

# DEVELOPMENT OF A BEAM-PIPE HOM ABSORBER FOR THE ATF DAMPING RING

F. Hinode and S. Sakanaka

KEK, National Laboratory for High Energy Physics, 1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305 Japan

This paper describes the development of a beam-pipe HOM absorber, which is used to damp higher order modes (HOMs) of accelerating cavities for the ATF damping ring (DR). This device is a short beam pipe equipped with a microwave absorber. The requirement for the absorber, to search for an absorbing material, and the design of a prototype absorber-pipe are presented.

## I. INTRODUCTION

A HOM damped cavity is under development at KEK [1-3], which is to be used for the ATF damping ring. This cavity has been designed to provide an accelerating voltage of 0.25 MV/cavity with a frequency of 714 MHz, while avoiding coupled-bunch instabilities arising from cavity HOM impedances. In order to damp the HOMs the cavity is equipped with waveguide ports dedicated to HOM damping. Because of the very high cutoff-frequencies of the DR beam pipe (typically, 9.6 and 7.3 GHz for the monopole and dipole modes, respectively), there exist many cavity HOMs ranging from the accelerating frequency to the above-mentioned cutoff frequencies. Even by equipping the HOM damping ports, it is difficult to effectively damp some of the harmful HOMs which have only weak fields near to the waveguide ports. For this reason we have adopted additional HOM damping using a beam-pipe absorber.

In this scheme the RF power of the high-frequency HOMs ( $> 2.30$  GHz for the monopole modes and  $> 1.76$  GHz for the dipole modes, respectively) is extracted from beam ports of  $\phi 100$  mm (inner diameter). The power is then absorbed in microwave absorbers in the beam pipe, which are located next to the cavity. For the absorbing material, some kind of silicon carbide (SiC) is most promising, since it has good thermal conductivity ( $\sim 100$  W/m/K) and a low outgassing rate.

## II. REQUIREMENTS FOR THE MICROWAVE ABSORBERS

The microwave dissipative property in lossy dielectrics, such as in the SiC, is characterized by the effective conductivity ( $\sigma_{eff}$ ), which is equal to  $\omega \epsilon'' + \sigma$ , where  $\epsilon''$  is the imaginary part of the permittivity,  $\sigma$  the conductivity and  $\omega$  the angular frequency [4]. In order to effectively damp the HOMs, the loss in the absorber should be as high as possible. On the other hand, an absorber that has too much loss is not acceptable, because it would have a large resistive-wall impedance, which may cause turbulent bunch-lengthening. According to the following considerations, we have concluded that an effective conductivity of  $\sim 100$  siemens/m is a good compromise between these conflicting requirements.

In the ATF DR the major contribution to the broadband impedance comes from the RF section, which comprises four cavity units. Figure 1 shows one cavity unit, where two beam-pipe absorbers are installed next to the cavity. We have considered that the total ring impedance would stay modest if we limit the loss parameter of one absorber to be less than  $\sim 10\%$  of that of one cavity unit. The loss parameter of the cavity unit is estimated to be  $\sim 1.0$  V/pC (without absorbers) for an rms bunch length of 5 mm. On the other hand, if we assume the absorber to be a simple resistive wall, having a constant conductivity of  $\sigma_{eff}$ , the loss parameter of the absorber would be given by

$$k_{rw} = \frac{\Gamma(3/4)\ell}{4\pi^2 r \sigma_i^{3/2}} \sqrt{\frac{\mu}{2\sigma_{eff}}},$$

where  $r$  is the inner radius of the absorber,  $\sigma_i$  the rms bunch length in time,  $\Gamma(x)$  the gamma function,  $\ell$  the absorber length, and  $\mu$  the permeability. Then, an effective conductivity of higher than 100 siemens/m is required, using the following parameters:  $\ell=150$  mm,  $r=50$  mm, and  $\sigma_i=16.7$  psec. It has been confirmed from a simulation of the longitudinal collective effects that the above-mentioned effective conductivity is acceptable [5].

The performance of HOM damping by the beam-pipe absorbers has been evaluated by two-dimensional calculations based on the cavity shape without waveguide ports. The Q-values were calculated using a perturbation

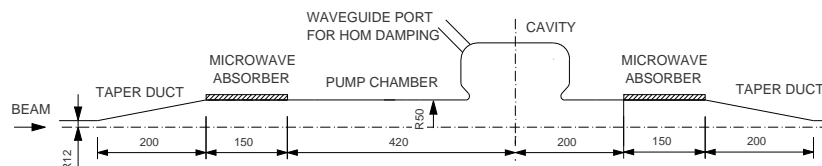
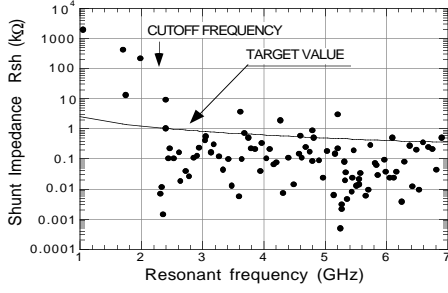
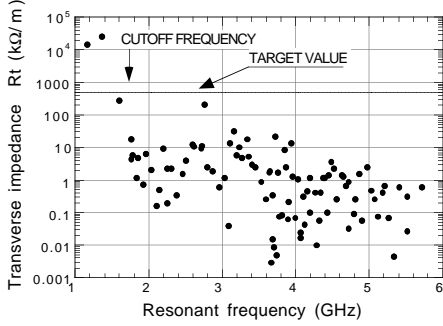


Fig. 1. Inner shape of one cavity unit. The unit for dimensions is mm.



(a) Shunt impedances of the monopole modes.



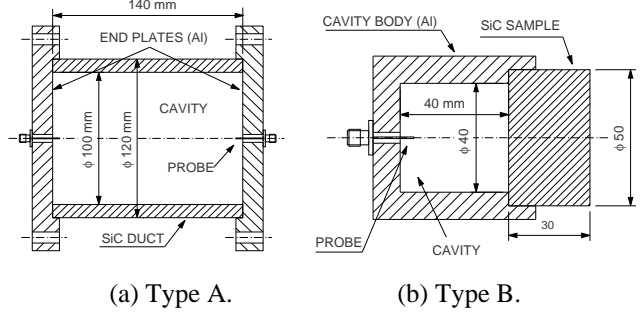
(b) Transverse impedances of the dipole modes.

Fig. 2. Calculated HOM impedances. We assumed an effective conductivity of 100 S/m for the absorbers.

method; the loss due to the finite conductivity was evaluated after the eigenmodes were solved for perfect conducting walls. Note that Koseki et al. found good agreement between the calculated Q-values (by the perturbation method) and the measured ones for their 500-MHz cavity, which was equipped with similar SiC absorbers [6]. Figure 2 shows the results of calculations in which an effective conductivity of 100 siemens/m was assumed for the absorbers. Regarding the monopole modes above the cutoff frequency, except for several modes, the shunt impedances could be reduced below the target value ( $R_{sh}[\text{k}\Omega] < 2.5/f[\text{GHz}]$ ). For several modes that could not be sufficiently damped by the absorbers, we can expect further damping by the waveguide ports, because such modes tend to have strong fields in the cavity. The reduction of the transverse impedances for the dipole modes (above the cutoff frequency) is sufficient.

The maximum power dissipated in the absorber has been estimated to be  $\sim 1$  kW/absorber under the most severe operation, which includes a resistive wall loss of about 20%.

### III. SEARCH FOR AN ABSORBING MATERIAL



(a) Type A. (b) Type B.  
Fig. 3. Cavity resonators used for the measurement.

Table 1. Measured effective conductivity (at 3 GHz) of three samples. The type A cavity was used.

Material	Product name	$\sigma_{eff}$ (S/m)
Sintered SiC	CERASIC-B <sup>*)</sup>	$\sim 5$ <sup>***)</sup>
Reaction bonded SiC	TPSS <sup>*)</sup>	800
TiC-contained ceramics	HC2 <sup>**)</sup>	$4.6 \times 10^4$

<sup>\*)</sup> Toshiba Ceramics Corp. <sup>\*\*)</sup> Nihon-tokusyuu-tougyo Corp.

<sup>\*\*\*)</sup> Not accurate due to the low Q-value of  $\sim 12$ .

A search for an absorbing material having an appropriate effective conductivity of  $\sim 100$  siemens/m is under way. The dissipative property of the samples was measured using a dielectric probe or cavity resonators. In the former, the real and imaginary parts of the complex dielectric constant are directly measured by a dielectric probe (HP85070A) attached to an HP8510C network analyzer. However, it was found that the samples having a conductivity higher than several hundreds siemens/m could not be measured by this method. Therefore, we mainly applied the latter method, in which the effective conductivity was estimated based on the Q-values of a pillbox cavity resonator, a part of which is made of SiC (other parts are made of aluminum alloy), using the perturbation method. We used two types of cavities (see Fig. 3). The effective conductivity of the SiC is estimated by:

$$\sigma_{eff} \approx \frac{2}{\omega\mu_0} \left( \frac{Q_0}{R} \right)^2 \quad \text{for cavity A}$$

and

$$\sigma_{eff} \approx \frac{1}{2\omega\mu_0} \left( \frac{Q_0}{\ell} \frac{2}{1 + \delta_{p0}} \right)^2 \quad \text{for cavity B.}$$

Here  $Q_0$  is the unloaded-Q of the  $\text{TM}_{mnp}$  mode,  $\omega$  the angular resonant frequency,  $R$  the inner radius of the cavity,  $\ell$  the cavity length, and  $\delta$  the Kronecker delta.

We first investigated several samples which are commercially available from industry. Two samples of SiC which have been investigated by Koseki et al. [6], and a sample of titanium-carbide(TiC)-contained alumina ceramics, were measured. The results are given in Table 1; they showed a wide-ranging effective conductivity.

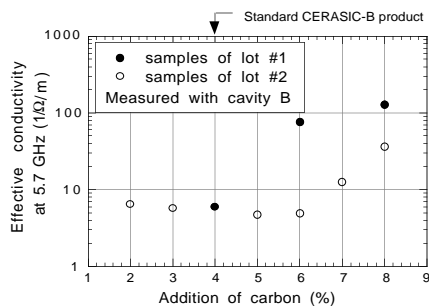


Fig. 4. Measured effective conductivity of the sintered SiC samples as a function of the addition of carbon.

Although the use of a reaction-bonded SiC (TPSS) would be acceptable for HOM damping [2], a search for a more appropriate material is under way.

One such R&D effort is to control the effective conductivity of the sintered SiC during the production process. Because some of the conductive property in the SiC is considered to be due to contaminated free carbon, we tried to control the effective conductivity by changing the addition of carbon to the raw material before sintering. The result is shown in Fig. 4, which is very promising. We could obtain an effective conductivity of  $\sim 80$  siemens/m with a 6% addition of carbon in the first case (lot #1). However, it could not be reproduced for the second samples (lot #2). In order to obtain reproducible products, we are searching for unknown parameters which also affect the conductivity.

#### IV. DESIGN AND FABRICATION OF THE BEAM-PIPE ABSORBER

In order to demonstrate the capability of high-power ( $> 1$  kW) absorption, a prototype beam-pipe absorber was designed and fabricated. For fitting the SiC to the inside of the beam-pipe, a shrinking technique was applied, which has been successfully used by Izawa et al. for constructing a similar-type absorber [7]. This method has the clear advantage that it provides good thermal contact between

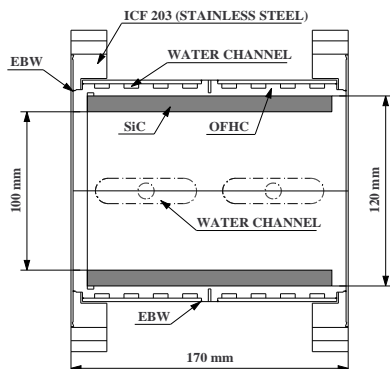


Fig. 5. Cross-sectional view of the beam-pipe absorber.

the SiC and the beam pipe without having to use any difficult joining techniques, such as brazing a large SiC to the metal.

A prototype beam-pipe absorber is shown in Fig. 5. The main body of the beam-pipe is made of OFHC copper. The cooling channels were milled from the outside. UHV flanges, made of stainless steel, were electron-beam welded (EBW) to the pipe. The SiC duct was fit into the copper pipe by shrinking.

The prototype absorber-pipe is ready for a heat-load test, which is to be carried out using a 2.45-GHz microwave source.

#### V. CONCLUSIONS

Some SiC materials having an effective conductivity of  $\sim 100$  siemens/m, are suitable for the beam-pipe absorber. A sample of SiC (TPSS) which could be used for the beam-pipe absorber was found, and an R&D effort to produce an SiC having more appropriate properties is under way. The fabrication of a prototype beam-pipe absorber has been completed, and will be tested under heat loads.

A measurement of the wideband characteristics of the SiC and an accurate estimation of the broadband impedance of the absorber using the measured properties are the next subjects to be studied.

#### VI. ACKNOWLEDGMENTS

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