NEW WAY TO ACCELERATING HIGH CURRENT BEAM IN ERL*

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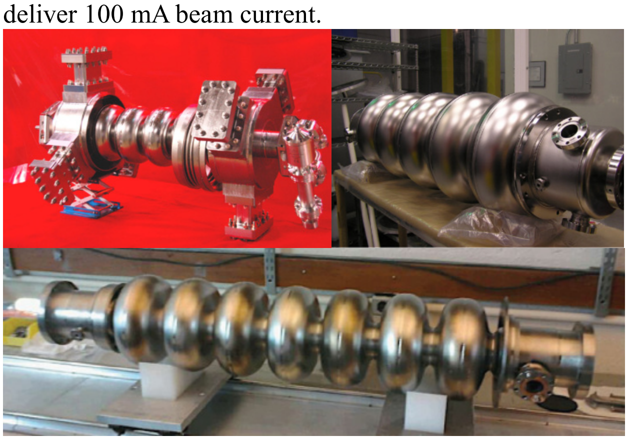
Abstract

High beam current is available for the Energy Recovery Linac (ERL). Different methods are adopted to increase the BBU threshold of the cavity to deliver hundreds of milliampere beam current. The key is to absorbing HOMs more efficiently. The BBU threshold of the slotted cavity is much higher than other high current cavities. However, new tuning method is needed and multipacting should be checked. Here we will present a new way to accelerating the high current beam by a highly HOMs damped cavity, the slotted cavity including the tuning method.

INTRODUCTION

In the past 10 years, high current superconducting cavity is developed worldwide. It was designed for the use of ERL, eRHIC, ADS etc.. Various cavity shapes and various HOMs damping methods were developed. A 5-cell superconducting cavity with waveguide HOMs absorber was designed at JLab and several prototypes were fabricated. The cavity reached 22 MV/m and is able to deliver 100 mA beam current [1]. Cornell University has developed a high current cavity for the 5 GeV ERL [2, 3]. A 7-cell superconducting cavity was designed and tested. The cavity was designed in several types with slightly changed cell shapes which can obviously increase the cavity BBU threshold from 100 mA to 450 mA. BNL has developed several types of high current cavity. Now a 5-cell 50 mA superconducting cavity (BNL3) was designed and fabricated [4, 5]. It can deliver 50 mA beam for eRHIC and 300 mA beam for ERL. KEK has developed a 1.3 GHz 9-cell cavity with flute structure to deliver 100 mA beam current for ERL use [6]. The cavity reached 25 MV/m. ANL and PKU has developed a 1.3 GHz 5-cell superconducting cavity in collaboration [7]. The cavity is for the APS upgrade pre-research and can deliver 100 mA beam current.



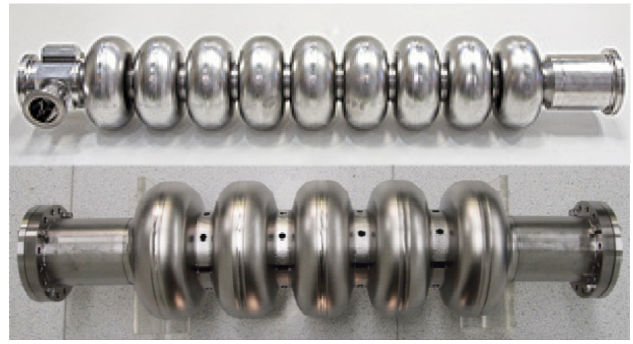


Figure 1: High current cavities around the world. From left to right and top to botom: Jlab, BNL, Cornell universiy, KEK, ANL&PKU [1-7].

To deliver high current beam, cavity is designed following such principles: low cell numbers, large iris and large beam pipe, optimized shape, efficient HOMs damping. Actually, the aim of all these designs is to increase the HOMs' damping.

HOMS DAMPING

The beam current that a cavity can deliver is limited by the BBU threshold of the cavity. For a single high-order mode, the BBU threshold is [8]

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

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 units of Ω), Q_λ is the quality factor, ω_λ is the HOM frequency, θ_λ is the polarization angle from 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.

Form equation (1), we know that the BBU threshold is inversely proportional to the cavity intrinsic parameter $(R/Q)_\lambda{\cdot}Q_\lambda$. The main focus to increase the BBU threshold is to decrease the impedance item $(R/Q)_\lambda{\cdot}Q_\lambda$.

In 1990, Y. Chen, D. Proch, and J. Sekutowicz experimentally investigated a broadband damping of monopole, dipole, and quadrupole modes by implementing small longitudinal slots near the equatorial region of a single-cell copper cavity [9]. And In 2010 Z. Liu and A. Nassiri proposed a novel rf structure for high current beam transportation [10] (Fig. 2). The structure

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shows extremely high damping of dipole and quadrupole modes which can give an ampere class beam current.

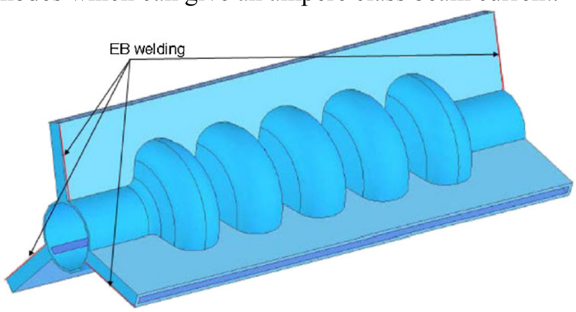

Figure 2: 5-cell slotted cavity [10].

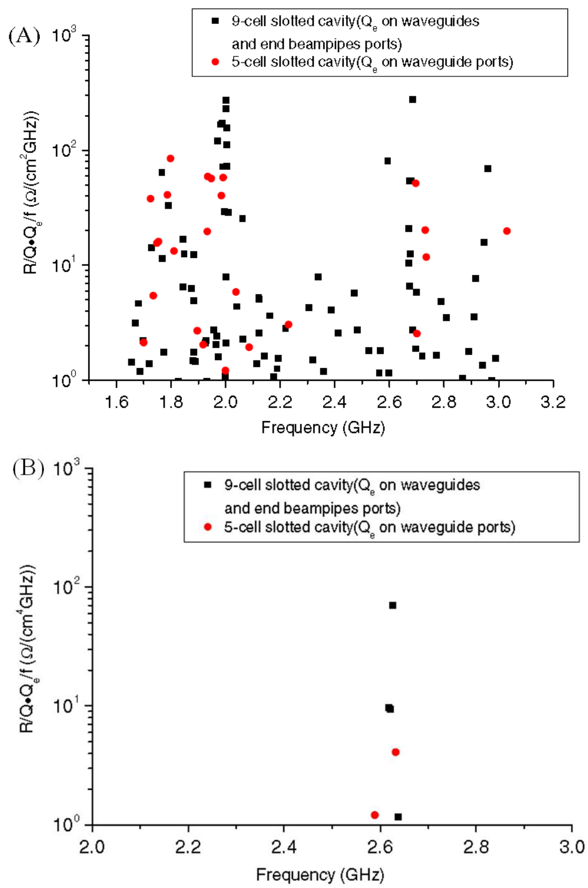

Figure 3: The impedance of dipole (A) and quadrupole (B) modes of 9-cell and 5-cell slotted cavity [10].

PROTOTYPE CAVITY DESIGN

To verify the physical design and develop related technology, we started the design of a 1.3 GHz 3-cell prototype cavity. The 1.3 GHz superconducting slotted cavity is used to accelerate electron bunches with a current above 100 mA. To accelerate 100 mA CW electron bunches, we need to follow these principles in the cavity design:

1) Proper cell numbers. For the test cavity, we chose a 3-cell cavity to simplify the fabrication and lower the cost.
2) Minimize E_{pk}/E_{acc} and B_{pk}/E_{acc}.
3) No hard multipacting barrier caused by cavity shape and the slotted structure.
4) Frequency can be easily tuned.
5) Easy to fabricate.

A 1.3 GHz slotted superconducting cavity prototype was studied and designed using CST-MWS [11]. The cavity parameters are shown in Table 1. And the cell shape parameters are shown in Table 2.

Table 1. The 1.3GHz slotted superconducting cavity parameters.

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
R/Q (Ω)	268.9
E_{pk}/E_{acc}	3.57
B_{pk}/E_{acc} (mT/(MV/m))	5.72
Field flatness (%)	>97

Table 2. The 1.3GHz superconducting cavity cell shape parameters.

Parameters	Center cell	End cell
L (cm)	57.7	57.7
R_{iris} (cm)	41.152	48.733
Requator(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

TUNING METHOD

The cavity can not be tuned the same as conventional elliptical cavity. There are six niobium walls longitudinally around the cavity. It is difficult to pull and squeeze the cavity to change the frequency. However, as there are slots at the cavity wall, we can use perturbation method to tune the cavity frequency. One slot of the cavity should be used for perturbation and the others should be connected to HOMs damping waveguide. Sticks should be put in each cell at the equator part. The cavity frequency can be tuned by moving the stick in and out. Fig. 4 shows the slotted cavity with perturbation stick. As the stick was put into the cavity with high magnetic

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field and electric field, the stick shape should be properly chosen to avoid E_{pk}/E_{acc} and B_{pk}/E_{acc} increasing and multipacting. And the stick size should be properly chosen to make enough tuning range.

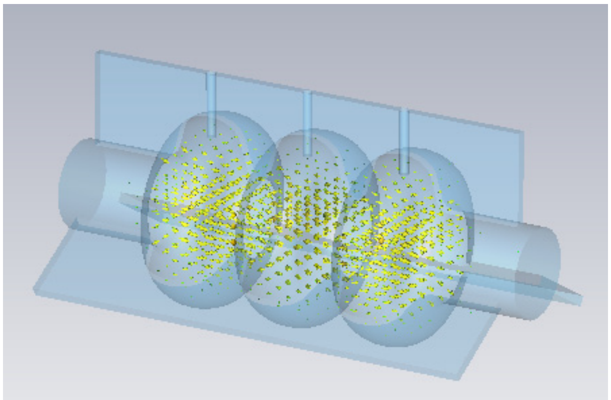

Figure 4: Cavity perturbation method.

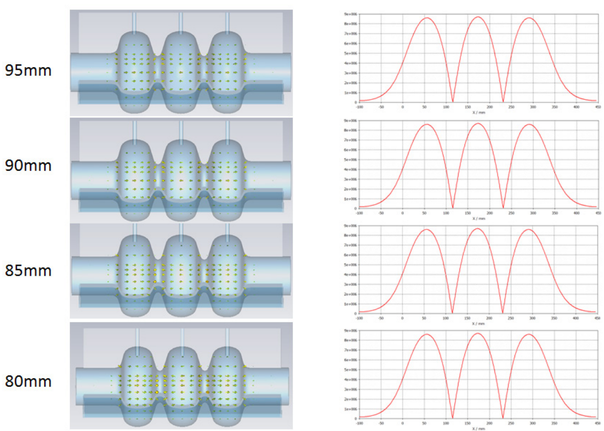

Figure 5: Field flatness of the cavity with different stick off axis distance (r=5mm stick).

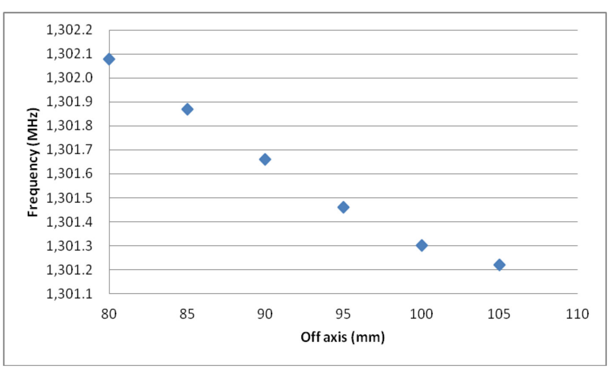

Figure 6: Frequency tuning range of the cavity (r=5mm stick).

The field flatness tuning is also a problem for this cavity. We need to find ways to pre-tune the cavity field to flat as the r=5mm stick can only tune about 7% field flatness. Otherwise, larger sticks should be used to tune the field flatness. Simulation shows that 50% field flatness can be tuned to about 100%.

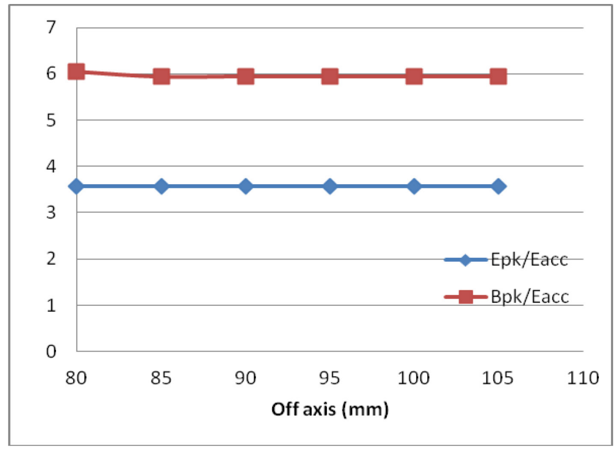

Figure 7: E_{pk}/E_{acc} and B_{pk}/E_{acc} versus sticks position.

MULTIPACTING

To achieve high accelerating gradient, one needs to eliminate the hard multipacting barrier in the cavity. Track3P [12] is used to simulate the multipacting phenomenon in cavity.

The criterion of multipacting event is that the particle resonant trajectories have successive impact energies within the right range for secondary emission yield (SEY) bigger than unity. Fig. 8 shows the SEY of normal niobium.

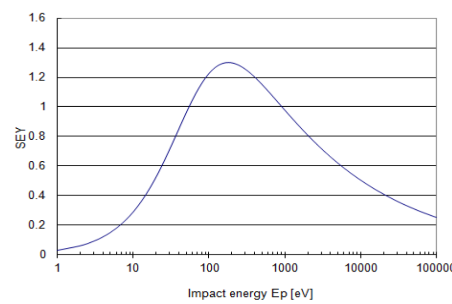

Figure 8: SEY of normal niobium.

We have simulated the multipacting phenomenon of the 1.3GHz slotted cavity without tuning parts from 1MV/m to 20MV/m with an interval of 1MV/m using the whole cavity. The simulation results show that there is no hard multipacting barrier in the cavity (see Fig.9). The multipacting of the slotted cavity with tuning sticks was simulated from 1MV/m to 40MV/m with an interval of 1MV/m using the whole cavity (see Fig. 10). The results show that the tuning parts will cause some resonant trajectories between the tuning sticks and the slot wall. Fig. 10 shows there will be no multipacting around 15MV/m.

FABRICATION

The deep drawing of the cell shape part is a difficult job. For the prototype cavity, we will deep draw each half-cell and then weld them together to form the cell shape part. We will fabricate the cavity sector as shown in Fig. 11. Firstly, weld the cell shape part and cut the slot wall; secondly, electron beam weld the cell shape part and the wall together to form a sector; then weld three sectors together to form a cavity.

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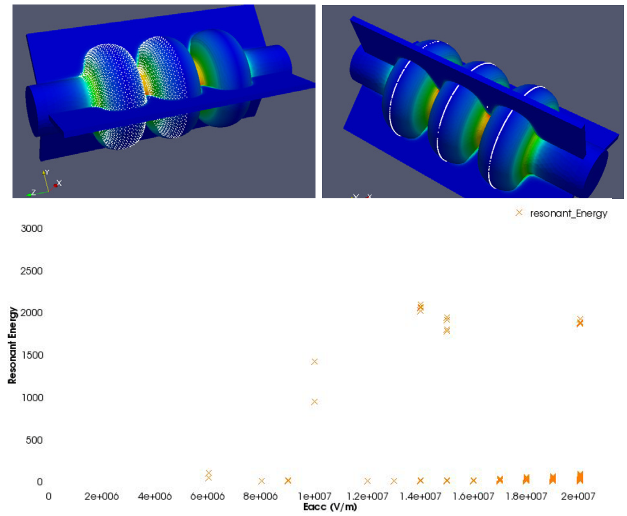

Figure 9: The initial emitting points in the cavity (up left) and the resonant points (up right). The impact energy versus E_{acc} of the 1.3GHz slotted cavity (down).

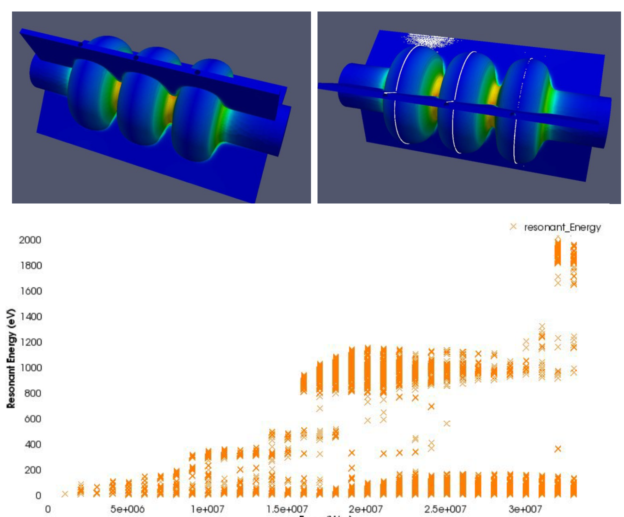

Figure 10: The cavity with one type of tuner (up left) and the resonant points (up right). The impact energy versus E_{acc} of the 1.3GHz slotted cavity (down).

SUMMARY

The benefit of ERL is delivering high average current beam for the use of beam cooling and high brightness free electron laser. Various high current cavities were designed for delivering 100 mA beam current for ERL. To deliver ampere class beam current, a new method was proposed. We are developing the slotted cavity which has extremely high damping of HOMs. The cavity fulfills the need of ERL. Now the 1.3 GHz prototype cavity has been designed. The cavity will be fabricated and tested in the future.

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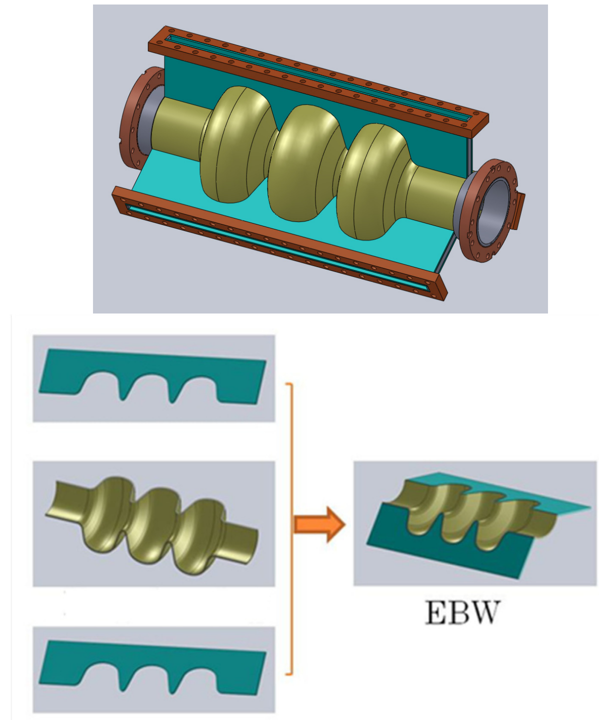

Figure 11: The mechanical structure of the slotted cavity (up) and the fabrication method (down).

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