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X-BAND RF SYSTEM AS LINEARIZER FOR SXFEL

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Abstract

High gradient accelerating structure is the core technology of compact linear collider facilities and compact free electron laser facilities. Meanwhile the important limitation of improving brightness in free electron laser facility is the non-linear energy spread, and the X-band accelerating structure can provide harmonic compensation in linac to linearize the bunch compression process. In this paper, a special X-band traveling-wave accelerating structure is primary designed for compact hard x-ray free electron laser facility. Then the structure is processed manufacturing, and realize high power experiment and linear bunch compression at Shanghai soft x-ray free electron laser facility.

INTRODUCTION

The X-band high gradient accelerating structure is original designed to meet the requirement of the development of the high energy physics. Now many institutes have been participating in the research on the X-band technology for implementation in advanced electron linear accelerator facilities, such as the Stanford Linear Accelerator Center (SLAC), the High Energy Accelerator Research Organization (KEK), the European Organization for Nuclear Research (CERN). Recently the X-band accelerating structure can be operated at 120 MV/m unloaded stable gradient, far greater than 20 MV/m of S-band and 40 MV/m of C-band [1]. With the development of the X-band technology in precision machining and high power sources, the X-band high gradient accelerating structure is applied to the X-ray free electron laser (FEL) facilities, which enables the production of widely tunable short-pulse x-ray radiation with high peak brightness and high coherence.

In the paper, a disk-loaded structure with the gradient of 80 MV/m is especially designed for the compact hard X-ray FEL facility, which had been planned to be constructed at the Shanghai Institute of Applied Physics (SINAP) close to Shanghai Synchrotron Radiation Facility (SSRF)[2]. It is a constant gradient structure with a $4\pi/5$ operating mode, under the consideration of radio frequency (RF) breakdown, RF efficiency and short-range wakefields. Due to suppressing the multi-pole field components, dual-feed racetrack couplers are adopted to ensure good beam quality.

However, the project of the compact hard X-ray FEL facility is changed to superconducting scheme at 2017, after the manufacture of sample cells are finished. The development of high gradient accelerating structure is also very important to keep the international competitiveness in advance accelerator field. The X-band structure is still fabricated and installed on the Shanghai soft X-ray FEL (SXFEL) facility to realize linear compression of bunch. The final compression is extremely limited by non-linear effects which lead to unwanted sharp temporal spikes by coherent synchrotron radiation (CSR) [3]. Higher harmonic compensation is a valid method to maintain the initial temporal bunch profile and avoid unnecessary amplification of undesired collective effects, which has been proposed at Boeing, DESY and SLAC [4-6].

DESIGN OF X-BAND ACCELERATING STRUCTURE

The designed X-band accelerating structure is shown in Figure 1, with parameters labeled a, b, t, t_b, and the cell period D of 10.497 mm. Through optimization of maximum electric field strength Emax, the new field quantity denoted as the modified Poynting vector Sc, the cavity breakdown rate (BDR) and wakefields [7], the final results of the X-band high gradient accelerating structure is presented in Table 1. The average of aperture radius is 3.74 mm, the Emax is less than 245 MV/m and Sc is less than 4.2 MW/mm^2. To ensure the high gradient of 80 MV/m, the input power should be 84 MW.

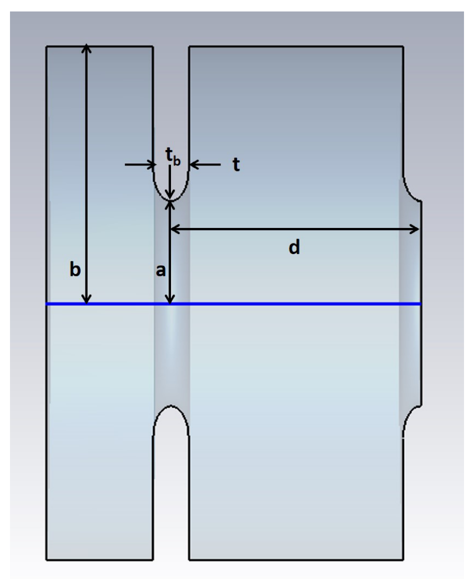

Figure 1: Schematic of the accelerating structure with 1.5 cells.

The dual-feed coupler is shown in Figure 4 and the results are presented in Table 2 which are matched by reflection coefficient R of Krolls method. The regular cell shown in Figure 2 (a) presents equivalent parameter values as those employed in the first accelerating cavity for the input coupler and equivalent parameter values as those employed in the last cell for the output coupler. In addition, the dimension of the narrow side of the WR90 waveguide (d0) is 10.16 mm.

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Table 1: The Parameters of Optimized Accelerating Structure

field component	ki(10-8)
Frequency	12.424 GHz
Phase advance	$4\pi/5$
Cell NO.	89+2
Effective length	944.73 mm
Group velocity	3.57-1.15
Shut impedance	82.67-115.36
Q-factor, Q	about 7800
Total attenuation	0.67
Filling time, Tf	146 ns

The parameters of the racetrack cell are plotted in Figure 2 (b). Among these, the length of the racetrack is 2a1, which is equal to the distance between the two arc centers. The radius of the arc is b1, and the length of the coupling hole is Lx. The distance H can be expressed as

$$H = \sqrt{(b_1 + r)^2 - (\frac{L_x}{2} - a_1)^2} + r \qquad (1)$$

The other parameters are 15 mm, 1mm, 45mm, 1mm and 2mm, corresponding to d3, r1, h, r and Rf respectively. The monopole field component (E0), dipole field component (E1) and the quadrupole field component (E2) are calculated at the center of coupling cell with the radial offset of aperture radius. The E2/E0 is mainly decided by the length of racetrack, and the value is obtained under matched status with reflection coefficient R less than 0.01. On the basis of a large amount of simulation, the frequency is greatly affected by the radius of coupling cavity (b1), and reflection coefficient is related to Lx and r. Usually the coupler is matched by adjusting b1 and Lx to ensure the frequency f = 11424 MHz and R < 0.01 when racetrack length is fixed.

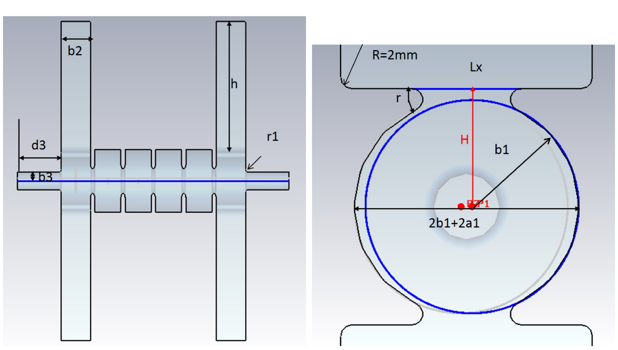

Figure 2: Layout of the racetrack dual-feed coupler. (a) the longitudinal cross section, (b) the transverse cross section.

Table 2: The Parameters of Couplers

Component	Input	Output
a [mm]	4.3	3.047
b [mm]	10.782	10.366
2a1 [mm]	5.3	3.4
b1 [mm]	8.464	9.004
Lx [mm]	9.617	8.384
f [MHz]	11.424	11.424
S11 [dB]	-58	-56
ϕ [degree]	144	144
R [dB]	0.006	0.008
E2/E0	0.0063	0.001

COLD TEST AND FIELD DISTRIBUTION MEASUREMENT

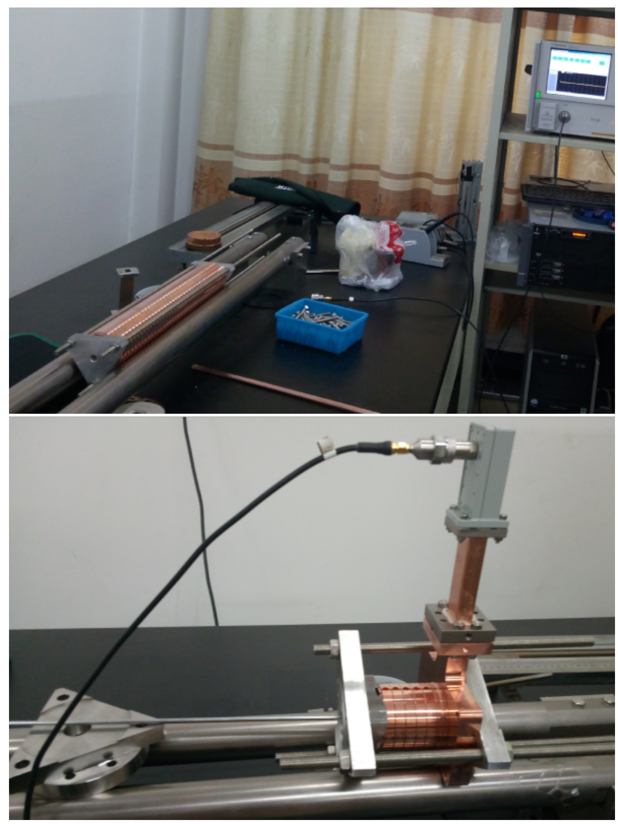

Figure 3: The measuring platform of regular cells and couplers

The measurement of regular cells adopts magnetic short-circuited plane, and the fixed of several cells is depend on finger tapping and screw, shown in Figure 3. The measuring platform consist probe, electric cable, vector network analyzer (VNA), support platform and computer. Through adjusting the position of probe, the frequency of different operation mode is detected. According the measuring principle, the four peaks are respectively the frequency of $\pi/5$ mode, $2\pi/5$ mode, $3\pi/5$ mode and $4\pi/5$ mode which value

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Table 3: Test Results of Regular Cells

Cell No.	f	Q
12-17 #	11425.319	6280
13-18 #	11424.666	6339
14-19 #	11424.684	6249
15-20 #	11425.653	6067
16-21 #	11424.884	6150
17-22 #	11423.272	6547
18-23 #	11422.303	6316

is higher than other three modes. The Table 4 lists the measured frequency by the above method. In addition, the cells number of 15-20 # represents that the probe are put into the center of 12th cell and 17th cell. The measured value of Q factor is 80% of simulation, and the measured value of frequency is credible. The error is in allowable bounds, which maybe come from imperfect assembly, and the test results listed in Table 3.

In the manufacture of X-band traveling-wave accelerating structure, the last step is to tune the whole tube followed by welding. The tuning depends on non-resonant perturbation technology, utilizing existing software and hardware platforms. It includes Labview software, stepper motor, computer and other accessory equipment, shown in Figure 5. The three contiguous cavities are matched in theory by tuning the intermediate cell, which can eliminate local reflection in whole accelerating tube. Before tuning, the operated frequency needs to be corrected as the followed expression,

$$f_p = \frac{f_0}{\sqrt{\varepsilon_p}} \quad (2)$$

$$\varepsilon_p = 1 + 210 * 10^{-6}\frac{P_d}{T} + 180 * 10^{-6}(1 + \frac{3580}{T}) * \frac{P_w}{T} \quad (3)$$

$$\Delta f_p = f_p - f_0 = f_0(\frac{1}{\sqrt{\varepsilon_p}} - 1) \quad (4)$$

Where Δfp is the frequency deviation calculated by water vapor pressure Pw and dry air pressure Pd. Assuming f0 = 11424 MHz, P = 760 torr, saturated water vapor pressure about 17.54 torr and the 77% humidity of steam, the Pw is 13.506 torr that is the product of 17.54 and 77%. The Pd is the difference between P and Pw. The coefficient of expansion of copper is 1.77e-5. The temperature is 24.2 degree in this room. According the sensitivity analysis above, the frequency deviation ΔfT influenced by temperature is about 4.00 MHz. Thus, the final frequency is 11424.38 MHz under the measurement state.

SUMMARY

In summary, the design and manufacture of the special X-band traveling-wave accelerating tube have been completed.

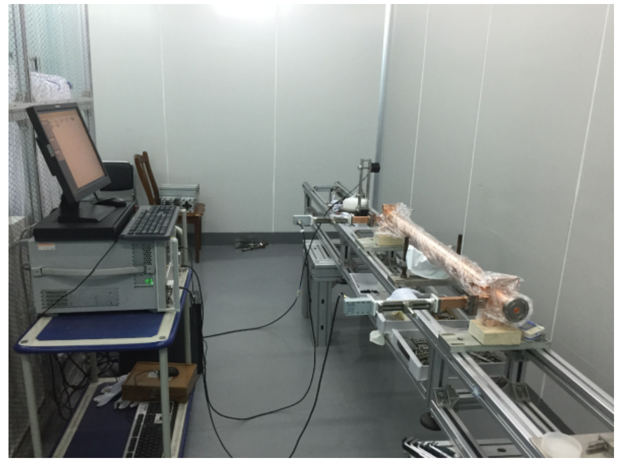

Figure 4: Non-resonant perturbation measurement platform

The sample tube realizes the linear compression of bunch experiment on the SXFEL facility for the first time in China. Although the tube exist shortages, it solves the engineering problem of SXFEL project and also accumulates the basis experience for the development of the subsequent X-band accelerating structure.

ACKNOWLEDGMENT

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