DESIGN OF A HIGH-POWER TEST CAVITY FOR THE ATF DAMPING RING

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We describe the design of a prototype HOM damped cavity which is being developed for the ATF damping ring. This cavity has been designed to demonstrate the feasibility of high-power operation, as well as to establish construction techniques. The mechanical design, fabrication method and design considerations are presented.

I. INTRODUCTION

A HOM damped cavity for the ATF damping ring (DR) [1] is under development at KEK. This cavity is capable of avoiding coupled-bunch instabilities driven by higher order modes (HOMs). In order to damp the Q's of HOMs the cavity is equipped with four waveguide ports, the cutoff frequency of which is higher ($f_c \approx$ 887.3 MHz) than the accelerating frequency. Additional HOM damping is provided by HOM absorbers in the beam pipes next to the cavity [2]. The basic design and results of low-power measurements are described in refs. [3] and [4], respectively. The overall design of the RF-system is presented in an accompanying paper [5].

In order to demonstrate the feasibility of high-power operation, the construction of a high-power test cavity is under way. The design parameters of the test cavity are shown in Table 1. Although a total wall loss of 17.4 kW is conservative, special care has been taken concerning the cooling design, because concentrations of wall losses exist around the openings of the waveguide ports. The possibility of multipacting, the surface field strength and other RF properties were considered during the design stage.

Table 1. Design parameters of the HOM damped cavity.

RF frequency	714 MHz	Shunt impedance	3.6 MΩ
Unloaded-Q	22,100	Gap voltage/cavity	0.25 MV
Coupling factor	2.4	Wall loss/cavity	17.4 kW

II. DESIGN AND FABRICATION METHOD

The design concept of the cavity is to realize a damped structure having effective cooling passages by using as simple a structure as possible. We have chosen well-established techniques, both machining and brazing, for the cavity construction. Other joining techniques, such as using electron-beam welding (EBW), tungsten inert-gas (TIG) welding and using a hot isostatic press (HIP) are applied as auxiliary methods. The raw materials used are OFHC copper for the principal parts and stainless-steel 304 for the flanges. The outer shape of the cavity is a simple polyhedron, which provides precise reference planes for further machining, such as milling of the waveguide openings.

Figure 1 shows a drawing of the designed cavity. The main body comprises a center part and a pair of side parts. Cooling of the main body is provided by several water channels (see Fig. 1): (A) a pair of circumferential channels at the outside, (B) three channels in the side body, which comprise an outer square channel and inner round channels, and (C) four straight channels in the center of the body. The typical heat load on the cavity wall has a 5-7 W/cm^2 range, which can be effectively removed by these cooling channels. On the other hand, there are concentrations of the heat load at small areas beside the waveguide openings (at narrower sides), which amount to ~18 W/cm^2. These hot spots are mainly cooled by heat transfer to the water channel (A) and the outer channel of (B), which are located ~20 and ~40 mm away from the hot spots, respectively. All of the ports, except for the pick-up ports and beam ports, have separate cooling channels.

The three parts of the main body are machined from forged OFHC blocks; the outside surfaces are precisely planed by a milling machine, and the inside roughly turned on a lathe. Openings for the waveguides and other ports, as well as the cooling channels, are then milled. The cooling channels are covered with lids by EBW, or later, by brazing at the same time as joining of the ports.

Subassemblies of the waveguide ports are machined from OFHC plates, the insides of which are bored by electro-erosion wire machining. Then, the cooling channels are milled, and covered with lids by EBW. Waveguide flanges are roughly machined from stainless-steel plates, and annealed. After being finish machined, their insides are plated with copper. The waveguide flange was designed by referring to that of the SLAC S-band waveguides, which allow vacuum sealing and electrical contact simultaneously. Between the waveguide ports and dummy loads, 35-cm long waveguides are inserted in order to evanesce the accelerating field. At an initial high-power test, the ends of the extension waveguides are blanked off without attaching any loads.

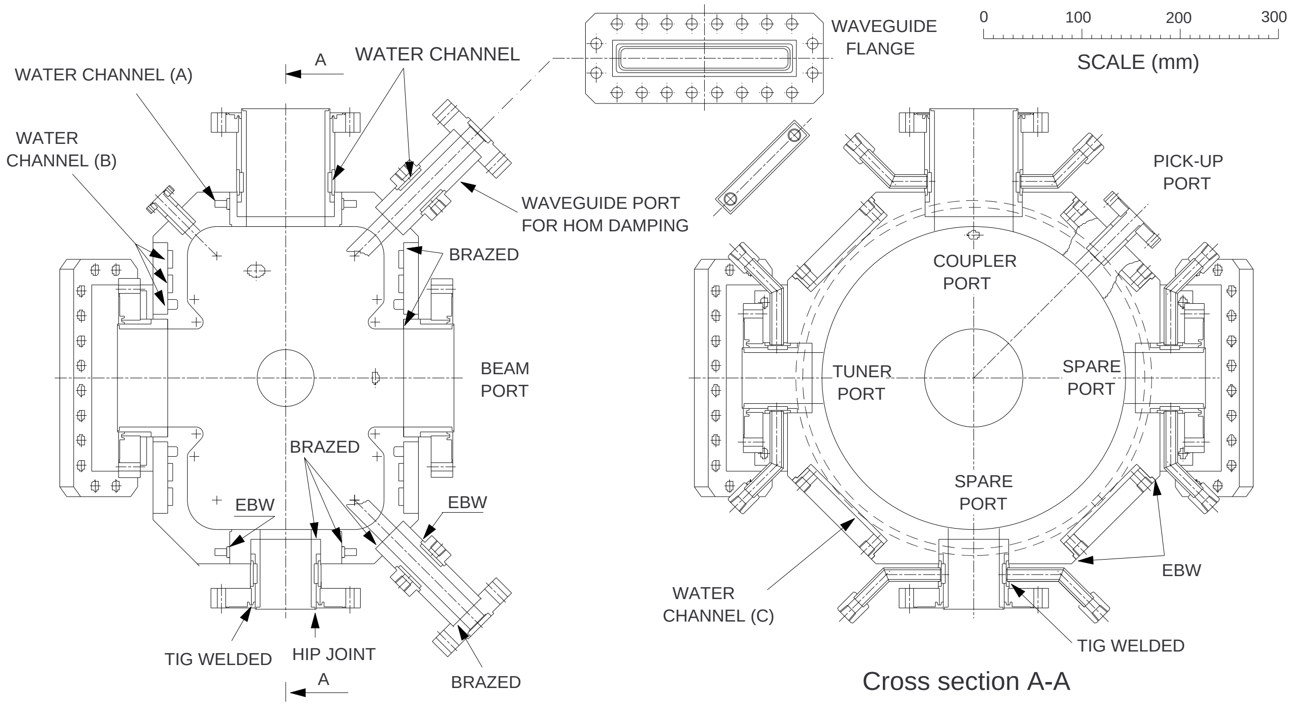

Fig. 1. Cross-sectional view of the high-power test cavity.

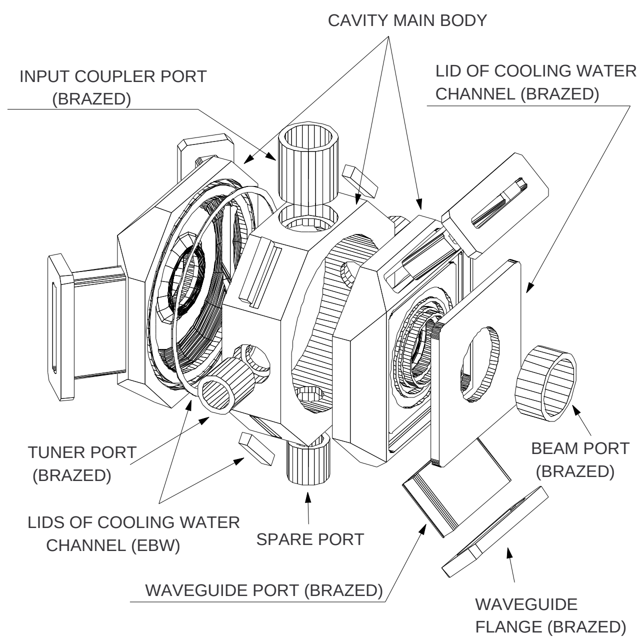

Fig. 2. Schematic drawing showing the cavity assembly.

Tuner and coupler ports as well as beam ports and spare ports are pre-assembled according to the following procedure: 1) a copper cylinder (inside) and a stainless-steel tube (outside) are joined by a HIP technique, 2) machined, and cooling paths milled, and 3) the lids and inlet/outlet pipes of the cooling water channel welded.

The cavity assembly is schematically shown in Fig. 2. The cavity parts are joined by brazing in two stages. First, all of the ports and lids of the water channels (at the side bodies) are brazed. Then, the cavity inner wall is finish machined using a high-precision lathe with a diamond cutting tool. At the same time, the edges of the port openings inside the cavity are rounded (R~1 mm) by hand. During a second brazing, the three bodies are joined together. The waveguide flanges are joined to the waveguide ports at the same time. After brazing, UHV flanges are TIG welded to the other ports.

The surface finish of the cavity inner wall is better than 3S (R_{max}), while that of inside the waveguide ports is slightly worse (~6S) due to the relatively long dimension for wire machining.

III. INPUT COUPLER AND TUNER

Because the transmission power through an input coupler is relatively conservative (41 kW max.), we chose a loop-coupler design with a cylindrical ceramic window. The coupler was designed by scaling from that for the TRISTAN APS cavities [6]. The coupling factor of the coupler can be changed from 0 to 4.1 by rotating the loop; a nominal coupling factor of 2.4 is obtained by 40˚ rotation from the maximum coupling.

The design of the tuner is basically scaled from that of the PF storage ring at KEK. The tuner has a 50 mm-diameter copper piston driven by a stepping motor with a stroke of from -10 mm to +30 mm of penetration from the cavity inner wall. This provides a tuning rage of -200 to

+1700 kHz. The mechanical resolution of the movement is 1µm/step which corresponds to 36 Hz/step. The bellows inside the tuner are shielded from RF currents by graphite contactors supported by finger springs.

Two spare ports are blanked off by water-cooled copper blocks. These dummy blocks are also used as fixed tuners, which can compensate for anticipated frequency shifts due to fabrication errors. The dummy block has a viewing port which allows the tuner and coupler to be observed from inside of the cavity.

IV. DESIGN CONSIDERATIONS

A thermal analysis of the designed cavity was made using the ANSYS code: a 2D analysis of the overall temperature distribution, and a 3D analysis using a simplified model for the neighborhood of the waveguide openings. A heat-transfer coefficient of 1.2 W/cm^2/K was assumed at the boundary of the cooling channels, which corresponds to an average water velocity of 2.7 m/sec. These analyses predicted the following temperature rises: 1) 22˚C and 16˚C at the narrower and wider sides of the waveguide openings, respectively; 2) 11˚C at the tips of the nose cones, and 3) 7-9˚C for other locations of the inner wall. Although no full thermal-stress analysis has been performed, these temperature rises are considered to be acceptable.

The surface field strengths and wall losses around the waveguide ports were extensively analyzed using the MAFIA code. It was shown that the field distribution inside the waveguides ports is well approximated by an evanescent field of the TE_{10} mode. The maximum wall loss around the waveguide perimeter (which occurs at the narrower sides) is given by P_{wall} [W/cm^2] ~ 7.1·exp($-2\alpha z$[m]), where α=10.96 m^{-1} is the attenuation coefficient and z is the distance from the opening. The electric field at the center of the waveguide is given by E ~ 1.4 exp($-\alpha z$) [MV/m, peak] for the inner locations and by E ~ 1.1 [MV/m] for the neighborhood of the entrance. The electric field at the round edge (R~1 mm) of the waveguide openings would be enhanced by a factor of two, which was shown by an electrostatic analysis. Although these field strengths are much lower than the Kilpatrick limit of 25 MV/m, a good surface finish is desirable for these locations. The field strength at the tip of the nose cone is ~5.8 MV/m, which is common for nose cones.

The field leakage to the tuner or to other ports is also considered. Basically, the leakage fields to these coaxial parts can be approximated by an evanescent field of the TE_{11} mode in a coaxial line. Low-conductive materials, such as stainless steel, should be located away from the evanescent field. Furthermore, if the symmetry of the cavity structure seen by the ports is broken, the accelerating field can be coupled to TEM-resonances (typically $\lambda/4$ or $3\lambda/4$ resonances) in the coaxial structure of the ports. Even in such a case, excitation of the resonances in the port can be avoided by detuning the resonant frequencies from that of the accelerating mode. In our cavity an asymmetry would be introduced by the damping waveguides. However, a harmonic analysis of the accelerating field showed that such distorted field components seen by the ports are lower than ~2% of the surface field.

The possibility of multipactor discharges was also investigated. With the designed waveguide height of being 2 cm, we can avoid the most severe multipacting of 1/2 cycle in the waveguide ports. The multipacting of higher cycles, which may arise, can be removed by conditioning if the inner surface is sufficiently clean and smooth. On the other hand, a gap of 1 mm was chosen between the tuner and its port wall, which can avoid any multipactor discharges regardless of the gap voltage.

V. CONCLUSIONS

The design of a high-power test cavity has been completed based on a thermal and RF analysis. The design was aimed at providing effective cooling passages by a simple fabrication process. The cavity is under construction towards a high-power test, being planned in the summer of 1995.

VI. ACKNOWLEDGMENTS

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