FABRICATION AND LOW-POWER TESTING OF AN L-BAND DEFLECTING CAVITY FOR EMITTANCE-EXCHANGE AT ANL

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Abstract

An L-Band RF deflecting cavity has been built at Tsinghua University for a planned transverse-to-longitudinal emittance exchange experiment at Argonne National Laboratory (ANL). The deflector is a 1.3-GHz, 3-cell cavity operated in a TM_{110}-like mode that delivers a deflecting voltage of 3.4 MV. In this paper, we review the cavity design and present detail of the fabrication, cold testing and tuning progress. Cell radii were left undercut to account for simulation errors, which yielded a higher frequency in the first bench measurement but removed by the final tuning on the lathe. Field distribution on axis was measured using the "bead-pull" method and tuned to balance in the 3 cells.

INTRODUCTION

Beam phase space manipulation of transverse to longitudinal emittance exchange can improve the performance of the Free Electron Laser (FEL)[1, 2, 3]. An experiment to test the concept is now under development at the Argonne Wakefield Accelerator (AWA) facility at ANL. The scheme consists of two identical doglegs (including four magnets) and an RF deflecting cavity in between. Based on the requirements of the experiment and the available RF source at the AWA, a 1300MHz, pi-mode, 3 cell deflecting mode cavity has been designed to deliver 3.4-MV deflecting voltage to the 15-MeV flat beam generated by a photo-injector.

The cavity works at TM_{110}-like mode, giving a phase dependent transverse momentum to the particles. When the center of the bunch is arranged to pass through the cavity on zero phase, it gets no deflecting at exit, but the head and tail get deflected in opposite directions. However, inside the zero-phase particle trajectory modes up and down, leaving the particle with an offset at the cavity esit though the net deflection is zero. This offset can be eliminated by adding end cells to a single cavity and carefully adjust the length of the end cells. Based on this idea, a 3-cell cavity with the appropriate end-cell length was designed.

Beginning with a copper cylinder, the disk-loaded structure was fabricated, tested, tuned and brazed step by step. This paper starts by reviewing the deflecting cavity design, and details the fabrication procedure, and presents rf measurement result.

CAVITY DESIGN

Besides the frequency and deflecting voltage, the design goals for the cavity are listed as:

(i) peak electric and magnetic fields not exceeding damage limits when transverse voltage is 3.4 MV (see below),

(ii) use a beam-pipe radius to match the U.S. standard vacuum pipe with $a = 36.5\mathrm{mm}$,

(iii) balanced transverse magnetic field distribution,

(iv) make the bunch center (zero-phase) offset zero at the exit.

We estimated the damage limit at L-band to be: peak E field less than ~100MV/m and peak magnetic fields on wall, H~100 kA/m.

The beam dynamic were simulated by a user written routine for particle tracking in the EM field exported from the eigen-mode solver in CST Microwave Studio. Thus the cavity geometry design was performed by iteratively running the above two codes until the design goals were met. Dimensions that are critical for the beam offset includes the length of end cells and the radii difference between the end cells and the central cell, which determines the relatively field distribution in each cell. These design values as obtained from parameterized simulations, which are listed in Table 1.

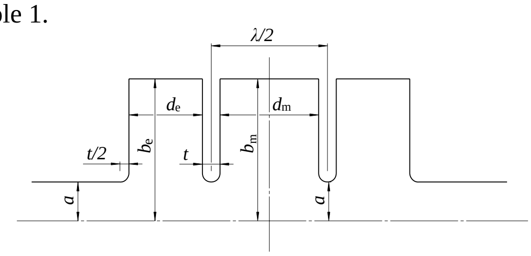

Figure 1: 2D Geometry of the 3-cell deflecting cavity

Also listed in the table are the Qs and $(R/Q)^{\perp}$ of the designed cavity. From these values, the required RF power can be calculated, which is 4.2 MW for 3.4 MV deflecting voltage. Meanwhile, the peak electric field was checked to be 46 MV/m in Microwave Studio, below the RF breaking limit.

A section of "WR650" waveguide was attached to the central cell as power input coupler. The RF coupling uses

Table 1: Parameters of the cavity

Dimensions in mm			
a	36.5	d_e	51.42
b_e	133.52	d_m	94.43
b_m	134.38	t	20.88
		b_m with coupler	133.40

Q_{sim} using copper	2.0×10^4
$Q_{sim} \cdot 85\%$	1.7×10^4
$(R/Q)^{\perp}$ / Ω	165
$R^{\perp}$ using $0.85 \cdot Q$ / MΩ	2.8
P_{in} / MW	4.2
$V_{\perp}$ / MV	3.4
E_{max} / MV/m	46

the standard θ-coupling in a race-track shape. The dimensions of the slot were also designed by parameterized simulation to critical coupling with $Q_0 = Q_{ext}$ using time domain analysis in CST transient solver. On the opposite side of the coupling slot, another slot with exactly the same shape was added for symmetry consideration and as the pump port for vacuum, which connect to pipe and flange in U.S. standard.

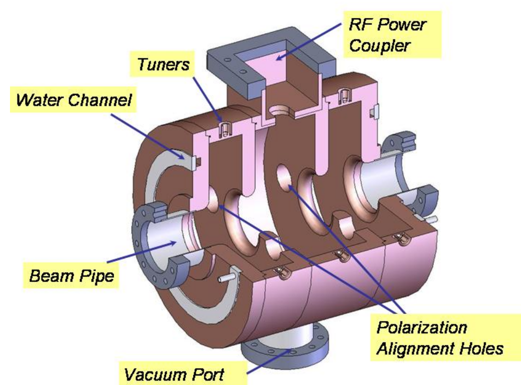

Figure 2: CAD drawing of the 3-cell deflecting cavity

A 3-D CAD model (Figure 2) shows the tuning holes on outside cavity wall. The water cooling channels are covered by stainless steel rings on the two end planes of end cells. Polarization alignment holes are cut on the disks between cells to separated the two degenerate, x- and y-dipole modes.

FABRICATION AND TUNING

The fabrication of the cavity started by machining cylinders of OFE, forged copper in a lathe and a milling machine. The final cut was diamond machined. The stainless steel rings on the end planes and a rectangular waveguide brick were brazed first onto their corresponding cells before bench measurement and tuning.

Frequency and Coupling Tuning

Since this was the first L-Band cavity built on site, we decided to make the first-cut cavity radii 0.2 mm smaller than designed value at first cut to account simulation errors. As expected, the initial frequency was higher, and was tuned after a further cut. The cavity was designed to work at 1300.00 MHz under 38 °C in vacuum., but measurements were made at room temperature in air. So the linear expansion coefficient of copper α and the refractive index of air n were used to estimate the operating frequency.

The designed Q_{ext} was 17700 in CST time domain simulation, but we get about 15% higher in the first measurement, showing that the coupling slot needed to be enlarged. Parameterized simulation indicated that we can increase the slot length by 1.8 mm. The Q_{ext} almost remains unchange within measurement error after this re-cut, during frequency tuning and brazing.

In first test, with the cavity clamped by flanges, we obtained a Q_0 around 13500, which was expected due to the bad RF contact between cells. After final cut for frequency tuning, the Q_0 increases to about 16000. However, while RF contact becomes better after brazing, the tested Q_0 reaches almost 20000, which was not expected since the value is as high as that using perfect copper in simulation. This history for frequency and coupling tuning was presented in Table 2.

Table 2: History of the Q factor and frequency

activity	f / MHz	Q_0	Q_{ext}
simulation	1300.00	17000 [a]	17700
first cut	1300.91	13491	20500
Q_{ext} tuning[b]	– –	13185	16877
frequency tuning[c]	1299.78	15842	16318
brazing	1299.91	19567	16158

[a] $Q_0 \approx 0.85 Q_{sim}$
[b] slot length +1.8mm
[c] radius fine cut

Polarization

Coupling loops were used to excite the modes through beam-pipe. With different loop orientation, the two polarization mode series can be measured separately. The frequencies and loaded Qs are posted on the snapshot of the network analyzer in Figure 3.

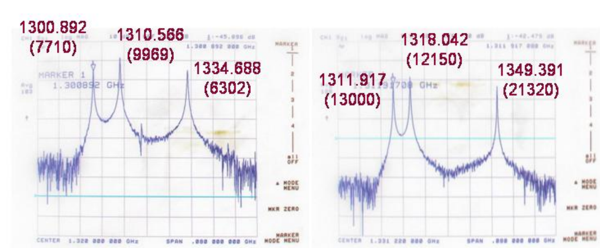

Figure 3: Frequencies (numbers on each peak) and loaded Qs (in parentheses) of both polarization (LEFT: working mode; RIGHT: unwanted mode

The frequency difference between the two polarizations of π-mode is about 11 MHz. This is due to the alignment holes cut through the disks and the coupling slot, which introduce an asymmetry to the cavity. The Q_{load} of these two modes are also different, the orientation of the working mode couples strongly to the power coupler and is heavily effected by the low Q_{ext}. On the other hand, Q_{load} of the non-working mode is approximately equal to Q as unloaded.

Field Flatness

Since the field flatness has a strong effect to the particle trajectory, it must be monitored during the low-power test. A "bead-pull" system was mounted vertically beside the cavity (Figure 4), with a motor controlled by a computer to pull the thread. The bead was 1-cm long and made of copper foil, which is also shown in the up-left corner in the figure.

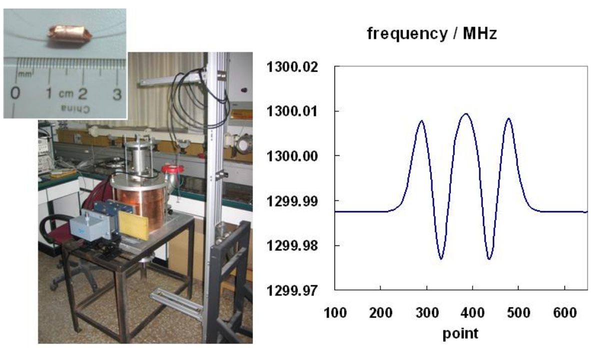

Figure 4: "Bead-pull" system and field distribution

The field distribution depends on the frequency of the individual cells. In general, the closer the frequency of the cell is to the mode frequency, the more energy is stored in it. Moreover, since the frequency of the π mode has the lowest frequency in the dipole band, the lower frequency of a cell makes higher field in it. In summary, the radii can cut to tune for field flatness before brazing.

Thermal deformation during brazing will change the frequency of each cell respectively. After brazing, the measured field was not as flat as before. Therefore they were tuned with push-pull tuning screws on the outside walls. Unfortunately, the tuner range was too small and the field flatness could not be made perfect even after the tuner exceeded the limit. In addition, the frequency is still 100 kHz below target and must be tuned by the working temperature. The final "bead-pull" result is plotted in Figure 4. The ratio of the 3-cells was 0.978:1:0.964, which may cause a 0.1mm orbit offset at exit by simulation.

CONCLUSION

A 3-cell deflecting cavity working at 1.3 GHz for the emittance exchange experiment at ANL was designed with the end cell length of the cavity carefully adjusted to cancel the trajectory offset of the zero-phase particle. The cavity has an outer radius of approximately 320 mm and mass of 100 kg. Six men was hired to lift and move the cavity.

In summary, the overall procedure can be described as follows:

- (i) rough cut and anealing
- (ii) fine cut with 0.5 mm left for deformation in brazing
- (iii) first brazing of cell + waveguide brick, endplane + cooling channel
- (iv) final cut to dimension with radii left 0.2mm for simulation error
- (v) bench test / re-cut tuning of coupling, field flatness and frequency
- (vi) brazing the whole cavity
- (vii) leak check
- (viii) final bench test and tuning by hole

Figure 5: Pictures of different period during fabrication. (1) RAW material, (2) cells, (3) middle cell brazed with waveguide, (4) hole brazed cavity

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REFERENCES

[1] M. Cornacchia and P. Emma, Phys. Rev. ST Accel. Beams 5, 084001 (2002)

[2] K.-J. Kim and A. Sessler, AIP Conference Proceedings, Volume 821, Issue 1, pp. 115-138 (2006)

[3] P. Emma, et.al, Phys. Rev. ST. ACCELERATORS AND BEAMS 9, 100702 (2006)

[4] J. Shi, et al, "Comparison of Measured and Calculated Coupling between a Waveguide and an RF Cavity Using CST Microwave Studio" This proceedings.