

R&D OF C-BAND ACCELERATING STRUCTURE AT SINAP*

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Abstract

Research and design of a C-band (5712 MHz) high-gradient travelling-wave accelerating structure is being carried out at Shanghai Institute of Applied Physics. The structure consists of 53 regular disk-loaded cells and two waveguide couplers, and its length is about 1 m. This paper presents a design of the accelerating structure, the experimental model, and the preliminary results of an RF cold test of the model structure.

INTRODUCTION

Shanghai Synchrotron Radiation Facility (SSRF), a third-generation light source in China, commenced routine user operation in May 2009 [1]. As a further development of light sources, a compact hard X-ray free electron lasers (FEL) facility is presently being planned at Shanghai Institute of Applied Physics (SINAP). This facility will be located close to SSRF and thus requires a compact linac with a high-gradient accelerating structure for a limited overall length of less than 650 m. A room-temperature linac operated at higher frequency with smaller scale can provide a higher accelerating gradient. However, a smaller-scale structure induces a serious wakefield and high gradient results in breakdown of the electric field. The C-band (5712 MHz) accelerating structure described in this paper is a good compromise for this compact facility. The technology of C-band accelerating structures has been well established at KEK and RIKEN/SPring-8. Field gradients have reached 45 MV/m at KEK [2] and 40 MV/m at SPring-8 [3].

The C-band accelerating structure under development at SINAP has a constant acceleration gradient, and it is planned for the operational gradient to exceed 40 MV/m, which is about twice that of the S band. A waveguide coupler, which is an electric coupler with two coupling ports, is used to input power. Comparing with a single-port magnetic coupler, the waveguide coupler has the advantages of a lower rate of breakdown and elimination of the asymmetry dipole field in the coupler cavity for high beam quality [4, 5]. This paper is a design study of the constant gradient structure and waveguide coupler. Results of a radio frequency (RF) cold test of the experimental model are found to be in good agreement with design values.

DESIGN AND SIMULATION

The present C-band accelerating structure comprises 53 regular cells and input and output waveguide couplers, and the effective length is about 1 m in Fig. 1. The gradient of the field should be constant. The operating frequency is 5712 MHz and the operating mode is $2\pi/3$.

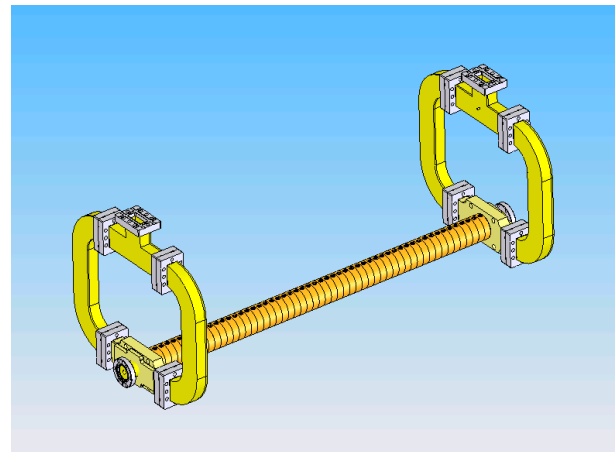


Figure 1: Overall accelerating structure.

Regular section design using SUPERFISH

FISH of SUPERFISH is adopted for calculating the 53 regular cells [6], and the characteristic parameters of the TW structure are presented in Table 1.

Table 1: Parameters of the regular section

Operating frequency : f (MHz)	5712.000
Number of cells	53
Operating mode	$2\pi/3$
Length of structure (mm)	944.73
Length of cell : d (mm)	17.495
Disk thickness : t (mm)	2.500
Diameter of aperture : $2a$ (mm)	10.405–12.475
Diameter of cell : $2b$ (mm)	41.001–41.492
Shunt impedance : R_s ($M\Omega/m$)	76.19–87.18
Quality factor : Q	9893–9864
Group velocity: V_g/c (%)	1.88–1.00
Filling time : t_f (ns)	226
Attenuation factor : τ	0.4565

Coupler design using MWS of CST

For this design, a waveguide coupler with two ports is adopted for the accelerating structure, and Kroll's method based on the time domain is employed to tune the coupler [7] using CST 3-D electromagnetic software [8].

Considering the running time and limited memory of the computer, a novel MWS model was designed for simulation, as shown in Fig. 2. The model is made of two identical regular cells and two identical couplers.

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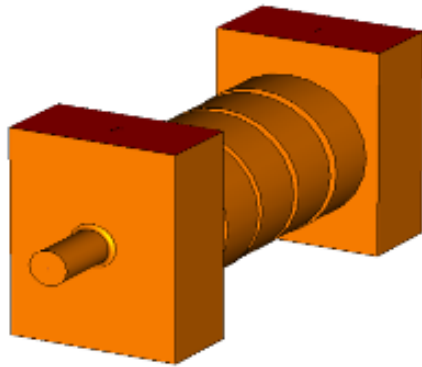


Figure 2: Novel model for CST simulation.

Figures 3 and 4 present the simulation results. In Fig. 3, $|R|$ presents the match level of couplers and ψ presents the phase advance per cell according to [7]. $|R|$ of the mismatched coupler is very large. In the matched case, the real part of $\cos\psi$ is -0.5 and the imaginary part is zero, and $|R|$ is 0.0135 between the two vertical red dashed lines. All results demonstrate that the couplers are matched and the phase advance is 120° , which is the design value. Fig. 4 illustrates the field and phase distribution on the axis. The field in the coupler is lower than that in the regular section, and the phase advance between the middle points of the two matching cells is about 360° . Figure 4 shows the phenomenon that the phase velocity of the rectangular waveguide is about $0.6c$, which is lower than the speed of a relativistic electron, and the beam dynamics of electrons with low velocity may be complicated because of non-synchronization between a bunch and travelling-wave; however, the field in the waveguide is very weak, and the transversal and longitudinal fields imposed on the beam can be omitted [9].

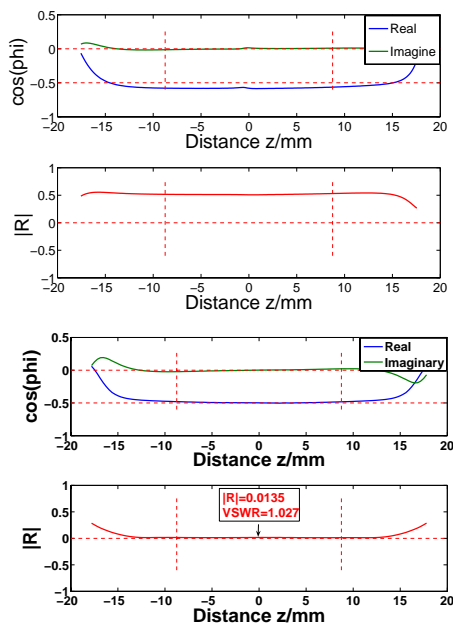


Figure 3: ψ and R for mismatched (top) and matched (bottom) couplers.

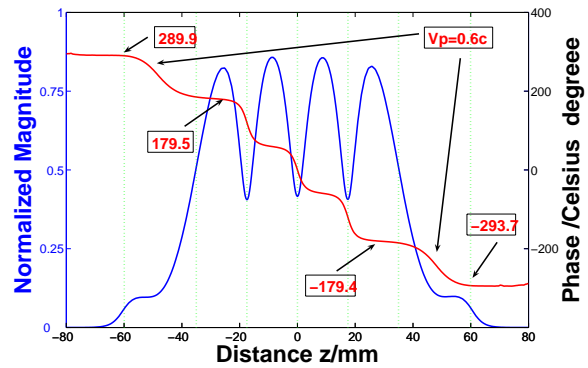


Figure 4: ψ and R for mismatched (top) and matched (bottom) couplers.

The above provides a systematic method for the design of a TW accelerating structure. The regular section can be designed cell by cell with SUPERFISH, and the input and output couplers can be calculated by MWS. However, there may be some slight mismatch between the simulation model and experimental model, which can be tuned in an RF cold test step as discussed in the next chapter.

STRUCTURE FABRICATION AND RF MEASUREMENTS

To check the structure design, an experimental model including 12 regular cells and two couplers was fabricated. The model is composed of an input coupler, output coupler and 12 identical regular cells (No. 53 cell of the constant structure above), as shown in Fig. 5. Results were acquired in tuning experiments and the field distribution on the axis is measured too.



Figure 5: Setup for experimental model cold test.

Tuning experiments

There is a resonant frequency shift between the experimental cells and simulation. Four tuning holes are machined on the wall of each cell for frequency tuning. Figure 6 shows the result of tuning. Curve fitting of the measurement data gives a tuning value of about 8 MHz/mm for each hole in the linear part. A value of 8 MHz/mm for tuning cells is large relative to the 4 MHz residual frequency, and thus, two tuning holes for each cell are sufficient.

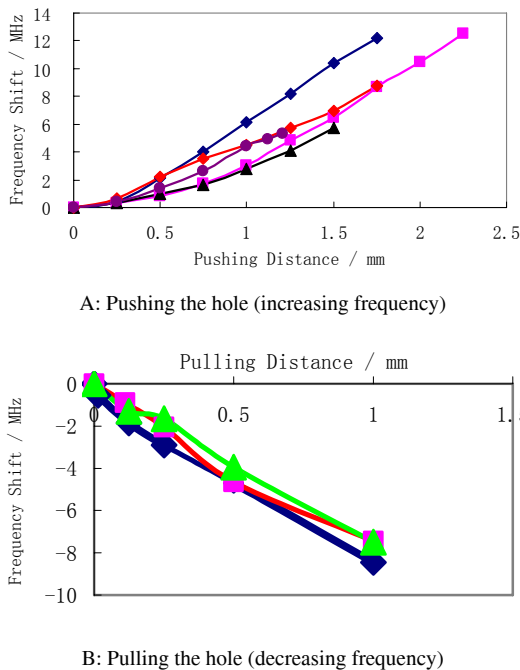


Figure 6: Tuning experiment results.

*Each curve corresponds to one tuning hole

Cold test of the experimental model

The whole model shown in Fig. 7 is the experimental model of the TW accelerating structure. According to non-resonant perturbation theory [10, 11], the tuning code was written based on LABVIEW 8.5. The software controls the RF cold test system comprising an NWA Agilent 8362B, step motor and computer, and then acquires the measurement data from the system. The amplitude and phase of the field distribution on the axis are analyzed, and then the residual tuning for each cell can be calculated cell by cell. According to the residual tuning value for each cell, the whole structure can be tuned cell by cell iteratively under the control of LABVIEW code [12]. The tuning results are shown in Figs. 7, 8, and the standing-wave ratio (SWR) is adopted to describe the matching status. Before tuning in Fig. 7, SWR is more than 2. However after some tuning cycles, SWR can reach 1.1, which is a practical result for accelerating structure.

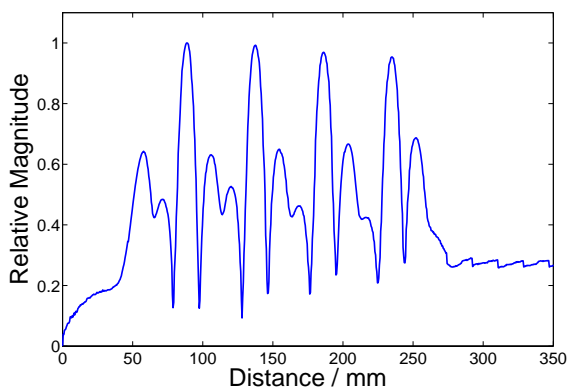


Figure 7: Field distributions before tuning (SWR > 2).

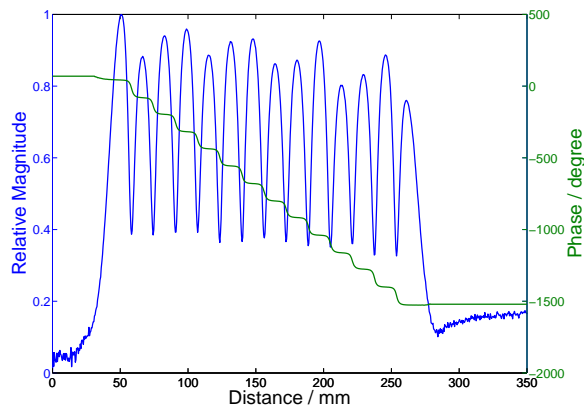


Figure 8: Field distribution after tuning (SWR = 1.1).

CONCLUSION

A C-band travelling-wave accelerating structure was designed, and an experimental model with 12 regular cells and couplers was fabricated and tested. To a large extent, the RF cold test results agree well with the simulation, and therefore most crucial techniques of the design, fabrication and tuning method are verified systematically, particularly the design of the waveguide coupler, which is able to reduce the rate of RF breakdown. And in the next step, the whole C-band accelerating structure will be fabricated and then high-power RF conditioning carried out.

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