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HOMS EXTRACTION STRUCTURE DESIGN FOR HEPS 166.6 MHz CAVITIES AT IHEP

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Abstract

Higher order modes (HOMs) may affect beam stability and refrigeration requirements of superconducting cavity such as the 166.6 MHz superconducting(SC) cavity, which is studied at IHEP. Under certain conditions beam-induced HOMs can accumulate sufficient energy to destabilize the beam or quench the SC cavities. In order to limit these effects, we considers the use of coaxial HOM couplers on the cut-off tubes of the SC cavity. However, HOMs cannot be effectively extracted by HOM couplers. Therefore, it is necessary to design a HOMs extraction structure to introduce the dangerous modes from the cavity into the bundle tube, which are designed to couple to potentially dangerous modes while sufficiently rejecting the fundamental mode. The HOMs extraction structure consists of an enlarged tubes, a coaxial structure, and the petal. The extraction of the dangerous modes and the suppression of the fundamental mode are realized by the petal structure and the coaxial structure. In order to verify the designs, a rapid prototype for the favored structure was fabricated and characterized on a low-power test-stand.

INTRODUCTION

High Energy Photon Source (HEPS) is a 6 GeV diffraction-limited synchrotron light source with a beam current of 200 mA. The fundamental RF frequency for the storage ring has been chosen to be 166.6 MHz in order to accommodate novel injection schemes as well as to compromise between the state-of-art kicker and RF technologies [1].

Higher Order Modes (HOMs) are components of the wake-field and can be excited by electron beam traversing an accelerating cavity. These modes may affect the beam stability as well as causing additional refrigeration load to the SC cavities if left uncheck. This is especially critical for high-current accelerators where impedance growth has to be well managed. Therefore, it is necessary to design a structure to suppress the establishment of HOMs field in the cavity. The main goal of the HOMs damping structure is to pick the HOMs out of the cavity, and it is necessary to suppress the fundamental mode to avoid energy waste and serious heat leakage problems.

First consider the mounting position of the HOM coupler: on the cavity or on the beam tube. The placement of the HOM coupler on the cavity makes it easier to extract HOMs, but it will cause great disturbance to the fundamental mode and the serious heat leak problem; The placement of HOM coupler on the beam tube can greatly reduce the disturbance to the electromagnetic field of the fundamental mode, but also weaken the effect on the HOMs.

In the pre-research stage of the project, the design of the 166.6 MHz resonant cavity has been completed [2]. In order to take advantage of existing prototype cavities, the design of the HOM coupler adopts the way of placing it on the beam tube. In the scheme of placing HOM couplers on the beam tube, in order to solve the problem of HOMs disturbance, it is necessary to design a HOM extraction structure to extract the HOMs from the cavity to the beam tube.

Therefore, a complete HOMs attenuation system requires three parts: HOMs extraction structure, HOM coupler, and an enlarge beam tube structure. The design of the system has been demonstrated in detail in paper [3]. The paper mainly starts from the HOM extraction structure, firstly analyzes the design of the extraction structure in detail, and then verifies the designed HOM extraction structure through experimental tests.

HIGHER-ORDER MODES DISTRIBUTION

The 166.6 MHz cavity has been designed and verified by experiments [2]. The design of the HOMs extraction structure is developed on the 166.6 MHz resonator cavity which has been verified in the vertical and horizontal test.

The HOM spectrum, essential for the design of a suitable HOM coupler, has already been simulated an test. Fig. 1 is an experimental test 166.6 MHz cavity scene. In the test, the coupler port acts as the stimulus and the pick up port acts as the receiver and the length of the antenna is 100 mm. At the same time, the 166.6 MHz cavity was simulated by CST microwave studio [4].

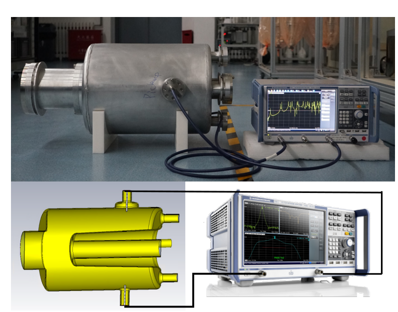

Figure 1: 166.6 MHz PoP cavity test.

Through the test and simulation, the transmission curve, S21, corresponding to the resonant cavity within 1 GHz is obtained, as shown in Fig. 2. In the figure, the red solid line is the simulation result, the black dotted line is the experimental

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test data, and the blue dotted line is the 800 MHz boundary line. It can be seen from the figure that the simulation results are consistent with the spectral distribution in the test results.

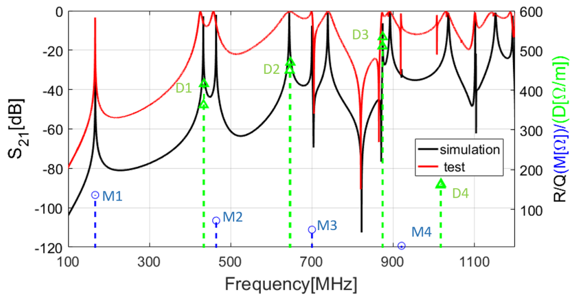

Figure 2: S21 for 166.6 MHz PoP cavity.

By analyzing the cavity transmission curve S21, the fundamental mode and the HOMs spectrum distribution can be clearly known, and the consistency between the test model and the simulation model can be confirmed. And each HOM electromagnetic field distribution has been analyzed and the impedance threshold corresponding to each HOM is given in paper [3]. Each resonant mode and impedance threshold are in the Table 1. Where M1 is the working mode, M stands for monopole, D stands for dipole. The 166.6 MHz cavity will be superconducting, with $Q_0 > 10^9$. In HOMs attenuation system, the loss of the fundamental mode at the port is lower than the loss of the inner wall of the SC cavity. This requires Q_{ext} to be greater than 10^9.

Table 1: RF Result for the 166.6 MHz Cavity

Mode	Freq. [MHz]	R/Q [Ω]	$Z_{\parallel}^{th}$ [Ω]	Q_{ext}^{th}
M1	166.6	136		$1.0E+09$
M2	464.5	71.8	$8.5E+04$	$1.3E+03$
M3	700.3	49.1	$5.6E+04$	$1.5E+03$
M4	920.8	8.4	$4.3E+04$	$1.1E+04$
Mode	Freq.[MHz]	R/Q [Ω/m]	$Z_{x,y}^{th}$ [Ω/m]	Q_{ext}^{th}
D1x	433.3	363	$5.3E+05$	$2.9E+03$
D1y	434.4	416	$3.0E+05$	$1.4E+03$
D2x	645.3	450	$5.3E+05$	$2.4E+03$
D2y	647.1	470	$3.0E+05$	$1.3E+03$
D3x	873.9	511	$5.3E+05$	$2.1E+03$
D3y	874.4	534	$3.0E+05$	$1.1E+03$

For HOMs distribution and impedance threshold requirements, there is a detailed analysis in paper [3], this paper will be directly used as a design indicator for designing HOMs extraction systems.

HOMS EXTRACTION STRUCTURE

The design of the HOMs extraction structure aims to: provide minimal transmission at the operating mode frequency while good transmission at the HOM frequencies. [5]

At first, considering an enlarged tube: the tube itself is a high-pass filter. As long as the tube can extract M2 and D1, the structure can extract all other HOMs. However, the radius of the tube needs to be 260 mm which will bring serious static heat leakage [6]. Considering the leakage heat of the beam tube and the HOMs extraction design, an enlarged beam tube with a diameter of 300 mm is used to extract the HOMs which higher than its cut-off frequency. And the HOMs which below the cut-off frequency of the enlarged beam are taken up by other means.

Secondly, the HOMs is extracted by inserting a coaxial structure on the enlarged beam tube as shown in paper [6]. The HOM coupler is taken out by the coaxial structure: under the condition that the HOMs are taken out, the fundamental mode is severely extracted; the inner conductor of the coaxial extends into the beam tube too long, which seriously affects the beam stability.

Finally, the petal structure is used as the high-order modes extraction structure. As shown in Fig. 3, a coaxial structure is attached to the petals, and the other two petal structures are welded directly to the inner wall of the enlarged beam tube which reduced the number of HOM couplers while meeting RF requirements. And the result is shown in Table 2: Only a HOM coupler is needed to complete the design goal.

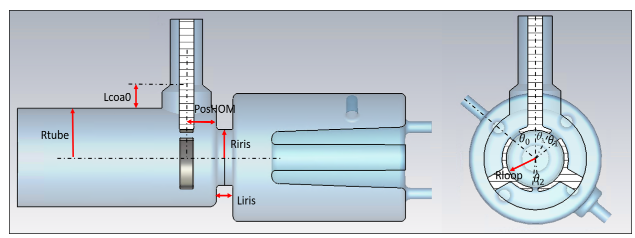

Figure 3: The petal(3) HOM coupler.

Table 2: RF Result for the 166.6MHz Cavity with PEtal(3) HOM Coupler

Mode	Freq. [MHz]	R/Q [Ω]	Q_{ext}
M1	166.8	136	2.6E+05
M2	463.5	88	1052
M3	698.6	33.5	892
M4	921.7	4.5	446
Mode	Freq.[MHz]	R/Q [Ω/m]	Q_{ext}
D1.1	431.9	210	786
D1.2	432.9	449	806
D2.1	642.3	525	456
D2.2	647.3	307	153
D3.1	867.3	142	284
D3.2	869.9	124	232

And the result are shown in Fig. 4 and Fig. 5. In the Fig. 4, the red ball is the result of the enlarged tube structure and the black ball stand for the patal structure. The harmful high-order modes are successfully extracted.

HOMS TEST

In order to better use the existing 166.6 MHz cavity platform, in the processing of the HOM extraction structure,

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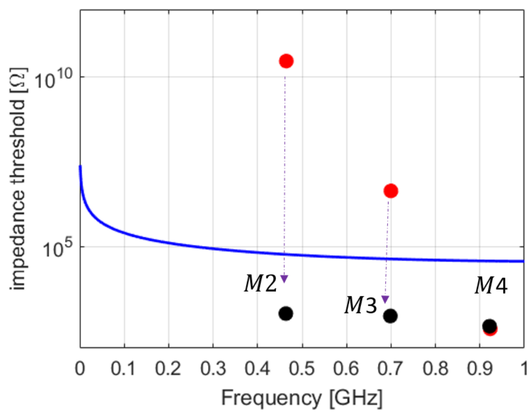

Figure 4: The impedance threshold of the monopole mode.

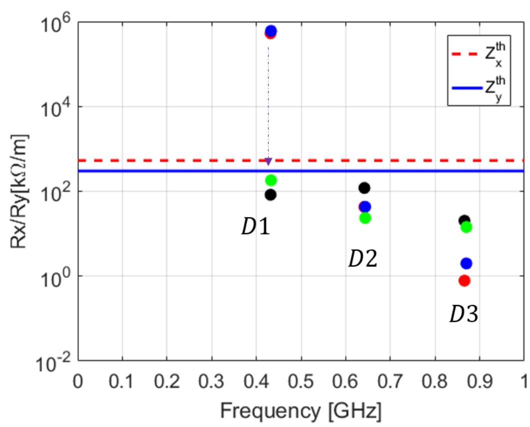

Figure 5: The impedance threshold of the dipole mode.

some parameters are appropriately changed for experimental application.

The HOMs characteristics were measured using a network analyzer. By setting the main coupler port as the excitation port and the HOM port as the receiving port, the transmission curve S21 and the coupler ports Q_{ext} and Q_{load} are measured.

Port Selection

When the HOM coupler acts as a receiving port, it may cause some HOMs to be ignored due to the HOM coupler suppression. Therefore, the modes distribution can be analyzed by comparing the pick up port as an accepting port, which is shown in Fig. 6.

As shown in Fig. 7, the main coupler is the excitation port, the pick-up and the HOM coupler are the receiving ports. The resonance mode is analyzed by comparing the S21 and S31 transmission curves. Among them, S21 is the transmission curve of the pick-up port as the receiving port; S31 is the transmission curve of the HOM coupler as the receiving port.

In Fig. 7, the red line stand for S31 and the black line stand for S21. Comparing the two transmission curves, the signal that the pick up port can receive is also acceptable at

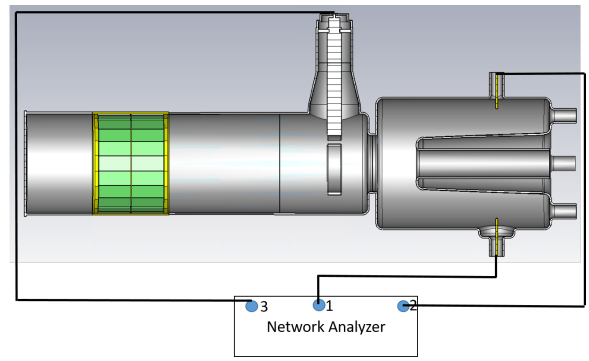

Figure 6: Port selection.

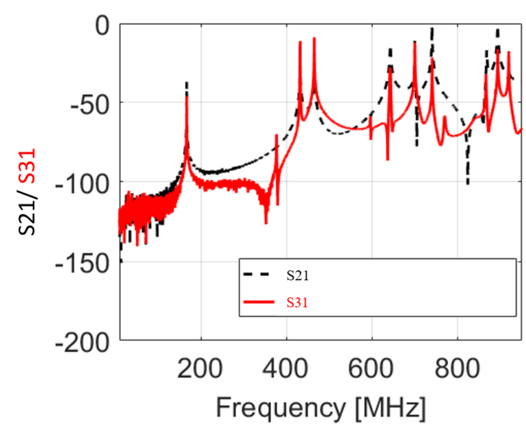

Figure 7: The excitation port test for the petal structure.

the HOM coupler port. And analysis of the S31 transmission curve shows that due to the introduction of the HOM coupler, the new resonance modes are generated. Therefore, in HOMs testing, the HOM coupler port can be used as the accepting port.

The HOM Coupler Test

In the HOMs test, a ferrite material is added to the inner wall of the enlarged tube to absorb the HOMs which transmitted through the enlarged tube. And the other port of the enlarged beam tube is blinded by a blind flange.

Figure 8: The petal structure test.

As shown in Fig 8, the upper part is a schematic diagram of the test model and the location of the damper structure is indicated; the figure below shows the test site. The verifica-

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Table 3: Damper

Mode	$freq.[MHz]$	Q_{ext}		Q_{load}	
		Sim.	Test	Sim.	Test
M1	166.7	8.73E+05	7.38E+05	1.21E+04	1.04E+04
M2	464.0	3.70E+03	5.31E+03	3.17E+03	4.14E+03
M3	698.6	1.00E+04	3.10E+04	2.26e+03	3.49e+03
M4	920.7	4.81E+03	1.10E+04	1.14E+03	2.64E+03
D1	433.1	1.20E+03	4.11E+03	1.14E+03	3.46E+03
D2	644.3	2.63E+03	7.57E+03	4.63E+02	5.00E+02
D3	866.1	1.95E+03	2.66E+03	1.13E+03	1.89E+03

tion of the HOM coupler can be carried out by comparing the results of simulation and test.

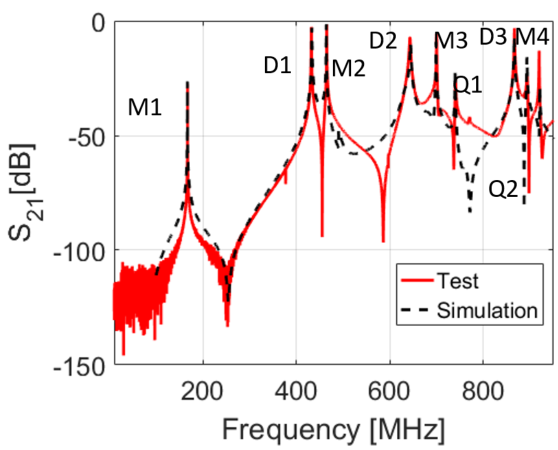

Figure 9: S21 for HOM coupler.

First of all, verify the performance of the HOM coupler by analyzing the S21 transmission characteristics, as shown in Fig. 9. Among them, the red solid line is the test result, and the black dotted line is the simulation result. M stands for monopole, D stands for dipole, and Q stands for quadrupole. Analysis of Fig. 9 shows that the resonant frequency and the suppression depth of the test and simulation are basically the same. However, there is an error in the suppression depth of HOM, M4.

And then, the measurements of HOMs peak frequencies and Q were performed at room temperature. And three methods were used to measure Q_{ext}: the impedance method, reflection method and transmission method [7]. In order to reduce the disturbance of the electromagnetic field in the cavity by the antenna, the coupling coefficient is between 0.1 and 0.2 by adjusting the length of the antenna.

The measured results of Q_{ext} using three methods are shown in Table 3. Comparative analysis test and simulation results: within 1 GHz, the center frequency of the resonant mode is basically the same; except for the D1 mode, the Q_{ext} and Q_{load} errors of other resonant modes are within the allowable range.

SUMMARY

In the paper, for the 166.6 MHz cavity, different HOM extraction structure models are compared, and the optimized structure is designed. Then the processing of the HOM extraction structure is completed and experimentally verified. In the process of processing the structure, in order to fully use the 166.6 MHz cavity platform, some parameters need to be properly corrected. In the experiment, the test port is used to select the excitation port and the receiving port required in the experiment; then, the test results and the simulation results are compared and analyzed to verify the reliability of the design structure; Finally, the absorbing efficiency of the damper structure was verified by experiments. The consistency of experiment and simulation means the feasibility of designing the extraction structure. And there is still a lot of room for improvement based on the verified structure, such as 340 mm for large beam tube radius and so on.

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REFERENCES

[1] G. Xu *et al.*, "Progress of Lattice Design and Physics Studies on the High Energy Photon Source", in *Proc. IPAC'18*, Vancouver, Canada, Apr.-May 2018, pp. 1375–1378. doi:10.18429/JACoW-IPAC2018-TUPMF052

[2] P. Zhang (et al.,"A 166.6 MHz superconducting rf system for the heps storage ring", in *J. Phys. Conf. Ser.*, vol. 874, p. 012091, 2017. doi:10.1088/1742-6596/874/1/012091

[3] X. Hao, Z. Li, F. Meng, P. Zhang, A higher-order mode coupler design for heps 166.6 mhz superconducting accelerating cavities, *Radiat. Detect. Technol. Methods*, no. 3, pages 5, 2019. doi:10.1007/s41605-018-0082-y

[4] Ver. 2017, CST DS SIMULIA, Darmstadt, Ger-CST Microwave Studio, many., www.cst.com, 2017.

[5] K. Papke, F. Gerigk, U. van Rienen, "Comparison of coaxial higher order mode couplers for the CERN Superconducting Proton Linac study", *Phys. Rev. Accel. Beams*, vol. 20

ISBN: 978-3-95450-211-0 doi:10.18429/JACoW-SRF2019-TUP008

p. 060401, 2017. doi:10.1103/PhysRevAccelBeams.20.060401

[6] H. X. Hao, Z. Q. Li, F. Meng, P. Zhang, and X. Y. Zhang, "HOM damping with an enlarged beam tube for HEPS 166.6 MHz SC cavities", in *Proc. SRF'17*, Lanzhou, China, Jul. 2017, pp. 389–392. doi:10.18429/JACoW-SRF2017-TUPB004

[7] Z. Hong-Juan, Z. Ji-Yuan, Z. Tong-Xian, "G. Jie, Homs simulation and measurement results of ihep02 cavity", *Chin. Phys. C*, vol. 39, p. 117006, 2015.