DEVELOPMENT OF A BROADBAND HOM LOAD FOR THE 714-MHz HOM-DAMPED CAVITY

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Abstract

A 714-MHz higher-order-mode (HOM) damped cavity was developed at KEK, and two cavities of this design are under operation in the Accelerator Test Facility (ATF) damping ring. Each cavity is equipped with four waveguide ports to extract HOM power. In order to achieve the very low HOM impedance required for the damping ring, each waveguide port should be terminated by a broadband, low-reflection load. We have developed a broadband HOM load for this purpose. We describe the design, construction and RF characteristics of the HOM load.

1 INTRODUCTION

For RF acceleration in the ATF damping ring [1], a 714-MHz HOM-damped cavity has been developed at KEK. After a successful test of the prototype cavity under high-power operation, two cavities were manufactured and installed [2] in the damping ring. Each cavity is equipped with four rectangular waveguide ports to damp higher-order-modes [3]. In order to attain the very-low HOM impedance, that is required for the damping ring, each HOM port should be terminated by a broadband, low-reflection load. Incoming power to the load is excited by an interaction between the beam and the cavity HOM impedance. The spectrum of the HOM power will spread over a wide frequency range of about 1-10 GHz, which comes from the short bunch length (5 mm) and narrow beam pipe (24 mm in diameter) of the ring. The total power to the load will be less than 500 W, which was estimated using a parasitic-mode loss parameter of 1.0 V/pC/cavity.

As the starting point, a preceding design of the HOM load [4] for the PEP-II cavity was very helpful. We have also decided to install a microwave absorber inside the vacuum, since this can eliminate a potential source of reflection due to the vacuum window. To operate the cavity under a ultra-high vacuum, the load should have a low outgassing rate, and should be bakable up to a temperature of about 150˚C.

2 DESIGN AND FABRICATION

The waveguide HOM load is required to have a low-reflection rate over a very-wide frequency range of 1-10 GHz. We set a practical design goal to achieve an input VSWR of less than 1.5 over a frequency range from 0.95 to 4 GHz. The specification of the HOM load is summarized in Table 1. For the microwave absorber, we have chosen silicon-carbide (SiC), which is a lossy dielectric material, because of its high loss-tangent, high thermal conductivity (170 W/m/K) and low outgassing rate.

Table 1. Specifications of the broadband HOM load.

Working frequency: 0.95 - 4 (0.95 - 10)† GHz
Waveguide dimensions: 170×20 mm^2 (corner:R5 mm)
Cutoff frequency: 887.3 MHz Input VSWR: < 1.5
Maximum input power: 500 W († Final target)

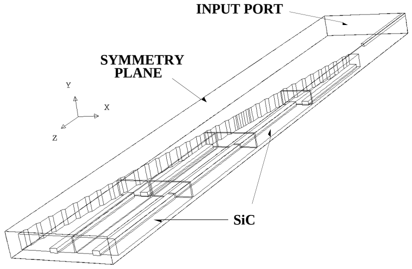

Fig. 1. A simulation model of the HOM load. Only one half of the structure was modeled.

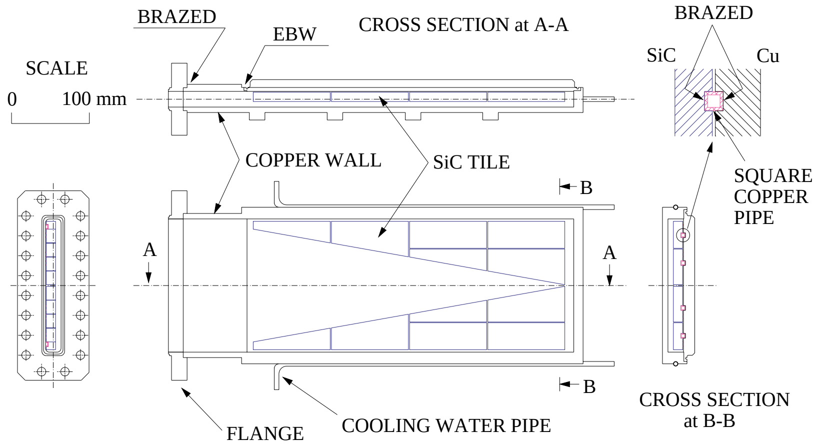

Fig. 2. Design of the HOM load.

The basic design was made using computer codes. We mainly used the MAFIA code [5], and sometimes verified the result using the HFSS code [6]. An example of the simulation model is shown in Fig. 1. In parallel with the simulations, we carried out R&D on brazing SiC tiles to a copper plate (used for the wall). The R&D results were then fed back to the basic design.

Figure 2 shows our final design. Several SiC tiles, separated by a gap of ~1.5 mm, were arranged to form two taper wedges. The SiC tiles were brazed on a wider side of the waveguide wall; cooling-water pipes were arranged at the side wall. The dimensions of each SiC taper are 400 mm in length, 12 mm in thickness and 10-81 mm in width. The thickness of the taper was optimized to obtain as low a reflection as possible for a given taper length.

During brazing the SiC tiles to the copper wall, a large thermal-stress arises due to the considerable difference in the thermal-expansion coefficient between them. In order to effectively ease this stress, we adopted a square copper-pipe (6mm×6mm, 1-mm thick) as a strain buffer (see Fig. 2). Although this causes a certain reduction in the thermal conductance, this is quite acceptable (see Section 5). An active joining material (Ag-Cu-Ti-In alloy) was used for the brazing. The optimum brazing conditions, such as a temperature and forced pressure, were established through R&D.

A prototype HOM load was manufactured by the following process. The main body of the load was first machined from an OFHC copper plate; then, a stainless-steel vacuum flange and cooling-water pipes were brazed. Each SiC taper was sintered by two pieces, 200-mm long each. These tapers were cut to several pieces, and a groove for the brazing was cut in each tile. After the SiC tiles were brazed on a copper-plate, this plate assembly was electron-beam welded to the main body, like a lid. To relax thermal stress due to the welding, we arranged a lip structure along the welding line.

3 DIELECTRIC CONSTANT OF THE SIC

In order to obtain low-reflection characteristics in the mass-production stage, it is very important to reproduce the dielectric constant of the SiC, which was obtained previously. We used an SiC product, named CERASIC-B, from Toshiba Ceramics corporation. In collaboration with industry, we produced SiC samples, and measured their complex dielectric constant using an HP85070A dielectric probe and an HP8510C network analyzer. After carrying out production several times, we have almost established reproducibility. The SiC tiles used for the load were then manufactured.

Figure 3 shows the measured dielectric constant of the SiC tiles which were used for the prototype load. At this time, we obtained an unforeseen result: two kinds of SiC tiles were produced in the same batch. About half of the tiles (referred as type A) had a permittivity close to that of the previous samples; the other half (type B) had a quite larger permittivity. It was found out that a large number of tiles had become warped due to a manufacturing error; these tiles had to be sintered once more to correct the warp. It was guessed that the irregular type-B dielectric property would be caused by this second sintering.

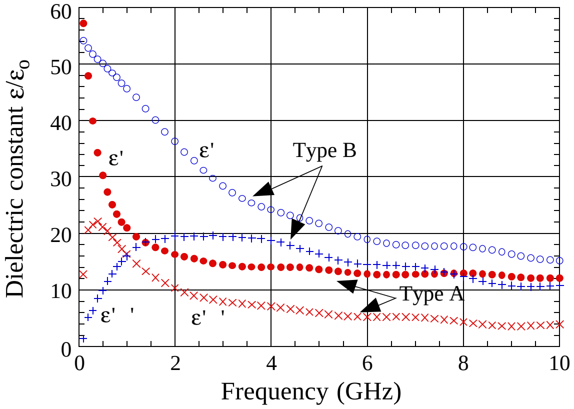

Fig. 3. Measured dielectric constant of SiC tiles used for the prototype load. The real and imaginary parts of the dielectric constant are shown for two different types of SiC tiles produced (for type A (regular) and type B (irregular)).

Fortunately, most of the irregular tiles were those used for the latter half of the taper. It was shown from a simulation that the reflection rate would be well within our specifications if we use irregular tiles only at the latter half of the taper. Therefore, we decided to use them for the prototype load as well as for mass-production.

4 RF CHARACTERISTICS

After successful fabrication, the reflection coefficient of the prototype HOM load was measured using an HP8510C network analyzer. We prepared four pairs of coaxial-waveguide transformers which, in combination, covered the frequency range of 0.95-4 GHz. In the measurement setup, the network analyzer was connected to a regular coaxial-waveguide transformer, and then transformed to the flat waveguide using a taper. Figure 4 shows the prototype HOM load being measured. Before the measurement in each frequency band, we carried out a full two-port TRL (Thru/Reflect/Line) calibration at the output ports of the tapers. The calibration was verified using an offset short and a sliding load.

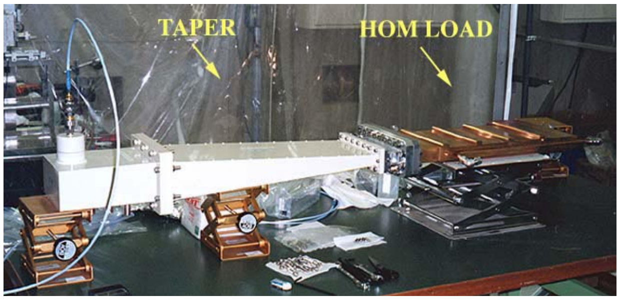

Fig. 4. Broadband HOM load under measurement.

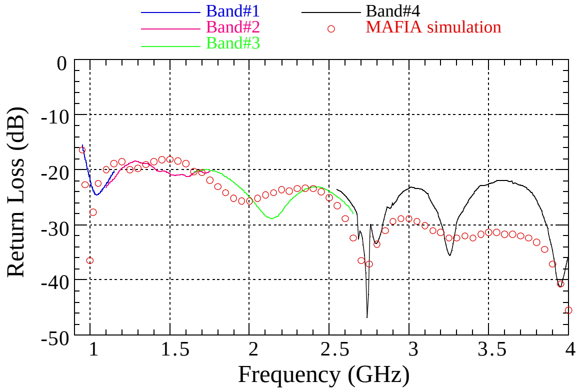

Fig. 5. Measured return loss of the prototype HOM load. The open circles indicate the MAFIA simulation results.

Figure 5 shows the results of the measurement and a simulation. The obtained return loss was less than -18 dB in the frequency range 1-4 GHz, which corresponds to a VSWR of less than 1.3. Even at the lowest frequency of 0.95 GHz, only 1.07-times the cutoff frequency, we obtained a return loss of -15.5 dB (VSWR: 1.4), which was sufficiently small.

The simulation result, indicated by open circles, was obtained from seven MAFIA runs. Each run covered a frequency span of about 0.5 GHz; we used the measured permittivity of the SiC at the center frequency of the span. There was a fairly good agreement between the measured and simulation results.

For the measurement in the frequency range 2.55-4 GHz, we used an S_{11} 1-port calibration rather than the TRL calibration, by using a flash and offset shorts as well as a sliding load. In this case, we obtained a better (but not sufficiently good) result when the calibration was verified using another offset short. This certain difficulty in the calibration would come from a possible mode conversion between the TE_{10} and TE_{30} modes, since the cutoff frequency (2.66 GHz) of TE_{30} mode lies in this range.

5 THERMAL ANALYSIS

Figure 6 shows a time-averaged power-loss distribution in the SiC tiles calculated with the MAFIA code. A monochromatic input wave of 1 GHz, with a total power of 500 W per load, was assumed in this simulation, although an actual incoming wave would have a broadband spectrum. It can be seen that there are two locations (about 110 and 230 mm apart from the tip of the taper) where the power-loss density obtains a maximum of about 4.5 W/cm^3.

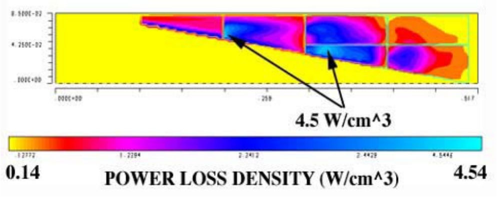

Fig. 6. Power-loss density in the SiC absorber on the median (half of the thickness) plane.

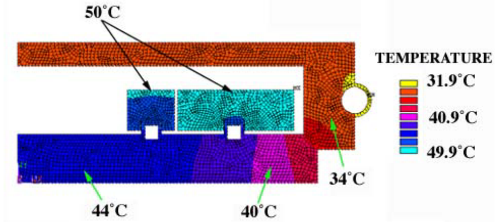

Fig. 7. Temperature distribution on a plane cut at ~230 mm away from the tip of the taper, which was calculated using the ANSYS [7] code. We assumed a film coefficient of 1.4 W/cm^2/K and a bulk temperature of 30˚C for the cooling water.

Figure 7 shows the result of a thermal analysis at the location where the maximum power is deposited. We assumed a longitudinally-uniform model and a rough power distribution. The maximum temperature in the SiC was expected to be about 50˚C, or even lower, by considering that the power density at other longitudinal location was smaller. The strain-buffer pipe caused the temperature difference of about 4˚C between the opposite sides, which is quite acceptable.

6 CONCLUSIONS

A broadband HOM load was designed based on computer simulations and R&D on fabrication techniques. A prototype load was then fabricated and measured under low power. It was shown that the load had excellent low-reflection characteristics. The VSWR of the load was less than 1.3 in the frequency range of 1 - 4 GHz.

With the same design, we have completed eight additional HOM loads. These loads will be installed in the damping ring during the summer shutdown of 1997.

7 ACKNOWLEDGMENTS

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