ISBN: 978-3-95450-191-5 doi:10.18429/JACoW-SRF2017-TUPB033

TESTS OF THE HIGH CURRENT SLOTTED SUPERCONDUCTING CAVITY WITH EXTREMELY LOW IMPEDANCE

Zhenchao Liu*, Jie Gao, Feisi He, Song Jin, Zhenghui Mi, TongXian Zhao, Hongjuan Zheng,
IHEP, Beijing, China
Fang Wang, Dehao Zhuang, PKU, Beijing, China

Abstract

Slotted superconducting cavity is a novel structure with extremely low impedance and high BBU threshold. It can be used in various high current applications. A 1.3 GHz 3-cell slotted superconducting cavity was designed and tested. The room temperature test results show the cavity has an extremely low impedance. The vertical test results show the cavity gradient can reach several MV/m, but it was limited by the test end group made of steel.

INTRODUCTION

Various methods are adopted to efficiently damp the HOMs of the cavity in order to increase the Beam Break-Up (BBU) threshold of the cavity and reach the desired current intensity. Since the circular collider needs to deliver a bunch with a large number of electrons or positrons, the HOMs power in the cavity can reach several kW. Both the ERL and the circular collider require superconducting cavities with heavy HOM damping and efficient HOM extracting. We have proposed a high HOM damping cavity which can fulfil such an application. Ampere class BBU threshold can be achieved for the slotted cavity as the external Q of the HOMs is extremely low. The power of HOMs can be efficiently extracted from the cavity by means of a waveguide which runs around the cavity body. To demonstrate this idea, we have built a 1.3 GHz 3-cell slotted cavity.

In order to deliver a high current beam, these cavities are designed according to the following principles: low cell numbers, large iris and large beam pipe, optimized cell shape, efficient HOMs damping and extracting structure. The common objective of all these designs can be found in the need to increase the HOMs damping.

Compared with the ERL application, the superconducting cavity used in the circular collider delivers a lower beam current; however, the HOMs power of the cavity is much higher than the ones used in the ERL since the charge of each bunch is very large. A low impedance superconducting cavity with high HOM extracting efficiency constitutes a key goal for both the ERL and the circular collider.

BBU THRESHOLD

The beam current in a cavity is limited by its BBU threshold. For a single high order mode, the BBU threshold is given by [1]

$$I_{th} = \frac{2c^2}{e\left(\frac{R}{Q}\right)_\lambda Q_\lambda \omega_\lambda} \frac{1}{T_{12}^* \sin \omega_\lambda t_r} \quad (1)$$

and

$$T_{12}^* = T_{12} \cos^2 \theta_\lambda + \frac{T_{14} + T_{32}}{2} \sin 2\theta_\lambda + T_{34} \sin^2 \theta_\lambda \quad (2)$$

Here, c is the speed of light, e is the elementary charge, λ is the mode number, $(R/Q)_\lambda$ is the shunt impedance (in Ω), Q_λ is the quality factor, ω_λ is the HOM frequency, θ_λ is the polarization angle with respect to the x direction, t_r is the bunch return time, and the matrix T describes how a transverse momentum is transported to a transverse displacement after one turn.

From equation (1), we know that the BBU threshold is inversely proportional to the cavity intrinsic parameter $(R/Q)_\lambda \cdot Q_\lambda$. Thus, in order to increase the BBU threshold, it is necessary to decrease the impedance item $(R/Q)_\lambda \cdot Q_\lambda$.

The HOMs power of the cavity is $P_{\mathrm{HOM}}=k_{||}IQ$, here $k_{||}$ is the cavity loss factor, I is the average beam current and Q is the quantity of electric charge of one bunch. For the circular collider, the bunch charge is about several nC which results in several kW HOMs power per cavity. For the ERL application, the HOMs power per cavity is about 1 kW or less.

CAVITY PARAMETERS

The slotted cavity was put three waveguide wings 120 degree separated around the cavity body to absorb the high order mode of the cavity. This structure shows extremely high damping of dipole and quadrupole modes which can give an ampere class beam current [2]. Table 1 shows the cavity main parameters. Table 2 shows the cavity shape parameters.

Table 1: Parameters of the 1.3 GHz Slotted Superconducting Cavity

Type	**Elliptical**
Operating frequency (MHz)	1300
Working gradient(MV/m)	15
Q_0	1×10^{10}
Beta	1
No. of cell	3
Dia. of iris (mm)	41.152
Dia. of beampipe (mm)	48.733
R/Q (Ω)	268.9
G (Ω)	265
E_{pk}/E_{acc}	3.57
B_{pk}/E_{acc} (mT/(MV/m))	5.72
Field flatness (%)	>97

---

* email address: zcliu@ihep.ac.cn

Table 2: Shape Parameters of the 1.3 GHz Superconducting Cavity Cell

Parameters	**Center Cell**	**End Cell**
L_{cell} (cm)	57.7	57.7
R_{iris} (cm)	41.152	48.733
$R_{equator}$(cm)	103.899	103.899
A(cm)	37.904	35.434
B(cm)	23.825	23.55
a(cm)	10.83	16.786
b(cm)	16.244	16.244

ROOM TEMPERATURE RF TEST

The slotted cavity was fabricated with three slots connected with three short waveguides. The HOMs can be extracted from these ports at different coupling angles. For the monopole mode, the cut-off frequency mainly depends on the length of the short edge of the waveguide, since the lowest mode excited in the waveguide is the TM_{11} mode. For the dipole and quadrupole modes, the cut-off frequency depends on the length of the long edge of the waveguide, since the lowest mode excited in the waveguide is the TE_{01} mode. If the polarization direction matches the waveguide, the TM_{11} mode is selected as the dipole mode. The TE_{01} mode can only be excited when there is an angle between the waveguide and the mode polarization direction. The waveguide cut-off frequency for monopole modes of this cavity is 13.636 GHz, and the cut-off frequency for dipole and quadrupole modes is 298.7 MHz. Therefore, all the dipole and quadrupole modes of the cavity can be extracted from these waveguide ports. The monopole modes below the slot waveguide cut-off frequency can be extracted from the beam pipe waveguide port which was not fabricated on the prototype cavity. Since there is no polarization angle for the monopole mode, the presence of one waveguide on each beam pipe is sufficient. To investigate the HOMs extraction effect from the waveguide, we have measured the external Q of the HOMs in two conditions, i.e. with and without aluminium covers in the waveguide port w/wo. Figure 1 shows the measurement scheme.

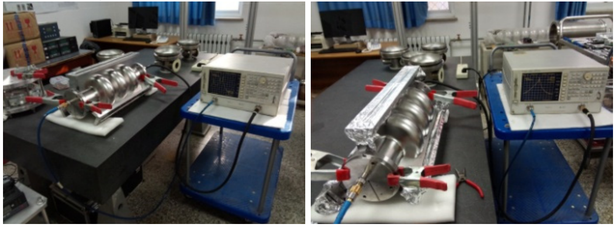

Figure 1: Measurement of the external Q of the HOMs at two conditions, waveguide port with and without covers. Left: without covers, Right: with covers.

$$\frac{1}{Q_L} = \frac{1}{Q_0} + \frac{1}{Q_e} + \frac{1}{Q_t} \tag{3}$$

Here, the Q_L is the loaded Q of the cavity, Q_e is the external Q of the waveguide port and Q_t is the Q of pick up. When Q_t >>Q_0 and Q_0>>Q_e, one can consider the $Q_L≈Q_e$. Table 3 shows the Q_e of the dangerous dipole HOMs with the three waveguides open.

Table 3: The Most Dangerous Dipole HOMs with the Three Waveguides Open

Frequency (GHz)	**Mode**	**R_T/Q**	**Q_e**
1.597	TE111	15.1	5.59
1.599	TE111	7.51	2.17
1.833	TM010	47.9	50.1
1.855	TM010	2.72	446
1.869	TM010	40.85	2.96

VERTICAL TEST

The cavity was tested at 4.2K first. The cavity has no hard multipacting barriers. However, the gradient is limited by the RF power. The gradient of the cavity reached 2.4 MV/m at 4.2 K with a Q_0 of $1.4x10^8$ limited by power. Fig. 2 shows the 1.3 GHz slotted cavity prepared for vertical test. The π mode frequency of the cavity at room temperature was 1.3013 GHz. The frequency changed to 1.30617 GHz after the cavity was pumped to high vacuum. The frequency further increased to 1.30976 GHz when the cavity was cooled down to 4.2 K. The reason for this increase is that there is no strengthening structure on this prototype cavity.

Figure 2: 1.3 GHz slotted cavity prepared for vertical test.

When the cavity was cooled down to 2K, the accelerating gradient can reach 2-4MV/m. However, the cavity Q_L decreased from $1x10^8$ to lower than $1x10^6$ when we increased the forward power. It shows that the forward power was dissipated on the end flange. Simulation shows the beam pipe is too short to keep a Q_e of $1x10^{10}$ for the coupling feed through. Therefore we put the coupling probe in the bellow a little off the flange inner plain. It made the forward power heating the end flange and caused the Q_L drop. To solve this problem, we will extend the end beam pipe with 14cm. In this design, the probe can be put in the beam pipe with enough length to keep a Q_e higher than $1x10^{10}$.

CONCLUSION

The ERL is a system of great interest due to its capability of delivering high average current beam which can be used for beam cooling and for the development of high brightness free electron lasers. To deliver an ampere class beam current, a new HOM damping method was proposed. We presented the development of the slotted cavity with an extremely high damping of HOMs. The cavity fulfills the requirements imposed by ERL. The 1.3 GHz 3-cell prototype cavity has been tested. The testing results show a great potential in the high current and high HOM damping application such as ERL and Circular collider.

ACKNOWLEDGEMENT

This work is supported by National Natural Science Foundation of China (Project 11275226).

REFERENCES

[1] G. Hoffstaetter, I. Bazarov, and C. Song, *Phys. Rev. ST Accel. Beams* **10**, 044401 (2007).

[2] Z. Liu and A. Nassiri, “Novel Superconducting rf Structure for Ampere-Class Beam Current for Multi-GeV Energy Recovery Linacs”, *Phys. Rev. ST Accel. Beams* **13**, 012001 (2010).