R&D OF NEW C-BAND ACCELERATING STRUCTURE FOR SXFEL FACILITY

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Abstract

C-band high gradient accelerating structure is crucial technology for Shanghai Soft X-ray FEL facility. Based on the prototype, the optimized C-band accelerating structure is proposed, and the experimental model is ready for high power test. In this paper, optimization design and some experiment results are presented, also design, fabrication and cold test of experimental model are introduced.

INTRODUCTION

Shanghai Soft X-ray Free Electron Laser (SXFEL) facility is proposed and started to construct soon, some analytical and simulation research is ongoing at the Shanghai Institute of Applied Physics . This facility will be located close to the Shanghai Synchrotron Radiation Facility which is a 3rd generation light source in China [1]. C-band (5712 MHz) accelerating structure is crucial technique for linac of SXFEL, which is operated at 40 MV/m [2].

For SACLA/Spring-8, C-band accelerating structure is operated at high accelerating gradient of 35 MV/m. and limits the linac to be less than 400 m for 8GeV, which is a suitable size for a compact facility with similar functions as LCLS and Euro-XFEL [3, 4]. In the future, hard X-ray FEL facility, which is similar as is proposed to be located at SSRF campus, and the length of linac is also limited less than 280m for 6.5GeV, so that C-band with 40MV/m is one crucial technique which is tested and proved in the facility of SXFEL.

The prototype of C-band accelerating structure has been designed, fabricated, cold tested and high power tested [2, 5, 6]. Based on experience of prototype and requirements of FEL facility, new scheme of optimized C-band accelerating structure is proposed, and some fabrication and test results support the feasibility of new scheme [6, 7]. According to optimization and feasibility support, new C-band accelerating structure is designed, which includes high accelerating gradient and high beam quality. Before new structure fabrication, one experimental model is ready for checking the feasibility. In this paper, the optimization scheme, experiment results and new design are presented briefly, and then the design, fabrication and cold test of experimental model are introduced particularly.

OPTIMIZATION, EXPERIMENTS AND NEW DESIGN

For use of FEL facility, some optimizations on prototype are proposed, and some experiments also have been done to find out feasibility of optimizations. Based on much work, new C-band accelerating structure for FEL is designed. In this section some key points of optimization, experiments and new design are presented briefly.

Short Range wakefield

Considering high peak current and ultra-short bunch of FEL, short range wakefield is the crucial factor against beam quality, which is determined by diameter 2a of accelerating structure aperture. For high beam quality of FEL, 2a is increased from 10mm to 15mm to suppress the short range wakefield.

Phase Advance

To the contrary, large aperture results in large group velocity, which is not good for high accelerating gradient and power efficiency. For better performance, higher phase advance $4\pi/5$ is used for new scheme, which carries out lower group velocity and high shunt impedance.

Cavity geometry

Cavity shape is one strong impact factor on peak E-field and shunt impedance, and new cavity geometry with rounded shape and elliptic iris tip is are optimized for new C-band structure. In figure 1 , the elliptic iris tip can suppress the ratio of peak E-field and average E-field to 2.6 from 3.2, and the rounded shape can improve shunt impedance by 10%.

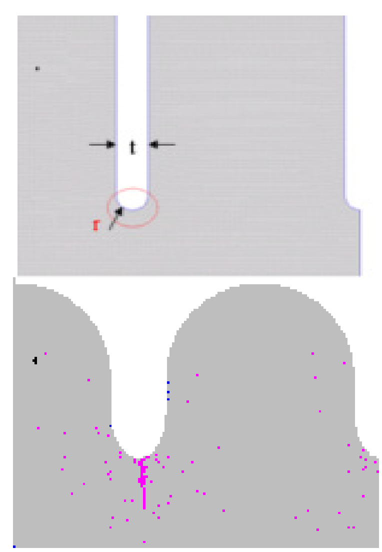

Figure 1: Original (top) and optimized (down) geometry.

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According to two types in figure 1, several cells are fabricated, and R/Q and Q of 4π/5 is measured shown in figure 2. In figure 2 the integration of curve represents R/Q, and mostly two curves are equal, so that shunt impedance is determined by Q. In the figure, Q of round cavity is 10% higher, and correspondingly shunt impedance is increased by 10% which is same to simulation results.

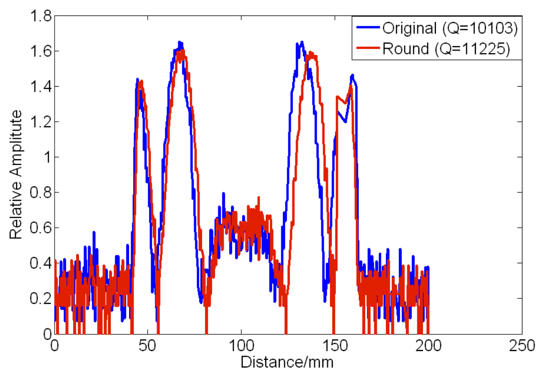

Figure 2: R/Q results of two types cavity on 4π/5.

Mechanical design

According to the prototype, the mechanical design is a little complicated, and is difficult to fabrication, install and test, so that some optimizations are used for improving the mechanical performance. Firstly mode-launch coupler is integrate into one body from three parts, so that it's more compact and movable; Secondly water cooling is changed to inner cooling, and tube is connected cell by cell, so that cooling efficiency is improved and structure looks like smart.

DESIGN AND FABRICATION OF EXPERIMENTAL MODEL

Based on optimization scheme above, one model for pre-research is designed by CST [10] and the Kroll method [11], which results are shown in Figure 3. For constant gradient structure, input and output coupler are different, and separated to design independently. In Figure 3, first and second S11 results present input and output coupler matching status.

This model has been fabricated, and is ready for cold test and tuning. Figure 4 shows product of this model. This model comprises of 20 round cells, and use the optimized scheme of compact coupler, inner cooling tube and tuning hole. On nest step, it will be cold tested and tuned, and then for high power test.

Based on the model in Figure 4, several new machining, brazing and tuning methods are and checked, and they will be used for C-band accelerating structure of SXFEL.

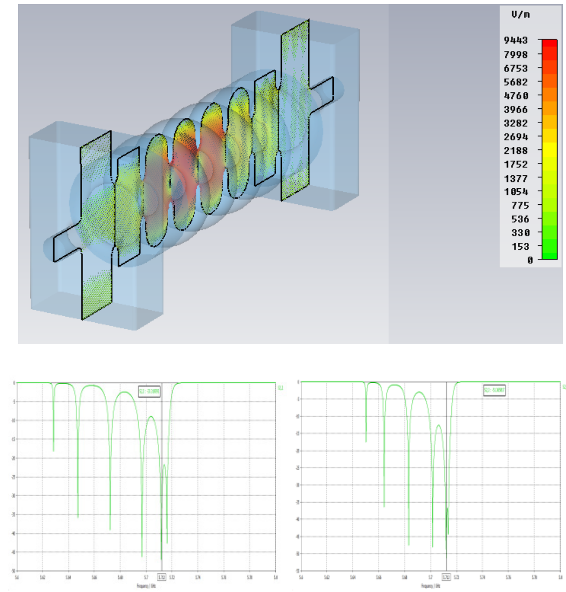

Figure 3: Simulation and S11 of two matching coupler.

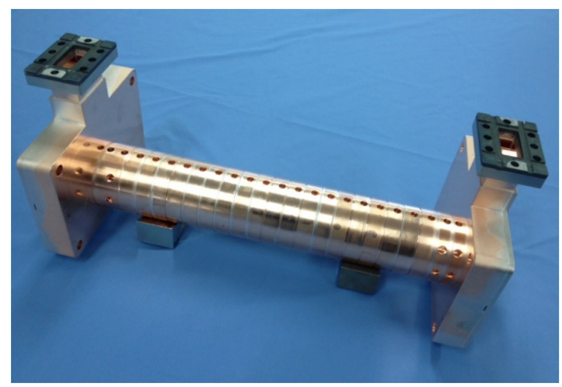

Figure 4: Product of experimental models.

CONCEPTUAL DESIGN OF NEW STRUCTURE AND SYSTEM

Based on optimization and experiment model experience, one new C-band accelerating structure is designed, and correspondingly C-band RF system is proposed.

Conceptual design of new structure

New conceptual design of new C-band accelerating structure is proposed, which will be operated in SXFEL facility, and the 3-D drawing is presented in figure 5.

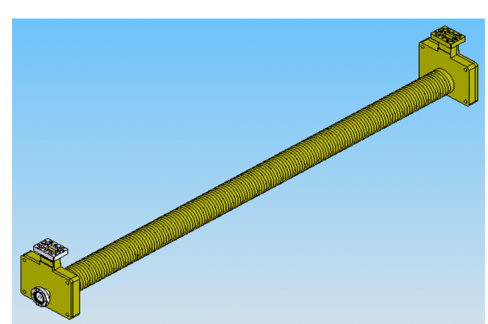

Figure 5: 3D design of new C-band accelerating structure.

New design selects compact coupler and inner cooling tube, which looks like very smart, also large aperture, 4π/5 phase advance, round cavity and elliptic tip are used for new structure, and finally it's expected to carry out 40MV/m at 60MW input power. All parameters of new design are shown in Table 1 below.

Table 1: Parameters for new C-band accelerating structure

Frequency	5712MHz
Field	Constant gradient
Phase advance per cell	4π/5
Length of cell	20.988mm
Cell No.	77 + 2
Total length	About 1.8m
Average 2a	15mm
Elliptical tip radius: 2B/2A	9mm/5mm
Width of iris: t	5mm
Epeak/E0	2.79 ~ 2.39
Shunt impedance: Rs	62 ~ 78.4 Mohm/m
Quality factor: Q	11848 ~ 11648
Group velocity : vg/c	2.4% ~ 0.95%
Filling time	372ns
Attenuation factor: τ	0.569

In Table one, average aperture 2a is 15mm, and it's remarkable to suppress short range wakefield. Phase advance is changed to 4π/5 for high gradient and power efficiency, and also constant gradient structure is better for power efficiency. The total length is 1.8m, and this is compromised for power use and short range wakefield.

C-band RF system

SXFEL facility will be started soon, and other components are also in the proceed. Together with new C-band accelerating structure, they are installed to the C-band RF system, which shown in Fig 6.

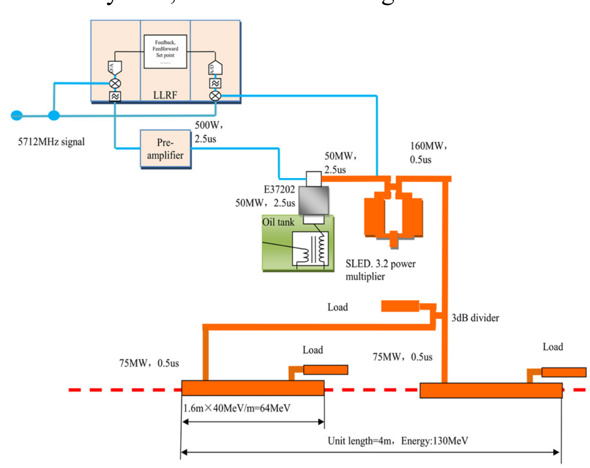

Figure 6: C-band RF system scheme for SXFEL.

In Figure 6, C-band RF system comprises of signal source, solid-state amplifier, modulator, klystron, SLED, two accelerating structure, and other waveguide components. C-band klystron output 50MW power, and compressed to 160MW by SLED. After transferring attenuation, 150MW power is provided for two accelerating structure, so that75MW input power for each accelerating structure is reachable. According to operating gradient 40MV/m at 60MW, the C-band RF system is potential to update SXFEL facility in the future.

CONCLUSION

C-band high gradient accelerating structure is a key technique of the linac for SXFEL facility at SINAP. Based on the prototype, optimizations are proposed, and specially one experimental model has fabricated successfully. All these solved many crucial technique of design and fabrication, and accordingly new robust C-band accelerating structure is designed conceptually. Finally C-band RF system for SXFEL is proposed, and it will be constructed soon.

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