

THE NEW DESIGN FOR CAPTURE CAVITY OF CEBAF*

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Abstract

In CEBAF, the electron beam from the injector must be sufficiently relativistic to match a 1 GeV recirculated beam in the first linac. The electron beam is produced with a — 130 keV electron gun, then accelerated by a room temperature, graded-beta standing wave linac, capture section, from 130 keV to 510 keV before enters two 5-cell superconducting RF cavities for further acceleration. Present capture cavity is a 5-cell side-coupled cavity. We designed a new slot-coupled cavity which has lower power consumption and more compact size.

INTRODUCTION

At the beginning of CEBAF, electrons are produced from 130 keV gun, and bunched before enter the capture cavity [1]. The SRF cavity after capture cavity has an aperture that is 7 cm in diameter. Because of this large aperture, the electric field extends well beyond the entrance of the first cell. Combined with the low energy of 130 keV, it is hard to efficiently capture the electrons directly by the SRF cavity. So a side-coupled five-cell capture cavity is added before SRF cavity to accelerate electron to 510 keV. In the old design of capture cavity, the cavity is copied from microtron design [2]. It is powered by two 5 kW klystrons in parallel. The cell length of capture cavity is optimized to obtain the desired electron beam properties. A new capture cavity is needed, so we designed a slot-coupled cavity to lower the power consumption, size and engineering cost.

THE OLD DESIGN OF THE CAPTURE CAVITY

The old design is a five-cell side-coupling standing wave cavity, made of copper, operate at room temperature, see Figure 1. It is operated in CW mode. The fundamental RF frequency is 1497 MHz. The cavity length is 0.4 m. When passing through the cavity, electron's energy increases from 130 keV to 510 keV. The relativistic velocity β is increased from 0.6 to 0.87. In order to accommodate the varying β and improve the capture and acceleration efficiency, the length of each cell is optimized with PARMELA simulation [3]. In order to compare the old and new design, we rebuilt the cavity model for the old design and measured the frequencies of the nine passband modes of the cavity. The simulation is done with SLAC's

ACE3P code [4]. The comparison result is shown in Figure 2. Because of the existing of 4 coupling cells in addition to 5 accelerating cells, there nine modes in the passband. The accelerating mode is the $\beta/2$ mode at the middle of the passband. Since electrons only fly through the five acceleration cells, what electrons see is an effective π mode.



Figure 1: The old capture cavity and its simulation model.

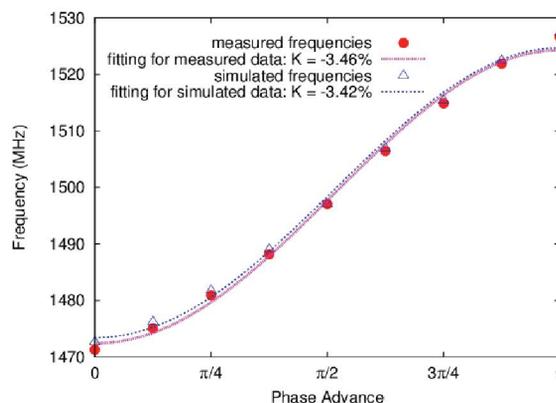


Figure 2: Passband frequencies and cell coupling factors for measured and simulated data.

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THE NEW DESIGN OF THE CAPTURE CAVITY

Slot Coupling

In order to minimize the transverse dimension of the cavity, we adopted slot coupling instead of using side coupling cells. From the viewpoint of electromagnetic field inside the cavity, some form of coupling is needed for electromagnetic energy transportation between cells and create a π mode accelerating field. Three kidney-shaped slots are positioned in the wall between cells, see Figure 3. Because of the existence of the slots in the wall, the radial-directed wall boundary currents of electromagnetic field's fundamental mode are limited in much narrower passages between slots. The maximum B field occurs at the end edges of slots, and so does the highest power density of wall loss, which limits the highest input RF power and defines the cooling requirements. The number of slots in one cell-to-cell wall and slot width, lengths are optimized to find balance between wall loss power density and effective coupling. The dimension of slots is also related to the vacuum design. The vacuum port is at the end of the cavity. To get good pumping results, slots' size must be large enough because the centre beam pipe's radius is relatively small. The total transection area of slots in the new design is comparable with that of coupling holes in the old design.

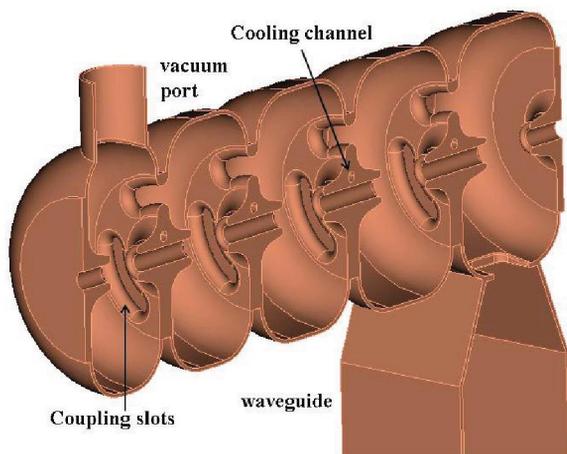


Figure 3: The new design of the slot-coupled cavity.

Cell Optimization

The cavity is a so called graded- β structure. From the entrance to exit of the cavity, the relativistic velocity β is increased from 0.6 to 0.87. In order to accommodate the varying β and improve the capture and acceleration efficiency, the lengths of cells increase as β increases.

In order to simplify the engineering difficulties and cost, each cell is designed with same basic geometry feature, see Figure 4. The centre equator strip is flat. The width of this strip is different for each cell, so the cell length is varied without varying cell side wall structure, including

coupling slots. All acceleration gap cone have same angle α , as shown in right graph in Figure 4. After equator strip width is changed for desired cell length, the cone tip extension is adjusted so that the acceleration gap length is changed and the natural resonance frequency of the cell is 1497 MHz. The cell side wall is straight and accommodates the coupling slots. In this way, all cells have same geometry for the side wall and acceleration gap cone. Only equator strip width and cone tip extension needs minor adjustment for each individual cell. This design will drop the cost significantly.

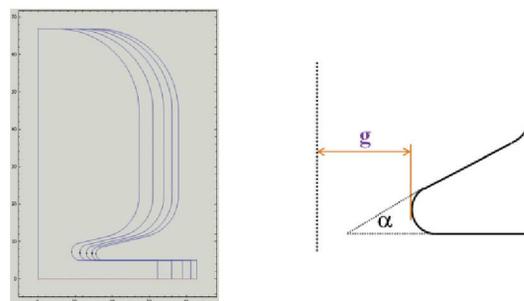


Figure 4: Cell geometry optimization.

With SLAC's code OMEGA3P [4], the Eigen mode of each cell is calculated separately with magnetic boundary condition. Each cell is tuned with above mentioned method to have a frequency of 1497 MHz, so the full cavity will have 1497 MHz for its n mode. For the first and final cell, a vacuum port and wave guide is also added respectively. The five passband modes are obtained and coupling factor is obtained through fitting curve, see Figure 5.

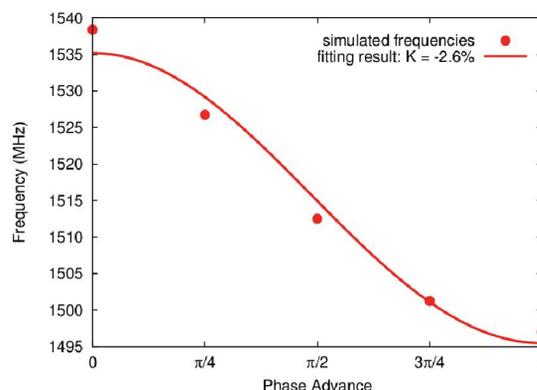


Figure 5: Passband frequencies and cell coupling factors for simulated data of new design.

After full cavity model is obtained, the peak gradient is tuned to be ~ 3 MV/m. 3D electromagnetic field data near beam pipe axis is extracted from the OMEGA3P output and fed to PARMELA [3] input file. Electron acceleration result is then obtained and shown in Figure 6.

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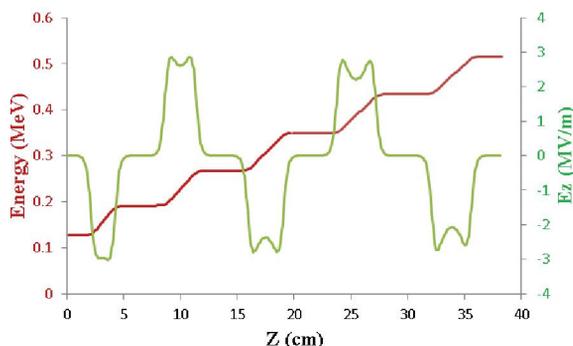


Figure 6: Cavity gradient and PARMELA simulation result.

Cooling

The highest wall loss power density occurs at the ends of coupling slots. The wall power loss limits the maximum input RF power and electric field gradient on beam axis. For CW operation at 3 MV/m gradient, the highest wall loss power density is about 50 W/cm². So cooling channels are added. The wall between cells has a width of 1 cm, cooling channel can be drilled between the slots as shown in Figure 7.

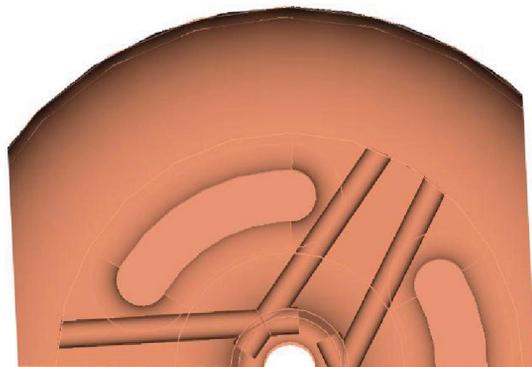


Figure 7: Cooling channel between slots in the cell-to-cell wall.

With the help of TEM3P [4], we performed an initial thermal simulation with 3 MV/m gradient and cooling channel, the result is shown in Figure 8. The highest temperature is 61 degrees with environmental temperature of 25 degrees.

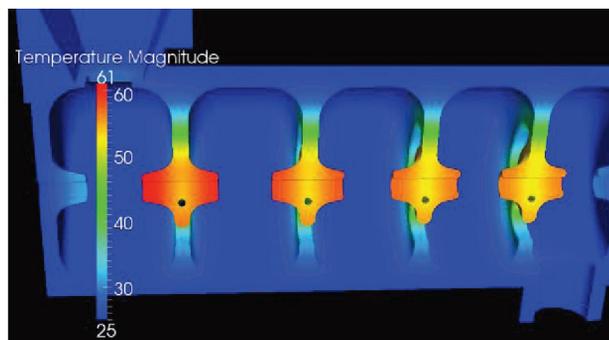


Figure 8: TEM3P thermal simulation with 3 MV/m gradient and cooling channels.

Compare the Old and New Design

The bounding box of the transverse dimension of old design is 14.3x30 cm², while the new design has bounding box of 13.4x13.4 cm² for the acceleration structure.

The unit shunt impedance of the new design is 22.2 MΩ/m which is higher than that of old design 18.8 MΩ/m.

To get a peak electric gradient of 3 MV/m, 7 kW RF power is required, which is also lower the old design.

CONCLUSION

This is an efficient, low cost and compact design for CW operation. It can be used in more applications with general purposes, like medical radiation therapy. A electron gun section could be directly added before the first cell, so a full injector is obtained. At the high energy end of the cavity, another cavity with identical cells can be added to further accelerate $\beta \sim 1$ electrons.

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