DESIGN OF A COPPER CAVITY FOR HLS

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Abstract

A 204MHz all copper RF cavity was designed for the phase II project of Hefei Light Source (HLS). The requirements of the storage ring, which will operate in General Purpose Light Source (GPLS) mode and High Brightness Light Source (HBLS) mode, determine the main parameters of the cavity. On the basis of the simulation of SUPERFISH, three kinds of cavity shape were designed, and one optimum shape was selected at last. The HOMs of the cavity were calculated with URMEL-T and they would be suppressed by the HOMs couplers. In addition, the construction techniques of the cavity, such as how to weld the cavity components and fabricate the cooling water channels, are described in this paper.

1 INTRODUCTION

HLS is a dedicated light source with beam energy of 800MeV and beam current of 200~300mA. Besides to compensate the synchrotron radiation power loss and provide enough beam lifetime, the RF system of the storage ring is used to accelerate the beam from 200MeV to 800MeV. In the phase II project, the ring was designed to operate in both GPLS and HBLS modes. The RF system is required to provide the RF voltage of 250kV and beam power of 5kW.

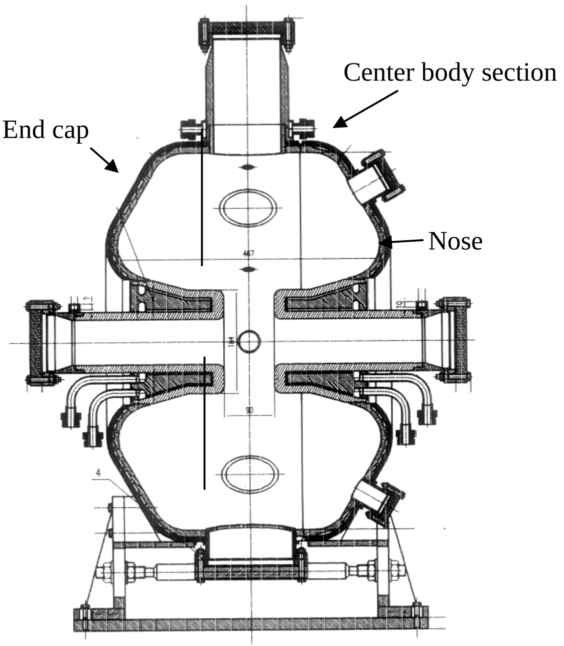

Figure 1: The designed cavity of HLS

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The existing cavity for phase I of HLS is a conventional re-entrant cavity, made of copper-clad steel, similar to the Beijing Electron Positron Collider (BEPC) RF cavities. From the experiences of the development and operation of the HLS and BEPC cavities, we paid our attention on the choice of the cavity material, the optimization of the cavity shape and the cooling channels in the design of this new cavity.

2 RF DESIGN

According to the requirements of the storage ring, the parameters of the new cavity were determined and listed in table1. [1]

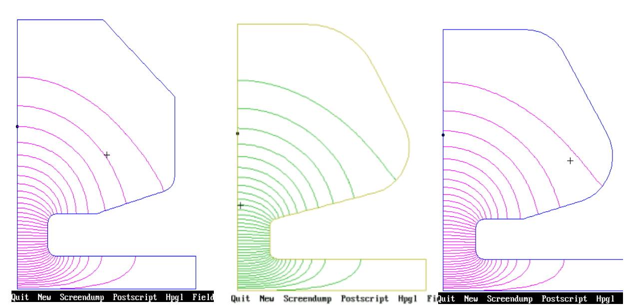
Table 1: Main Parameters of the cavities of HLS

Parameters	**Existing Cavity**	**Designed Cavity**
Frequency	204MHz	204MHz
Max. Voltage	150kV	250kV
Calc. Rs*	3.5MΩ	3.9MΩ
Calc. Q	27000	33000
Coupling factor	2.5	2.0
Tuning range	300kHz	300kHz
Temperature.	42.5°C	42.5°C

*$Rs=V^2/2P_c$

After the comparison of the benefits of several commonly used materials for room temperature cavities, we selected Oxygen Free High Conductivity Copper (OFHC) as the fabrication material, which might eliminate the cooling problems caused by the low thermal conductivity of the steel.

Similar to the existing cavity, the new cavity shape is also based on the conventional re-entrant profile. But because mechanical stiffness of the copper is not so high as that of the steel, the cavity shape is spheric, chosen from the three candidates shown in Figure 2.



(I) (II) (III)

Figure 2: Three cavity shapes considered.

Table 2: Parameters of candidate cavities

Shape	Radius	Gap	R/Q*	Q
I	37.70cm	8.0cm	112.5	35197
II	33.55cm	8.0cm	99.0	32134
III	33.50cm	8.0cm	119.7	32581

$^*R=V^2/2P$

The above three cavities were simulated with SUPERFISH. Since cavity-III is of small radius, high shunt impedance, and relatively easy to be manufactured, it was selected and carefully optimized to maximize the shunt impedance, to rationalize the wall power density (see figure 3), and reduce the peak surface field. The peak field (4.4MV/m at 250kV) is well below the Kilpatric level (~14.8MV/m at 204MHz). SUPERFISH was also used to determine the rate of the change of resonance frequency with the changing gap size, and the predicted rate is 0.75MHz/mm.

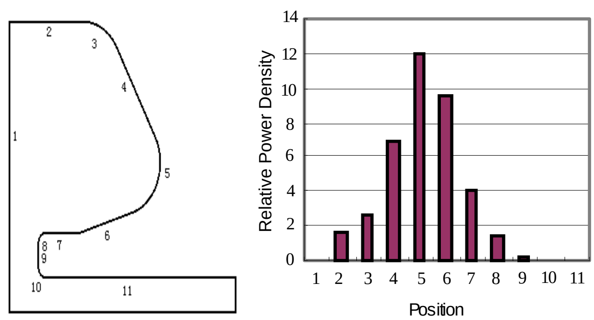


Figure 3: Wall power density distribution

Because of the small beam-pipe diameter there are many HOMs trapped in the cavity below cut-off frequency. More than 100 HOMs were calculated with URMEL-T and 8 most dangerous HOMs are listed in table 3.

Table 3: Main HOMs of the cavity

Monopole	Freq.(MHz)	R/Q(Ω)*	Q
0-E-3	796	16.4	58519
0-E-4	1101	2.6	48457
0-E-6	1338	10.4	69419
0-E-8	1713	3.1	81615
Dipole		$R_\perp$/Q(Ω/m)	
1-E-1	579	56.3	51687
1-E-3	935	26.2	59384
1-E-5	1139	2.6	49311
1-E-7	1475	0.45	80704

$^*R=V^2/2P$, $^\wedge R_\perp=R(r)/(kr)^2$

TM_{01} cut-off=2869MHz, TE_{11} cut-off=2196MHz

In the storage ring of HLS, some longitudinal coupled bunch instabilities caused by the HOMs of the existing RF cavity have been observed. Sometimes these instabilities result in the beam injection difficulty and the loss of the running beam. To suppress the HOMs of the new cavity and simplify the RF system, a damping antenna and loop will be added to reduce the Q value of the HOMs.

3 MECHANICAL DESIGN AND FABRICATION CONSIDERATIONS

This is the first time for us to design an all copper cavity whose frequency is less than 500MHz. To ensure that our design is robust and the overall cost and fabrication time is minimized, we have investigated the current cavity-construction techniques and chosen the advanced or/and tested techniques.

Referring to the designs of the 200MHz SPS cavities and the 476MHz PEP-II cavities[2][3][4], this new cavity will employ many related technologies developed interiorly in the recent years.

The cavity consists of 5 parts: a center body section, two end caps and two noses with beam-pipes. In the center section, there are eight openings: a coupling port, a pick-up port, a pumping port, an observation port, two tuner ports and two ports for loop-type HOMs damper. Two ports for the antenna-type HOMs damper are in the two ends, and two beam ports with the nose parts. All of the ports and their interface with the body are simple figures of revolution and can be lathe turned.

The fabrication of the cavity is designed as follows:

The center section of the body including the eight round ports on the equator will be machined from a copper cylinder, whose inner diameter is about 600mm and the outer about 1200mm. This will eliminate a number of joints and machining operations compared with an assembly fabricated from separate parts. The noses with beam pipes will also be machined from copper cylinder, whose inner diameter is about 70mm and outer about 220mm. The end caps will be machined from plate stock by spinning method. The cooling channels are milled on the outsides of the center body section and end caps (see section 4). Then they will be sealed for the plating process. Plating wax will be cast into the cooling channels and the surface will be made conducting with silver powder and activated. The thick jackets of plated copper will be grown over all of the channels. Once plating is completed the wax will be melted and flushed out of the channels. After these processes, the noses with multi-cooling channels will be brazed to the end caps. One end cap is then joined by e-beam welding to the center section. The other end cap will then be put in place, the frequency be measured and adjusted by a final tuning on the nose if necessary. Once the frequency is correct the second cap will be e-beam welded in place. Any frequency change from the final weld will be taken out by the fixed tuner (see section 5), or the change of the cavity length if necessary.

After the welding, the cavity will be leak-checked and the cooling channels be hydrostatically tested. The flanges will then be attached by e-beam welding. These are standard stainless steel circular knife-edge flanges with copper inserts. The final process is to clean the inside of the cavity using a mild chromic acid bright dip. This removes any residue from e-beam welding that may have condensed on the inside surface and improve the surface finish.

4 COOLING CHANNELS

From the development and operation of the existing RF cavities, we found that the effective cooling of a cavity was very important. So, we put much attention on the cooling of this cavity. The water flow and the distributions of the cooling channels were determined by the theoretic analysis and the experiences, and the code ANSYS was used to check the cooling system design.

The real shunt impedance of the cavity is estimated to be 80%×Rs (calc.) =3.12MΩ. The cavity's total amount of heat, which has to be carried away, is:

$$P_c = \frac{V_c^2}{2 \cdot R_s} = 10.1\text{kW} \qquad (1)$$

The total water flow needed is about 3 tons/hrs. According to the wall power density distribution of the cavity (figure 3), the water flow was designed as table 3.

Table 3: Water flow distributions of the cavity

	Parts shown in Fig. 3	**Power (kW)**	**Flow (t/h)**
Center section	2	1.5	0.4
End caps	3+4+5	2.6×2	0.8×2
Noses	6+7+8+9+10+11	1.7×	0.5×2

The dimensions of the cooling channels on the center body section are 25mm × 4mm, and they will be fabricated with milling and electroplating techniques, like the PEP-II cavities. Similar are the channels in the end caps. However, the noses with the beam pipes adopted cuneate structures, like the CERN SPS 200MHz cavities.

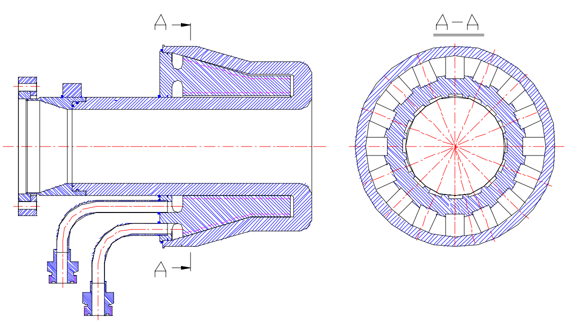


Figure 4: Cuneate cooling structure of the nose

The Reynolds numbers of the water flow, the water resistances and the temperature increases in the five parts of the cavity were calculated with empirical equations or estimated by experiences. The results show that the water flow of the cavity will be well turbulent and the cavity can be cooled effectively for the required voltage. For example, the Reynolds number of the water flow in the center section is 14600, the resistance is 1.9m and the temperature increase is less than 1 ^{o}C

5 TUNER

In view of the change of the beam current, the tuning range should be:

$$\Delta f = f \cdot \frac{I_0 \cdot R_s}{V_c \cdot Q} \cdot \sin\phi \qquad (2)$$

Where ϕ is the synchronous phase angle.

The real Q of the cavity is estimated to be 80%× Q(calc.)=26400. When the storage ring works in general mode, the beam current is I_0=300mA, and the RF voltage is Vc=100kV (with Φ=80.6^{o}), the tuning range under this condition is larger than that of the HBLS mode.

$$\Delta f = 71.4\text{kHz} \qquad (3)$$

To take out the frequency error from the fabrication and tune away the harmful HOM, two tuners are used. One is fixed and the other is moveable with a commercial stepper-motor driven actuator. Both of the tuners are piston types, with the tuning range of 300kHz respectively. The tuners will be water cooled and the dimensions will be chosen so that the tuning range is adequate and the harmful resonance can be avoided.

6 CONCLUSION

This is the first time for us to design an all copper cavity (<500MHz). The material, the cavity shape, the deeply damping of the HOMs and the construction methods of the cavity were investigated extensively. Now, the cavity is being manufactured under the charge of K. Jin and it will be finished in this August.

7 ACKNOWLEDGMENTS

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