems risked water leaks into the vacuum. To increase the safety of operation, the dummy-load was modified to use an indirect cooling method with brazed rod shaped SiC pieces in 1995 [2]. 250 of the improved SiC dummy-loads has now been in daily operation on the KEKB 8-GeV injector linac since 1998 [2].

The aim of the first phase of the Linear Collider project (GLC-I) in Japan is to build a new high energy e^+e^- linear collider for the 300-500 GeV C.M. energy region. For the GLC-I, the klystrons will be of the 50-100 MW class, and the accelerator will have to employ more than 7,000 of them [3] and also more than 10,000 high power rf dummy-loads will be used. When compared with accelerators currently in operation, this sort of large-scale machine requires an almost astronomical total component count; certainly heretofore no laboratory has any experience in fabricating, or operating, so many accelerator devices. Therefore, manufacturability, reliability and maintainability are all critical considerations.

There are no 50-MW class rf loads available for the C-band (5712-MHz) frequencies commercially in the world. Therefore we have developed a new type rf load using SiC ceramics with an indirect water-cooling structure. We decided to use very simple cylindrical cavity of TM_{011} chained cavities. As can be seen in it can be manufactured easily using a conventional turning lath. There are no special structural features required in the main body. Each TM_{011} cell is of same physical dimension, with four SiC disks of 8-mm in diameter and 3.3-mm in height brazed symmetrically about the loading-disk. Thus, from the reliability point of view, it is greatly advantageous over the previous rf dummy-loads. Furthermore, the new type rf dummy-load allows elimination of 7,000 of the E-bend high power waveguide components, also contributing to cost reduction and system simplicity.

This paper will discuss the detailed design of the new type rf dummy-load, especially using the HFSS (High Frequency Structure Simulator) code.

2 OVERVIEW

The first model of the 50-MW SiC C-band rf dummy-load is shown in Figure 1. The rf dummy-load consists of three main parts; an impedance matching section, a mode filter and a main body. The impedance matching section matches the impedance between the TE_{01} rectangular waveguide from the power inlet and the TM_{011} mode cylindrical cavity.

As can be seen in Figure 1, we decided to use the simple impedance matching method (the so called door knob

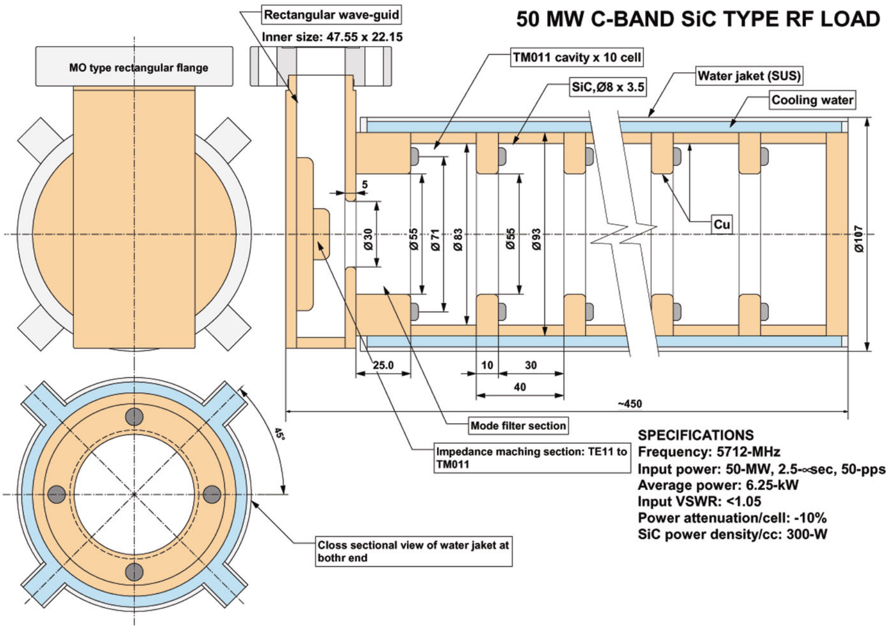

Figure 1: A conceptual drawing of 50-MW class SiC rf dummy-load. (A cut away view)

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type), which comprises of two rf elements. Although it is actually a distributed field situation, the two steps of door knob dominate the effective capacitance C and the distance between the center of the door knob and the short end of the waveguide dominates the reactance L. Thus various impedances at the matching section can be effected easily through combinations of C and L easily.

The mode filter, which is used to excite only the TM_{011} mode into the chained cavities, and it can suppress unwanted modes (at 83-mm cavity inner diameter) such as TE_{11} (2116.6-MHz), TM_{01} (2764.9-MHz), TE_{21} (3511.3-MHz), TM_{11} (4405.4-MHz), TE_{01} (4405.7-MHz), and TE_{31} (4830.0-MHz).

The main body includes a chain of 10 TM_{011} mode cavities with 4 SiC disks per cavity, surrounded by a cooling water jacket. The cavities are separated by a 10-mm thick loading-disk with a 55-mm diameter coupling iris. The coupling iris aperture diameter is determined so as to keep the transmitted rf power safely below a 300-W per cc power absorbing density in each SiC disk. The loading disk thickness of 10-mm was chosen to provide good thermal conductivity for the SiC disks and to give mechanical strength.

Four SiC disks are brazed on one side of each loading-disk; so there are 40 SiC disks in all which absorb the rf power. We will use the same brazing method as was used for the KEKB injector linac dummy-loads.

The 30 °C cooling water flow at the inlet is within range of 10 to 20 L/min when running at the maximum rf input power (50-MW, 1-µsec and 100-pps). In that case, the cooling water temperature rise at the outlet should be only about 8 °C only. Therfore, we will use a very simple water jaket, which has the pipe shape strucutre and one way water flow system.

3 SIMULATION

We used the ANSOFT commercial FEM code, HFSS, for simulation of the TM_{011} cylindrical cavity during the cavity design process. To understand the basic characteristics of the TM_{011} cavity, we started with single cavity, which is connected with the circular waveguide at both sides as shown in Figure 2, then we added the SiC disks to the simulation.

The loaded quality factor of cavity Q_L, which corresponds to the rf transmission loss was determined to find the optimum diameter for the coupling iris between cavities. To separate the TM_{01} mode from other unwanted modes as well as to reduce the calculation time, the simulation was done for an idealized quarter-cavity assuming perfect H boundary conditions at the truncation surfaces as shown in Figure 2.

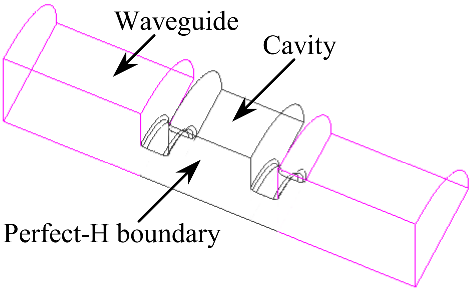

Figure 2: The drawing of single cavity for simulation.

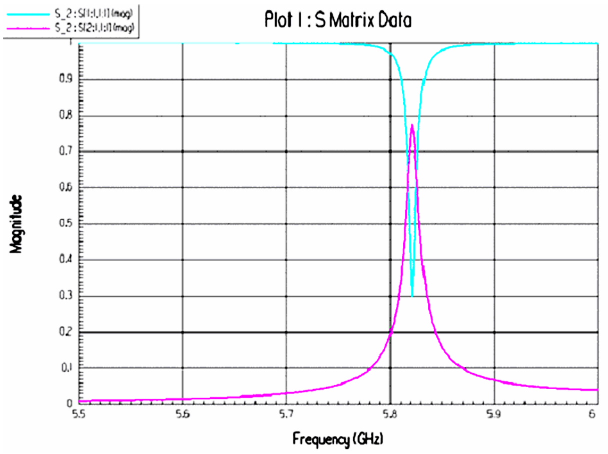

Figure 3: Typical resonance curves of TM_{011} cavity. Up: S_{11} (reflection). Down: S_{21} (transmission).

Figure 3 shows the typical resonance curves of the TM_{011} mode for the reflection (up: S_{11}) and the transmission (down: S_{21}) power respectively. From the measurement of the plot, Q_L may be calculated by the equation $Q_L = f/(2\Delta f)$ and the group velocity v_g by the equation $v_g = 1/2\ k\omega L$ where k is the coupling factor when the cavities are in series. Table 1 shows the Q_L, and v_g as a function of the coupling iris diameter.

Table 1: Group velocity, v_g, and loaded quality factor Q_L.

Diameter of coupling iris [mm]	V_g/c	Q_L
40	0.07	632
50	0.21	71
55	0.33	29

The coupling iris diameter was chosen to be 55-mm, and then the power loss in each cavity was calculated with the SiC disks mounted on the one side of the loading-disk as shown in Figure 4. The power loss per cavity was calculated while varying the dimension of the SiC disks (see Table 2). Finally the total cavity transmission loss taking into account the coupling factor between the cavities for 5-cavity chain or 10-cavity chain were calculated again by combining cavities in series.

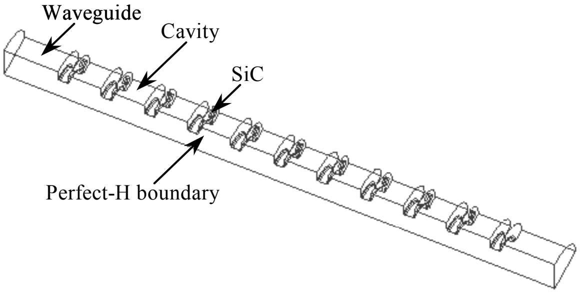

Figure 4: The drawing of the cavity-chain for simulation.

The power loss per cavity is 0.05 if the SiC is 8-mm in dia and 3.3-mm in height. The loss per cavity is 0.16 when SiC in 8-mm in diameter with 3.8-mm in height. Therefore, to achieve the power loss per cavity of 0.1, choose the SiC to be between 3.3- and 3.8-mm high with a diameter of 8-mm.

Table 2: The various combinations of SiC dimensions and cavity loss.

SiC size D (mm) × H (mm)	Power loss/cavity
Single cavity	
6.0 × 3.0	0.02
8.0 × 3.0	0.04
5-cavity-chain	
8.0 × 3.0	0.04
8.0 × 3.7	0.15
8.0 × 3.8	0.16
8.0 × 4.0	0.29
10-cavity-chain	
8.0 × 3.3	0.05
8.0 × 3.8	0.16

4 TEMPERATURE RISE OF SiC

To reduce the variation in the microwave loss-tangent, we use β-crystallized SiC, which has a good uniformity of powder size due to the chemical reaction that occurs between silicon-dioxide (SiO_2) and carbon-black (C) powders when processed at a temperature range of 1500 to 1800 °C in an inert gas atmosphere. The resulting SiC characteristics are listed in table 3.

Table 3: Basic characteristics of the SiC-ceramics.

Density (g/cm^3)	3.14	
Hardness (Knoop, kgf/mm^2)	2900	at RT$^{1)}$
Thermal conductivity (cal/cm·sec·°C)	0.19 0.14	at RT$^{1)}$ at 600 °C
Thermal expansion coefficient (°C^{-1})	4.6 x 10^{-6}	RT$^{1)}$ to 1200 °C
Oxidation weight gain (mg/cm^2)	0.015	at 1200 °C for 24 hours
DC Resistivity (Ω·cm)	5 x 10^5 7 x 10^{-1}	at RT$^{1)}$ at 800 °C
Dielectric constant	30~35	0.5 to 20 GHz$^{2)}$
Loss tangent	0.3~0.5	0.5 to 20 GHz$^{2)}$

Note: 1) RT: Ambient Room Temperature, 2) The measured frequency range is limited by the network analyzer.

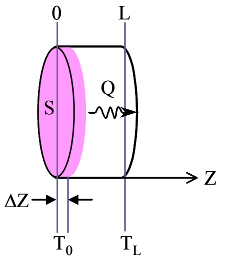

Figure 5: Heat flow in SiC at steady state.

The heat flow through the SiC at steady state is shown in Figure 5. From our design study, the size of each SiC disk is 8-mm in diameter and 3.3-mm in height so that the volume per one SiC disk, V_{SiC}, is 0.166-cm^3. Using the total of 40 disks, N_{SiC}, the thermal energy Q per unit volume corresponding to the maximum input rf power can be calculated as follow;

$$Q = \frac{P_{ave}}{V_{SiC} \times N_{SiC}} = \frac{50[W]}{0.166[cm^3] \times 40} = 7.53 \quad [W/cm^3]$$

The temperature rise of a SiC disk is calculated from the equation;

$$\Delta T = \frac{Q}{\lambda}\left(\frac{L^2}{2}\right) = \frac{7.53}{0.8}\left(\frac{0.33^2}{2}\right) = 0.52 \ [°C]$$

where λ is 0.8 joules/cm-s-°C and L is the height of SiC disk in cm.

Table 4: SiC temperature raise as a function of rf repetition rate.

rf repetition rate [pps]	ΔT [°C]	T_{water}(30°C)+ΔT [°C]
1	0.52	30.52
10	5.13	35.13
50	25.63	55.63
100	51.25	81.25

5 SUMMARY

We have designed a new type 50-MW rf dummy-load using SiC absorber. From the simulation using the HFSS code it was found that the use of the cylindrical TM_{011} mode cavity loaded with SiC disks provides a great advantage over existing rf dummy-loads. As the main parts of the rf dummy-load are axially symmetric and can be manufactured by using conventional turning lathe, the result is much better manufacturability in mass production due to the ease of machining. In addition, it allows elimination 7,000 E-bend high power waveguide components; that will also contribute to overall cost reduction and system simplicity for the linear collider. Moreover, a very simple jacket type water cooling system can be used as the cooling water temperature rise at outlet is only ~8 °C for an average power dissiapated is 5-kW.

From this work, for the next step we will develop an integral rf dummy-load for the accelerating structure so as to replace the output coupler. That would eliminate all 7,000 output couplers and thus reduce the cost enormously. It will also increase the reliability especially in high gradient operation.

6 REFERENCES

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