R&D OF C-BAND PULSE COMPRESSION FOR SOFT X-RAY FEL AT SINAP*

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Abstract

A compact Soft X-ray Free Electron Lasers facility is presently being constructed at SINAP, and 8 C-band accelerating structure unit are required for third-stage including 4 pulse compressors. The field mode of C-band SLED is $TE_{0.1.15}$ with high quality factor Q, and the coupling coefficient is 8.5. Based on the design, the power pulse of klystron is compressed from 2.5μs to 0.5μs, and finally the power gain is about 3.1. In this paper, the details and simulation of 3-dB coupler, mode convertors and the resonant cavities are presented, meanwhile some cold test results of cavity are also analyzed at the end of this paper.

INTRODUCTION

A compact soft X-ray Free Electron Laser facility is presently being constructed at shanghai institute of applied physics (SINAP), Chinese academy of science. This facility will be located to the shanghai synchrotron radiation facility which is a third generation light source in china. And it requires a compact linac with a high-gradient accelerating structure for a limited overall length less than 230m. The c-band technology is a good compromise for this compact facility and a c-and traveling-wave accelerating structure was already fabricated and tested at SINAP including a c-band pulse compression fir the cold mode measurerment. For it will enhance the peak RF power by expense of RF pulse length, so it will not increase the average power and at the same time reduce the total number of the klystron, it also increases the gradient of the accelerating structure, all of this have driven research in the c-band pulse compressor. And a SLED type RF compression scheme is proposed for the C-band RF system of the soft X-ray FEL and this scheme uses $TE_{0.1.15}$ mode in the resonant cavity for high Q-value and high energy mutiplication.

This scheme use $TE_{0.1.15}$ mode in the storage cavity to compress an RF pulse into a short square high peak-power pulse for the course of R&D study of the soft X-ray FEL. Figure 1 shows the schematic diagram. This scheme consists of one 3-db coupler, two mode convertors, and a pair of high-Q resonant cavities.

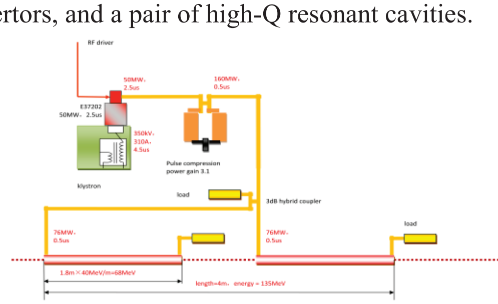

Figure 1: The schematic diagram of the R&D microwave unit.

C-BAND PULSE COMPRESSION

The c-band accelerator structure for the soft X-ray FEL is supposed to operate at high acceleration gradient about 40MeV per meter, this requires very high peak RF power about 160MW at frequencies 5712MHz. So the design goal of the pulse compression is to compress the pulse width from 2.5μs to 0.5μs and to multiply the input RF power of 50MW to generate 160MW peak RF power. To satisfy this requirement , we adopted a SLED type pulse compression. This scheme is composed of two identical high Q-value cavities attached to mode convertors and then to a -3db hybrid coupler. The performance of the pulse compressor depends on the design of the resonant cavities as show in Figure 2.

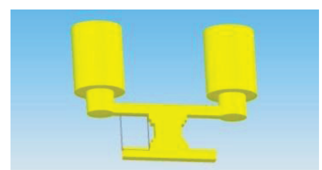

Figure 2: Schematic of the SLED type pulse compression.

The expression of the power for the resonant cavity is

$$T_C \frac{dE_e}{dt} + E_e = -\alpha E_K \tag{1}$$

Where $\alpha = 2\beta/(1+\beta)$, $T_c = \frac{2Q_L}{\omega}$, Ee: emitted wave from the coupling aperture, E_K: reverse wave that is equal in magnitude to the incident wave Ei from the klystron.

The expression of the energy multiplication factor Vmax is :

$$V_{max} = \gamma * e^{-\frac{T_a}{T_C}}[1-(1+g)^{1+v}] * [g*(1+v)]^{-1} - (\alpha - 1) \tag{2}$$

$\gamma = \alpha(2 - e^{-T_1})$, $T_a = (L/gv_{g0})\ln[1/(1-g)]$ is the filling time for the structure.

g is the gradient of group velocity along accelerating structure, v=Ta/TC[ln(1-g)]-1.

THE CAVITY OF THE C-BAND PULSE COMPRESSION

The Q-value of the TE_{0115} Mode for the Cavity of the C-band Pulse Compression

TE_{0115}mode was choosed as the resonant cavity mode and the Q factor can be expressed as:

$$Q_0 = \frac{\lambda*[\upsilon_{mn}^2+(p\pi R/l)^2]^{\frac{3}{2}}}{2\pi\delta\left[2p^2\pi^2\frac{R^3}{l^3}+\upsilon_{mn}^2\right]} \tag{3}$$

The Optimize the Cavity Diameter for the Cavity of the C-band Pulse Compression

The relation among resonant frequency, mode and geomensions can be expressed as:

$$\left(\frac{f_0 D}{c}\right)^2 = \left(\frac{\nu_{mn}}{\pi}\right)^2 + \left(\frac{pD}{2l}\right)^2 \quad (p \neq 0) \tag{4}$$

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Considering the resonant frequency, the cost, unloaded Q value, it is suitable to choose the resonant cavity length is 429.18mm and the diameter is 152.6mm. And a tuner also is designed at the end of the each resonant cavities, it used to tune the frequency.

Table1: The Parameter of Storage Cavity for the C-band Pulse Compression

Operation frequency	5712MHz
Mode	TE0.1.15
Cavity size: diameter	152.6mm
length	429.18mm
Iris size: diameter	48mm
length	15mm
Quality factor	181710
Power gain	3.1
Coupling coefficient	8.5

The Results of Simulation by CST for the C-band Pulse Compression Cavity

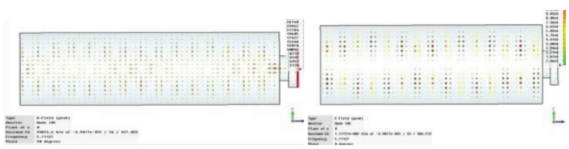

Figure 3: The electric and the magnetic field for the cavity of the c-band pulse compression.

SIMULATION THE FIELD AND Q-VALUE OF THE CAVITY

The Transverse Magnetic Field of the Centre of the Cavity, for in the Centre of the Cavity only has the Magnetic Field

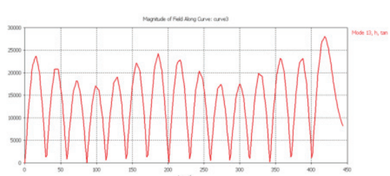

Figure 4: The transverse field in the of the centre of the cavity.

The Longitudinal Field of the Cavity

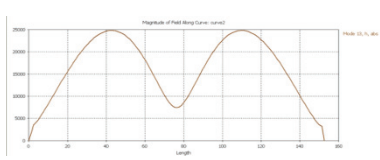

Figure 5: The longitudinal field of the cavity.

The Q-value

The result of the Q-value by CST for the resonant cavity is 181710.

THE COLD MODE MESUREMENT OF THE FREQUENT AND THE Q-VALUE

The Measurement Table of the C-band Pulse Compression Cavity

Figure 6: The cavity of the c-band pulse compression.

The Cold Measurement of the Frequency and Q Value

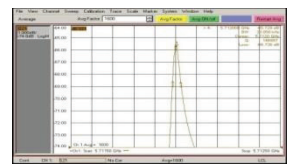

Figure 7: The Q-value and the frequency for the cavity.

Measurement of Magnetic Field in the Centre Cavity Diameter

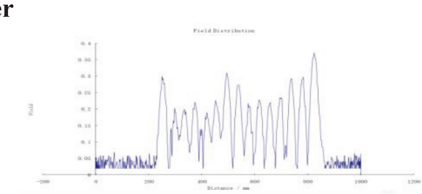

Figure 8: The field in centre cavity diameter.

Measurement of the Electric Field in Longitudinal

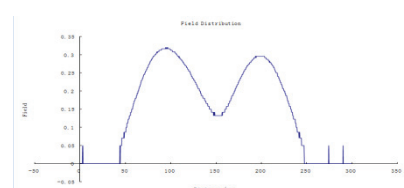

Figure 9: The field in longitudinal.

Tuning Experiments

Based on the design, the c-band pulse compression cavity has successfully accomplished cold testing. The tuner show that the length of the cavity turn 1mm, that the frequency turn 10.5MHz.

COMPONENTS FOR THE C-BAND PULSE COMPRESSION

3-dB Coupler Hybrid

3-dB coupler hybrid is an essential element to direct the flow of RF power to the RF pulse compression system. In the SLED type compressor, through this coupler an output RF power of the klystron is guided to two over coupled cavities, and waves from the each cavity are combined so as to add and transmitted to the accelerating structure. The value of the coupling depends on the width and the length of the coupling region. For the 3-dB coupling hybrid of the c-band pulse compressor, they were designed 76mm and 60mm, respectively.

Figure 9: Schematic drawing of the 3-db coupler hybrid.

The distance of the coupling section L is a function of the width 2a as followings

$$L = \frac{1}{4\left(\frac{1}{\lambda_{g10}} - \frac{1}{\lambda_{g20}}\right)} \qquad (5)$$

Where $\lambda_{g10} = \frac{\lambda}{\sqrt{1-(\frac{\lambda}{4a})^2}}$; $\lambda_{g20} = \frac{\lambda}{\sqrt{1-(\frac{\lambda}{2a})^2}}$

Here we used a ladder type hybrid which has excellent divided ratio, phase condition, broad frequency response characteristics and the coupling is -3dB

Table2: Parameter of the 3-db Coupler and the Simulation Results

Coupling region: width	76mm
length	60mm
First ladder: length	176mm
depth	6.2mm
Second ladder: length	124mm
depth	13mm
Simulation coupling	S_{21},S_{31}=-3dB; S_{11},S_{41}<-30dB

Results of simulation by CST：

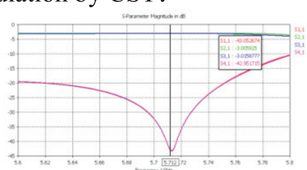

Figure 10: Simulated S-parameter of the 3-db coupler.

Mode Converter

The main impact of the mode converter is convert the square TE_{10} to the cyclo-TE_{01} and prevent the unnecessary mode that around the TE_{01} mode, for many modes are concentrate around the target $TE_{0.1.n}$ mode in the high-Q cavity of the RF Pulse Compressor. The high purity of the cylindrical TE_{01} mode must be needed to produce the designed Q-value and efficiency. Thus the many unnecessary modes can reduce the high Q-value and the efficiency if we directly connect the rectangular waveguide to the resonant cavity, so that the 4-hole coupling type mode converter is applied between 3-db hybrid coupler and the cavity, and it can also reduce the surface electrical field strength each coupling hole. This is very important to provide the stable operation at 150MW class RF power. And in order to limit the number of propagation mode inside the circular waveguide, its diameter was chose as small as 80mm. The four coupling irises generate rotation electric field symmetrically to excite only the TE_{01}mode. Computer simulation using CST predicted the VSWR is 1.05 for the 5MHz bandwidth.

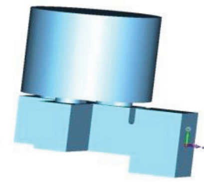

Figure 11: Schematic drawing of the mode converter.

Figure 11 shows the simulated S-parameters of the mode converter. From this plot, we can see that the transmission coefficients of the other inconvenient modes become lower than 0.1 as S_{11}.

Table 3: Parameter of the Mode Convertor

Rectangular:	BJ48, l=31.25mm
Cross rectangular:	l_1= 22mm h= 35mm
Cylindrical:	R=40mm,l=65mm
Coupling hole: height	h=4mm,a=22.18mm,b=16mm
Simulation	S_{11}<30dB; S_{21}=0dB

Results of simulation by CST：

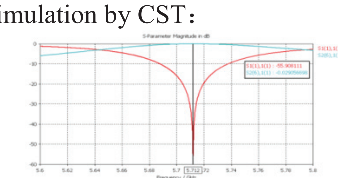

Figure 12: Simulated S-parameter of the mode converter.

CONCLUSION

C-band pulse compressor, as a key technology for the SINAP soft X-ray FEL, have been simulated in this paper. The resonant cavity is fabricated and measurement. The simulation result and the measurements are matching well. Some components for the c-band pulse compression are also designed and will be constructed in the future.

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