ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPRI066

DESIGN OF A 1.3 GHZ TWO-CELL BUNCHER FOR APEX*

H. Qian#, K. Baptiste, J. Doyle, D. Filippetto, S.Kwiatkowski, C.F. Papadopoulos, D. Patino, F. Sannibale, J. Staples, S. Virostek, R. Wells, LBNL, Berkeley, CA 94720, USA

Abstract

The design of a 1.3 GHz buncher cavity for the APEX project, a MHz repetition rate high-brightness photoinjector, is presented. The buncher cavity operates at 240 kV in CW mode, and it compresses the 750 keV beam from APEX gun through ballistic compression. Compared with a single cell design, a two-cell cavity doubles the shunt impedance to 7.8 MΩ, which greatly relaxes the requirements for both RF amplifier and cavity cooling. Coupler design, multipacting analysis, HOM analysis and thermal analysis will be presented in this paper.

INTRODUCTION

The Advanced Photo-injector Experiment (APEX) is for demonstration of MHz repetition rate high brightness electron beam (~300 pC/bunch, ~0.6 mm mrad) injection for the next generation high repetition rate X-ray free electron lasers [1, 2]. The electron beam out of the 186 MHz RF gun is 750 keV and ~60 ps, and it will be compressed by the 1.3 GHz 240 kV buncher cavity to ~10 ps for injection into the 1.3 GHz linac booster. A previous design of APEX buncher was a single cell cavity scaled from ALS harmonic cavity [3], in order to relax RF power and cavity cooling requirement, a two-cell design is proposed [4]. In the following, detailed designs of the new APEX buncher cavity are presented.

CAVITY PROFILE

Due to a lack of beam line space and stay clear requirement of photocathode laser, the cavity flange to flange distance is 21.9 cm, and the minimum beam aperture radius is 2.5 cm. Within these limits, the 2D cavity profile is designed by SUPERFISH code, as shown in Fig. 1. Table 1 gives cavity and beam parameters.

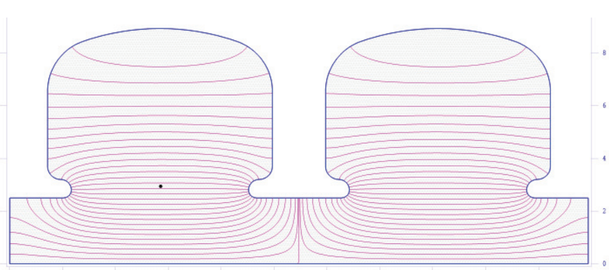

Figure 1: 2D cavity profile in SUPERFISH.

**This work was supported by the Director of the Office of Science of the US Department of Energy under Contract no. DEAC02-05CH11231
#hqian@lbl.gov

Table 1: Beam and Buncher Cavity Parameters*

	Units	Values
Beam energy	keV	750
Beam current	mA	0.3
Mode separation	MHz	0.88
PI mode frequency	MHz	1300
PI mode Q_0		2.35×10^4
Shunt impedance	MΩ	7.8
Nominal cavity voltage	kV	240
Dissipating power	kW	7.4
Peak surface electric field	MV/m	4.7
Peak surface power density	W/cm^2	5.8

* Parameters are calculated assuming 45 C wall temp.

Compared with a single cell design, the cavity power dissipation decreased from 15 kW to 7.4 kW, so the cavity can be powered by a 10 kW solid state amplifier, and both the RF source cost and the thermal power density are reduced.

COAXIAL INPUT COUPLER

The optimization of shunt impedance results in a weak intra-cell coupling and small mode separation. To avoid mode mixing, the two cells are excited independently by coax loop couplers, and the coax loops are mirrored between the two cells to create a 180 degree phase shift. Besides, dual RF feed and dummy ports perpendicular to the input couplers are employed to minimize dipole and quadrupole kicks. RF pickup and vacuum pumping are at the dummy ports.

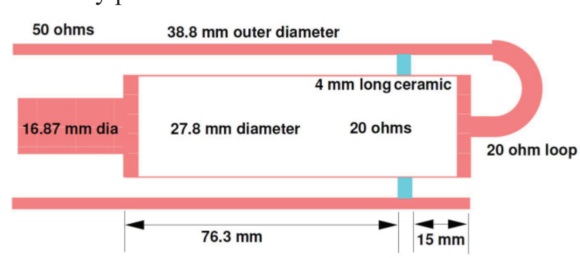

Figure 2: Schematic drawing of 1.3 GHz input coupler.

A high vacuum coaxial RF window product at this power and frequency range seems not available commercially. A low impedance resonant type coax RF window is proposed and one prototype is under fabrication [5], shown in Fig. 2. A large diameter thin-wall copper center conductor through the ceramic window

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPRI066

would mitigate the problem of the differences of the thermal expansion of copper and ceramic, which tends to separate the braze joint upon cooling after braze. Proper length selections of ceramic window and 20 Ω coax line will match impedance back to 50 Ω. RF losses on the vacuum coax line and ceramic window are evaluated to be ~0.2 W and ~1 mW, so no water cooling is required.

HIGH ORDER MODES

Beam induced longitudinal and transvers high order modes (HOM) may degrade the beam quality, thus are simulated by Eigen solvers of CST Microwave Studio. Single bunch induced HOM cavity voltage is calculated by Eq. (1) and (2), and periodic bunch train induced steady state HOM cavity voltage is calculated by Eq. (3) and (4) [6, 7],

$$V_{//}(t) = 2k_{//}^{loss} q e^{-t/\tau} \cos\omega_0 t \, . \qquad (1)$$

$$V_{\perp}(t) = 2k_{\perp}^{loss} q k x e^{-t/\tau} \sin\omega_0 t \, . \qquad (2)$$

$$V_{//}^{s}(t) = \mathrm{Re}\{\frac{2k_{//}^{loss} q}{1 - e^{-T/\tau} \exp i\omega_0 T} e^{i\omega_0 t}\} e^{-t/\tau} \, . \qquad (3)$$

$$V_{\perp}^{s}(t) = \mathrm{Im}\{\frac{2k_{\perp}^{loss} k x q}{1 - e^{-T/\tau} \exp i\omega_0 T} e^{i\omega_0 t}\} e^{-t/\tau} \, . \qquad (4)$$

where $k_{//}^{loss} = \frac{\omega_0}{4}\frac{r_{//}}{Q}$ and $k_{\perp}^{loss} = \frac{\omega_0}{4}\frac{r_{\perp}}{Q}$ are longitudinal and transverse loss factors, τ is time constant of HOM, k is wave number, x is beam transverse offset, T is bunch train period.

In order to reduce mesh cells in CST, the longitudinal symmetry plane is set to either E or B plane, and HOM results are summarized in Table 2 to 3. CST frequency has a limited resolution, and APEX bunch harmonics are only separated by 1 MHz, so $\exp i\omega_0 T$ in Eq. (3) and (4) approx. 1 for conservative purpose.

Based on 300 pC bunch charge at 1 MHz, integrated HOM longitudinal voltage is 680 V, which is 5×10^{-4} of beam energy, and 3×10^{-3} of buncher voltage, thus is negligible. HOM horizontal voltage is 63.4 V/mm, and vertical voltage is 37.3 V/mm. Since the bunch head and tail will receive different dipole kicks, projected emittance will increase, a rough evaluation can be done with Eq. (5),

$$\Delta\varepsilon = (\frac{V_{\perp}}{0.511}) k \sigma_x \sigma_z \, . \qquad (5)$$

where k is wavenumber, σ_x and σ_z are bunch sizes. Assuming a 50 V/mm dipole kick, 1 mm bunch offset, 5 mm transverse rms size and 3 mm rms bunch length, dipole frequency of 2856 MHz, then emittance growth is 0.08 mm.mrad. Since actual beam offset is much smaller, and HOMs are not coherently excited, emittance growth should be negligible, and additional HOM damping is not necessary.

Table 2: Longitudinal HOMs*

Mode	***f* (MHz)**	**r/Q (Ω)**	**τ (μs)**	$V_{//}^{s}(t)$ (V)
TM011 (E)	2281.94	22.2	2.66	153
TM011 (B)	2283.35	42.3	2.65	290
TM020 (E)	3052.57	8.1	0.58	28
TM020 (B)	3057.71	0.3	0.58	1
TM021 (E)	3792.15	20.5	1.27	135
TM021 (B)	3804.14	7.6	0.95	42
TM012 (E)	3835.44	1.8	0.29	7
TM012 (B)	3836.04	6.4	0.31	24

* Beam pipe TM cut off frequency is 4.5 GHz

Table 3: Transverse HOMs*

Mode	***f* (MHz)**	**r/Q (Ω)**	**τ (μs)**	$V_{\perp}^{s}/x$ (V/mm)
TM110x (B)	2087.43	52.4	3.7	18.9
TM110y (B)	2087.57	53.3	1.1	7.7
TM110y (E)	2096.54	44.6	0.9	5.6
TM110x (E)	2096.61	44.5	3.9	17
TM111x (B)	2779.91	69.4	2.1	27.5
TM111y (B)	2779.91	69	1.7	24
TM111y (E)	2821.78	0.0	1.7	0.0
TM111x (E)	2821.84	0.0	2.3	0.0

* Beam pipe TM cut off frequency is 4.5 GHz

MULTIPACTING

In terms of cavity voltage, buncher may work within a wide range depending on specific applications, thus multipacting is unavoidable and investigated by Track3p code [8]. Simulation results in Fig. 3 show a lot of two-point multipactings in between coupler and cavity walls, so RF input coupler will be coated with thin layer Titanium Nitride (TiN) to mitigate multipacting.

It's almost multipacting free inside the cavity except few high order multipactings, which can be avoided during operation.

THERMAL ANALYSIS

A multistep ANSYS analysis is performed to determine frequency sensitivity due to RF heating and other operation parameters and to instruct design of the cavity's cooling system.

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPRI066

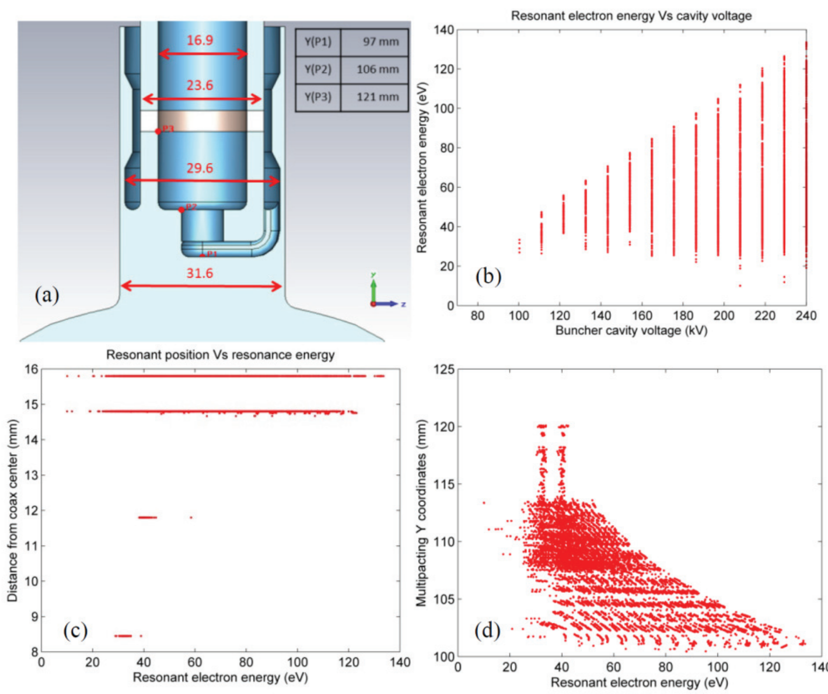

Figure 3: Multipacting near coupler region (a) Geometry of input coupler, (b) Resonant energy vs cavity voltage, (c) Multipacting radial position, (d) Multipacting vertical position.

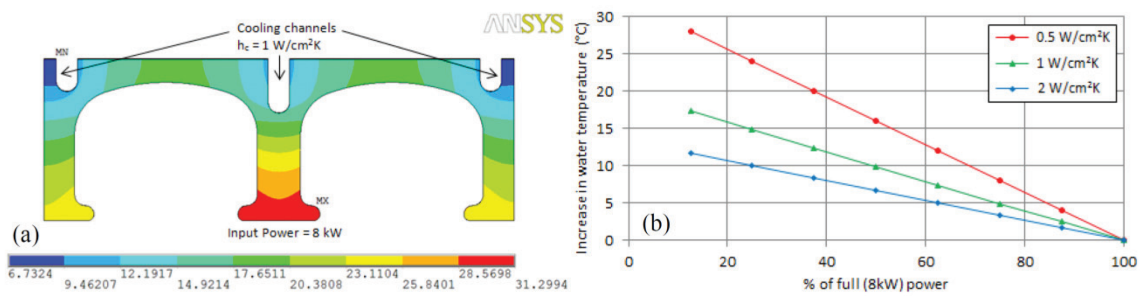

Figure 4: (a) Temperature profile in cavity body. Values are relative to water temperature. (b) Water temperature rise needed at reduced power levels, at 3 convection coefficient values.

Fig. 4 (a) shows an example temperature profile in the copper cavity body under specified power and cooling conditions. Repeated analysis yields Fig. 4 (b), which describes the water temperature change necessary to maintain a constant cavity frequency if shifting from full to reduced operating power. This analysis, combined with facility and equipment constraints, will guide final cooling channel design and determination of parameters like nominal operating temperature and cooling flow rate.

CONCLUSION

A 1.3 GHz two cell buncher cavity, which provides 240 kV in CW mode for velocity bunching, has been designed for APEX. Both RF and thermal analysis are presented, and the cavity is under mechanical design now.

REFERENCES

[1] F. Sannibale et al., Phys. Rev. ST Accel. Beams 15 (2012) 103501.
[2] F. Sannibale et al., these proceedings.
[3] R.A. Rimmer et al., "A Third-Harmonic RF Cavity for the Advanced Light Source," (1998), EPAC'98.
[4] J. Staples et al., CBP tech note, "1.3 GHz APEX Buncher Cavity Parameters," (2013)
[5] J. Staples et al., CBP tech note, "Low-Z 1.3 GHz Coupler," (2014)
[6] T. Wangler, RF Linear Accelerators (Wiley-VCH, Weinheim, 2008).
[7] D. Li et al., "Deflecting RF Cavity Design For A Recirculating Linac Based Facility For Ultrafast X-RAY Science (LUX)," PAC'03.
[8] ACE3P, Https://confluence.slac.stanford.edu/display/AdvComp/ACE3P+-+Advanced+Computational+Electromagnetic+Simulation+Suite.