# STUDY ON THE HIGH ORDER MODES OF THE 3.5 CELL CAVITY AT PEKING UNIVERSITY *

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*Abstract*

As part of the updated DC-SC injector, a 3.5cell cavity has been fabricated at Peking University, which includes two Coaxial High Order Mode (HOM) couplers. The effect of the HOM couplers has been studied by numerical simulation and measurement. The results are highly uniform and show that the two couplers do effectively damp the HOMs.

## INTRODUCTION

The 3.5cell cavity is part of the DC-SC injector, the feasibility of which is proved in 2004 [1] with beam done test. The updated 3.5cell cavity was designed and fabricated from large grain niobium, and the vertical test result ($E_{acc}$=23.4MV/m@$Q_0$>$10^{10}$) at JLAB is exciting. The main RF parameters are listed in Table1.

Table 1: RF Parameters of 3.5 Cell Cavity

| | |
|---|---|
| Type of accelerating structure | Standing wave |
| Accelerating mode | $TM_{010}$, pi mode |
| fundamental frequency | 1300MHz |
| Quality factor | ⩾$5x10^9$ |
| Active length | 41.7cm |
| Cell-to-cell coupling | 1.8% |
| Effective shunt impedance | 418Ω |
| Transit-time factor | 0.74 |
| Total longitudinal loss factor* | 3.95(V/pC) |
| transverse loss factor* | 2.15(V/pC/cm) |

*the standard deviation length of the bunch is 2mm

Among those RF parameters, the total longitudinal loss factor and transverse loss factor are from ABCI simulation; all the others are from Superfish.

## NUMERICAL CALCULATIONS OF HOMS

The electron bunches passing through the cavity excite the eigenmodes of higher frequency which are HOMs. Here Microwave Studio is used to simulation the HOMs. To check whether there are trapped modes, two different boundary conditions at the end of beam pipes are used in two separate runs [2]. Large frequency shift of one mode indicates the mode depends on the boundary condition sensitivity; otherwise the mode could be trapped.

The simulation shows $TM_{110}$(2) and $TM_{020}$(1)could be trapped. But they will not be excited by the beam as the beam bunch repetition frequency is 81.25MHz. All of the interested modes with ideal electric boundary condition below 3GHz are listed in Table 2.

Table 2: HOMs of 3.5 Cell Cavity by Simulation

| Mode | Mode | f（MHz） | *R/Q |
|---|---|---|---|
| Mode1 | $TM_{010}$（1） | 1278.69 | 9.75 |
| Mode2 | $TM_{010}$（2） | 1286.80 | 13.09 |
| Mode3 | $TM_{010}$（3） | 1296.83 | 16.63 |
| Mode4 | $TM_{010}$（4） | 1301.07 | 417.26 |
| Mode5 | $TE_{111}$（1） | 1634.35 | 0.07 |
| Mode6 | $TE_{111}$（2） | 1681.53 | 2.49 |
| Mode7 | $TE_{111}$（3） | 1747.03 | 10.07 |
| Mode8 | $TM_{110}$（1） | 1798.05 | 3.43 |
| Mode9 | $TM_{110}$（2） | 1849.61 | 3.47 |
| Mode10 | $TM_{110}$（3） | 1872.20 | 1.42 |
| Mode11 | $TM_{110}$（4） | 1883.84 | 0.77 |
| Mode12 | $TM_{011}$（1） | 2391.49 | 0.62 |
| Mode13 | $TE_{111}$（4） | 2391.79 | 0.18 |
| Mode14 | $TM_{011}$（2） | 2421.67 | 12.65 |
| Mode15 | $TM_{011}$（3） | 2449.83 | 84.33 |
| Mode16 | $TM_{020}$（1） | 2658.30 | 23.97 |
| Mode17 | $TM_{020}$（2） | 2690.74 | 8.93 |
| Mode18 | $TM_{020}$（3） | 2728.82 | 4.26 |
| Mode19 | $TM_{020}$（4） | 2762.00 | 2.08 |
| Mode20 | $TM_{111}$（1） | 2819.80 | 0.71 |
| Mode21 | $TM_{111}$（2） | 2880.96 | 0.85 |

*unit of R/Q is Ω/$cm^n$; for monopole mode, n=0; dipole mode，n=2.

The number next to the mode indicates the passband of the mode. For some modes, the electric field along the beam centre axis is almost zero, so the voltage is zero. Here we integrate the electric field along the axis 10 mm away from the beam centre and get the accelerating

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voltage $V_c^*$, and the effective shunt impedance is $(R/Q_0)^* = (V_C^*)^2/\omega U$, where ω is the angular frequency of the mode, U is the stored energy.

The effects of HOM couplers are simulated on a 2cell cavity also by CST Microwave Studio, which deduces the simulation time obviously [3]. The simulation shows $Q_e$ of HOM coupler on 2-cell TESLA cavity is $10^{13}$ for fundamental mode, and $10^3$~$10^6$ for HOMs.

## MEASUREMENTS OF THE RESONATE MODES

In order to confirm the type of the modes, the electric field profile of the modes is measured by bead pulling. Two beads are used, one is a teflon cylinder with diameter of 4 mm and length of 4mm, the other is a copper cylinder with diameter of 5mm and length of 4mm. By comparing the measured electric fields with the simulated ones, 16 of all the 21 interested modes are obtained. The block diagram of the test bench is shown is Figure 1.

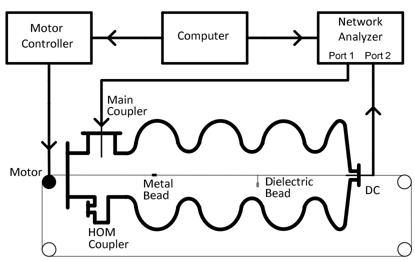


Figure 1: Block diagram of the test bench.

## RF MEASUREMENTS OF THE HOM DAMPING ON THE CAVITY

Before the HOM couplers are welded to the cavity, they are tested on a self-designed coaxial transmission line [4], to ensure the tuning range of the resonate frequency. The antenna of the HOM coupler is match to the load and with a round tip to increase the coupling as shown in Figure 2.

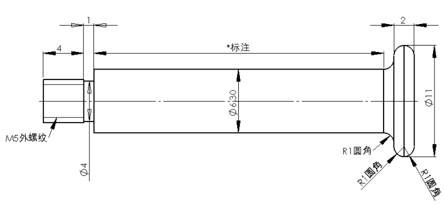


Figure 2: The shape of the antenna.

The antenna is made of copper in a series of length. With these antennas amounted, the gap from the antenna to the HOM coupler is 0.5mm, 1mm, 1.5mm, 2mm, 2.3mm. During this change, the $Q_{ext}$ does not change much. Finally 1mm is chosen and the result is shown in Table 3.

Table 3: $Q_e$ of the HOMs by Measurements

| mode | f (MHz) | $Q_e$ |
|---|---|---|
| TE111（1） | 1652.406 | $9.55x10^6$ |
| TE111（2） | 1693.484 | $3.82x10^6$ |
| $TE_{111}$（3） | 1757.300 | peak overlaps |
| $TM_{110}$（1） | 1797.265 | $1.66x10^6$ |
| $TM_{110}$（2） | 1864.493 | $1.89x10^7$ |
| $TM_{110}$（3） | 1876.990 | $1.06x10^7$ |
| $TM_{110}$（4） | 1882.496 | $3.45x10^6$ |
| $TE_{111}$（4） | 2374.582 | $4.69x10^6$ |
| $TM_{011}$（1） | 2412.774 | $7.46x10^5$ |
| $TM_{011}$（2） | 2429.367 | $2.27x10^5$ |
| $TM_{011}$（3） | 2462.537 | $7.26x10^5$ |
| $TM_{020}$（1） | 2678.580 | $1.57x10^5$ |
| $TM_{020}$（2） | 2703.662 | $1.60x10^4$ |
| $TM_{020}$（3） | 2732.066 | $1.50x10^4$ |
| $TM_{020}$（4） | 2769.828 | $8.93x10^4$ |

During the measurements, one HOM coupler is used because the available vector network analyzer has only two ports. For $TE_{111}$(3) pass band, the two polarization modes are too close to measure directly by the vector network analyzer. Table 3 only lays out one polarization mode of each passband, the $Q_e$ of the other one is much bigger. Obviously one coupler is not enough for all the modes.

## CONCLUSION

The test results of the coaxial HOM coupler on the 3.5cell large grain niobium cavity at room temperature indicate that the coupler works efficiently after a careful adjustment. The effects at 2K with beam loading are looking forward.

## REFERENCES

[1] J. Hao et al., NIM A 557 (2006) 138-141.
[2] F. Marhauser, P. Huelsmann, H. Klein, Proceedings of the 1999 Particle Accelerator Conference, New York, 1999. 3405-3407.
[3] X. Luo, CPC (HEP & NP), to be published.
[4] E. Wang, CPC (HEP & NP), 2009, 33(5): 401-405