HIGH-POWER TEST OF A 714-MHz HOM-DAMPED CAVITY FOR THE ATF DAMPING RING

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ABSTRACT

We describe the fabrication and high-power test of a prototype HOM-damped cavity for the ATF damping ring which is being constructed at KEK. This cavity is loaded with four waveguids for damping higher order modes (HOMs). In order to demonstrate the feasibility of high-power operation, as well as to establish construction techniques, a prototype high-power test cavity has been fabricated. This cavity was successfully tested under dissipated power of up to 50 kW, three-times higher than the design goal.

1 INTRODUCTION

The Accelerator Test Facility (ATF) at KEK is a dedicated test facility for accelerator technology and design for future linear colliders [1]. The production of electron beams with extremely low emittance and high intensity will be investigated at the ATF. It comprises a 1.54-GeV damping ring (DR), which is currently under construction, and an injector linac, which has already been operating. The total beam current in the ATF DR amounts to 600 mA with several bunch trains. In order to achieve this design current without having coupled-bunch instabilities, it is essential to reduce the longitudinal and transverse HOM-impedances of the RF cavities.

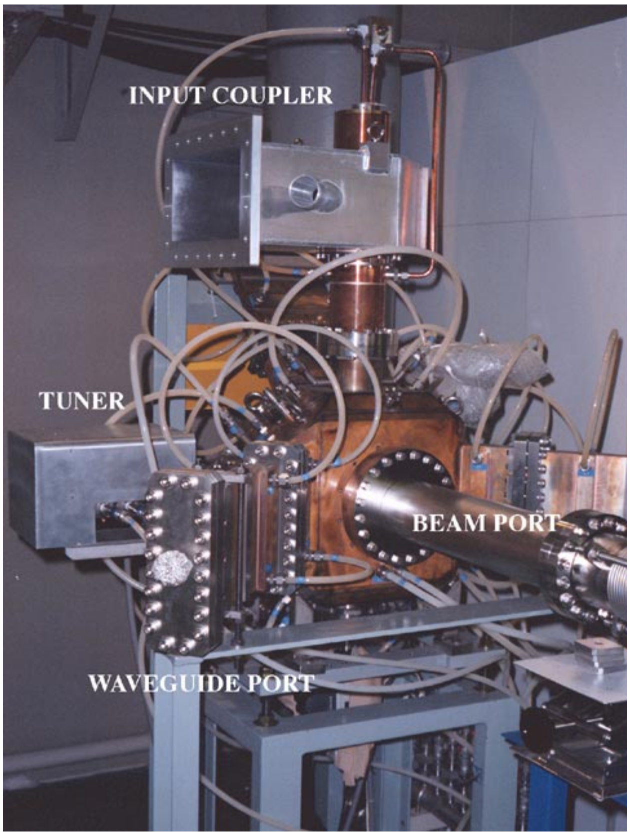

Fig. 1. High-power test cavity mounted on a test bench.

As the basic design of the cavities, we have chosen a 714-MHz single-cell cavity loaded with rectangular waveguides for damping the HOMs (see Fig. 1). This scheme is similar to those of the PEP-II[2] and the DAΦNE[3], except for the number and location of the waveguide ports. In our design, the cavity is equipped with four waveguide ports, two of which are located at an upstream corner of the cavity, while the other two are at a downstream corner together with a 90° rotation. The inner shape of the cavity was designed so that the magnetic fields of harmful HOMs would be as strong as possible at the outer corner of the cavity where the waveguides are located, while keeping the shunt impedance of the accelerating mode reasonable. The basic design of the cavity is described in ref. [4]. The characteristics of the HOMs were investigated with a cold-model cavity [5], which showed good performance of the HOM damping. As the next step, a prototype high-power cavity was fabricated, and then tested under high power.

2 FABRICATION

Based on the design described in ref. [6], a high-power test cavity was fabricated by a manufacturer (Keihin Product Operations of Toshiba corporation). The basic fabrication method was machining from copper blocks and assembling by brazing. We experienced no serious troubles during the construction process. Several components that are compatible to our 714-MHz cavity, such as a movable tuner, fixed tuners and an input coupler, were also developed. Figure 1 shows the completed cavity assembly, which was mounted on a high-power test bench.

The final dimensions of the prototype cavity were designed based on a measurement on the cold-model cavity, while considering the different operating conditions between the model and the high-power cavities. The finished cavity showed a resonant frequency of only 170 kHz lower than the target, which was easily adjusted by machining two fixed tuners.

The performance of the prototype cavity is summarized in Table 1. We obtained an unloaded-Q value of 24900, with an input coupler and tuners (one movable- and two fixed-ones) attached to the cavity. This value was well within our

Table 1. Obtained parameters of the prototype cavity.

Resonant frequency*	f_{res}	714.000 MHz
Unloaded-Q (at low power)	Q_0	24,900
Shunt impedance/Q **	R_{sh}/Q	166 Ω
Shunt impedance (= V_c^2/P_c)	R_{sh}	4.1 MΩ

* After being adjusted by tuners.

** Calculated value. Also checked with a cold model.

target, and was 94% of that calculated using the MAFIA code. Note that a calculation by MAFIA on an axi-symmetrical cavity gives a Q-value of about 95% of that calculated using the SUPERFISH code, in the case of our typical mesh size. This suggested that the Q-value obtained was about 89% of that of an ideal cavity, which was reasonable.

The obtained shunt impedance was 4.1 MΩ at low power. In order to produce a design gap voltage of 0.25 MV/cavity, a dissipated power of 15.1 kW is required. Under this heat load, the reduction of the Q-value was estimated to be about 1.5%, which is sufficiently small.

3 HIGH-POWER TEST

3.1 Set-up

A high-power test of the prototype cavity was carried out at KEK from August 30 to September 18, 1995. We used a 714-MHz, 50-kW klystron (Philips YK1265) as a power source, and a100-kW circulator to isolate the klystron from the cavity. The coupling coefficient of the input coupler was adjusted to 1.1 by rotating the loop, in which case most of the input power was dissipated in the cavity. Each end of the waveguide port was capped by a stainless-steel flange, since terminating loads were under development. Because the accelerating field was sufficiently weak at the flanges, this did not affect the high-powertest. Each cap flange and fixed tuner has a viewing port, which allowed us to observe the insides of the cavity and the waveguides during the test.

The cavity was evacuated by a turbo-molecular pump through the beam port. An effective pumping speed was about 60 liters/sec. The cavity was cooled by a total water flow of 120 liters/minutes. A ceramic window was additionally cooled by forced air flow. The temperature of the ceramic window was monitored using a radiation thermometer.

3.2 High-power test

The base pressure of the cavity was 5×10^{-8} Torr at the start. During the conditioning, we kept the cavity pressure below 2×10^{-6} Torr, above which the input power was turned off. The input power was also cut off when a large reflected power was detected.

First, the RF power was fed at a power level of 50 W; then, the input power was gradually increased. The conditioning progressed smoothly without any serious problems, as shown in Fig. 2. After conditioning for 50 hours, we could fed an input power of 50 kW, about

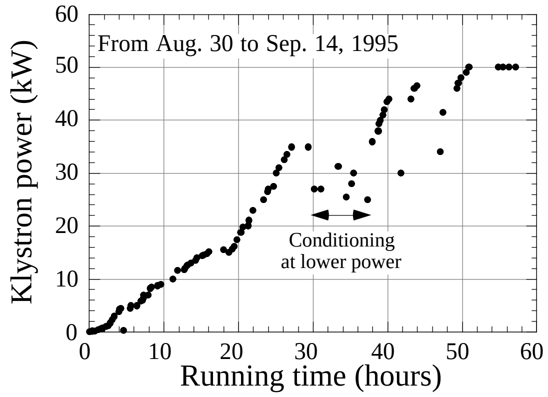

Fig. 2. Progress of the conditioning. The output power of the klystron is plotted against the net conditioned time. Note that the input power of the cavity was about 2% lower than the klystron power, due to the insertion loss of the circulator.

three-times higher than the design goal. The maximum temperature at the center of the ceramic window was ~36 °C at an input power of 50 kW, which was sufficiently low.

The following is a summary of some observations made during the conditioning: 1) We sometimes (but not always) observed a visible discharge in the cavity at the same time as detecting a spike of reflected power. 2) We observed considerable outgassing in several power bands (typically 75 - 250 W and other ranges that were not clearly specified). In such a condition, although we sometimes detected spikes of reflected power, we could not observe any visible multipactor discharges in the waveguides. 3) Several dots of light, which would indicate local discharges, were observed around the nose cones above certain input powers (at first ~3 kW, and then ~16 kW after the conditioning). These dots appeared constantly, but not accompanied by spikes of reflected power. As the input power increased, the dots increased in number and became lighter. This phenomenon did not disturb the practical operations.

3.3 Temperature rise and thermal detuning

Figure 3 shows the measured surface temperatures of the cavity under an input power of 50 kW. The maximum temperature was 51 °C (20 °C higher than that of the input water), which occurred around the waveguide ports. Figure 4 shows the result of a thermal analysis on an axi-symmetrical model having no waveguide ports. The measured and calculated surface temperatures agreed, except for that around the waveguides.

We also measured the cavity detuning due to thermal expansion from the movement of the tuner. The detuning frequency was proportional to the input power, which amounted to -240 kHz at 50 kW. This almost agreed with the calculated detuning of -300 kHz using the same model. These results suggested that the overall temperature distribution and deformation could be understood by the axi-symmetrical model, except for in the neighborhood of

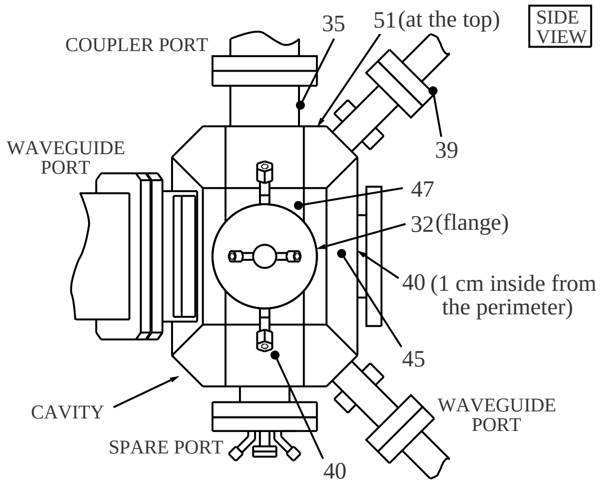

Fig. 3. Measured temperatures (°C) of the cavity under an input power of 50 kW. Input water temperature, 31°C.

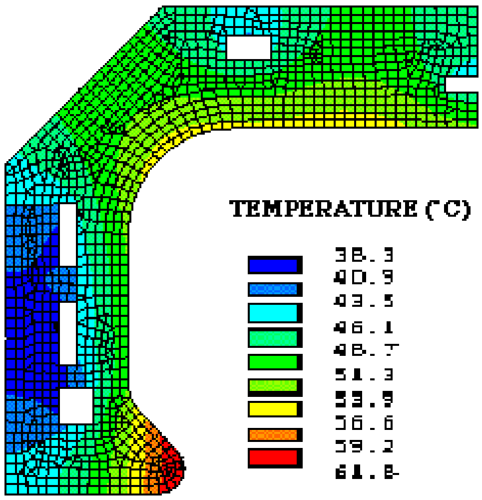

Fig. 4. Result of a thermal analysis on the axi-symmetrical cavity model using the ANSYS code. Assumed a dissipated power of 50 kW/cavity, water temperature of 30°C and a heat-transfer coefficient of 1.2 W/cm^2/K on the cooling channels.

the waveguide ports. Then, the reductions in the Q-value due to the heat loads were estimated to be ~1.5% and ~4.5% with dissipated powers of 15 kW and 50 kW, respectively.

3.4 Discussion

At the design stage, there were several points that had to be considered: 1) Concentrations of heat load exist beside the openings of the waveguides. The peak power density was estimated to be ~16 W/cm^2 at 15 kW/cavity using MAFIA, or even several times higher due to rough modeling in the MAFIA calculation [7]. In our cavity, the corner edges of the openings are rounded by hand to ~1 mm in radius, which do not relax the heat concentration. Thus, thermal stress may cause fatigue destruction of the copper wall beside the openings. 2) At these rounded corners of the openings, the surface electric field amounts to ~2 MV/m (at 15 kW/cavity). If the surface finish made by hand is insufficient, violent discharges may occur at the corners. 3) There is a possibility of multipacting by higher cycles in the waveguides. In our case, the smoothness of the inner wall of the waveguides is slightly worse (~6 S) due to wire machining. In addition, there was some leakage of the filler alloy to the inner wall of the waveguides during brazing. These may promote the possibility of multipacting.

A successful test of the prototype cavity showed that these potential problems were not severe under a dissipated power of up to 50 kW, at least for a short time. After the high-power test we vented the cavity and observed the inner wall of the cavity, especially around the openings for the waveguide ports, using a telescope. We could not find any marks or roughness indicating violent discharge or fatigue destruction.

4 CONCLUSIONS

We have established fabrication techniques of the HOM-damped cavity. The resonant frequency and Q-value obtained were satisfactory. The success of a high-power test under a dissipated power of up to 50 kW demonstrated the high-power capability of this cavity, up to three-times the design goal. It was also proved that the newly-developed input coupler was capable of transmitting power of 50 kW, which was above the required power of ~41 kW.

Based on the prototype design, we have fabricated two additional cavities, which are to be installed in the ring. Vacuum-compatible dummy loads using silicon-carbide (SiC) as a microwave absorber, which terminate the waveguide ports, are also under development. The ATF damping ring will be commissioned at the end of 1996, using two cavities driven by a 50-kW klystron.

Acknowledgments

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