THE C-BAND RF PULSE COMPRESSION FOR SOFT XFEL AT SINAP

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Abstract

A compact soft X-ray free electron laser facility is presently being constructed at Shanghai Institute of Applied Physics Chinese Academy of Science (SINAP) in 2012 and will be accomplished in 2014. This facility will be located to the shanghai synchrotron radiation facility (SSRF) which is a third generation light source in china. It requires a compact linac with a high-gradient accelerating structure for a limited overall length less than 230m.The c-band technology which is already used in KEK/Spring-8 linear accelerator is a good compromise for this compact facility and a c-and traveling-wave accelerating structure was already fabricated and tested at SINAP[1], and a c-band pulse compression will be required. There are some reasons, why RF pulse compression devices are quite useful to be applied in RF power supply of the soft XFEL. For it can 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, so we need the c-band pulse compressor. AND a SLED type RF pulse compression scheme is proposed for the C-band RF system of the soft XFEL and this scheme uses TE0.1.15 mode energy storage cavity for high Q-energy storage.

The C-band pulse compression under development at SINAP has a high power gain about 3.1 and it is designed to compress the pulse width from 2.5μs to 0.5μs and multiply the input RF power of 50MW to generate 160MW peak RF power, and the coupling coefficient will be 8.5. It has three components: 3-dB coupler, mode convertors and the resonant cavities. In this paper C-band pulse compression and some components for the c-band pulse compression will be described.

INTRODUCTION

The future c-band accelerator structure of SXFEL 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 as to reduce the total number of the klystron and enhance the peak RF power, the RF pulse compression is needed.

RF pulse compression is one of the methods to compress the RF pulse length and at the same time increase the peak RF power that klystron deliver. RF pulse compression is based on the principle that the RF pulse is stored in a resonance cavity or a delay line and emitted within a short time to create the short RF pulse with high peak power and then deliver it into accelerating section. At present, several RF pulse compressions systems have been already utilized successfully in the s-band or c-band linear accelerator, such RF pulse compression, the SLAC Energy Double (SLED) was the first, it was successfully applied in SLC operation, and now SLED-I，SLED-II，SLED-III（coupled cavities），BPC，DLDS and VPM（BOC）were already developed.

BPC，SLED-II and DLDS use the delay line as the energy storage cavity, have the flat output, high power gain and high efficiency, but the delay line is long and not economical. SLED-III（coupled cavities）use coupled cavities as the energy storage cavity, reduce the length of the delay line, but the output power irregular. It is applied a complex amplitude modulation on the input RF power, it is hard to control the accuracy and the stable. SLED-I has the simple structure and work stable, but it has the low power gain and less efficiency and a decaying exponential output pulse shape, so the technology AM-PM is applied for the flat output pulse shape.

In the soft XFEL, 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 for the soft XFEL, we adopted a SLED type pulse compression as the c-band pulse compressor. This scheme use TE0.1.15 mode for 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 XFEL. 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.

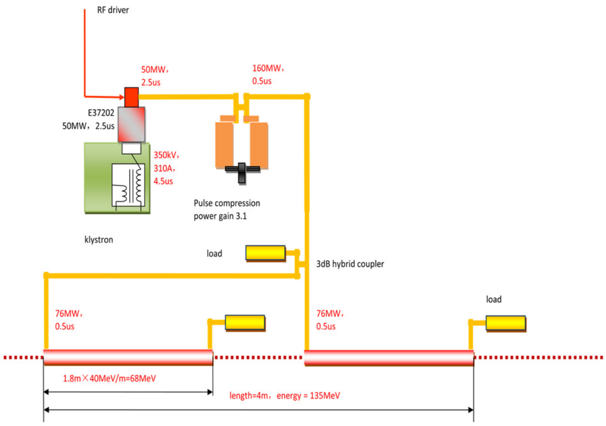

Figure1: C-band 50WM RF Scheme.

C-BAND PULSE COMPRESSOR

C-band Pulse Compressor

For the SLED type RF pulse compression, the expression of the power for the resonant cavity is[2]

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

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

The expression of the energy multiplication factor Vmax is

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

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

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

Q value of the TE_{0115}mode[3]

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

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

Optimize the cavity diameter：

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

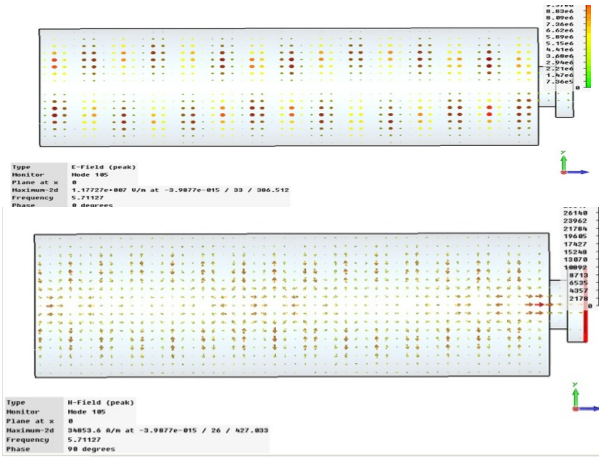
$$\left(\frac{f_0D}{c}\right)^2 = \left(\frac{\upsilon_{mn}}{\pi}\right)^2 + \left(\frac{pD}{2l}\right)^2 \quad (p \neq 0) \quad (4)$$

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.

Table 1: Parameters of the pulse compression cavity

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

The results of simulation by CST are shown in Fig. 2.



Type E-Field (peak)
Monitor Mode 105
Plane at x 0
Maximum-2d 1.17727e+007 V/m at -3.9877e-015 / 33 / 386.512
Frequency 5.71127
Phase 0 degrees

Type H-Field (peak)
Monitor Mode 105
Plane at x 0
Maximum-2d 34853.6 A/m at -3.9877e-015 / 26 / 427.033
Frequency 5.71127
Phase 90 degrees

Figure 2: The cavity mode simulated by CST.

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 for the RF pulse compression system. In the cavity 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 3-dB coupling, they were designed 76mm and 60mm, respectively.

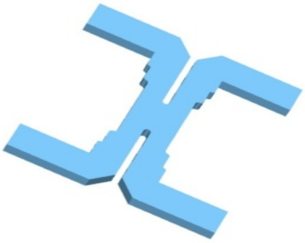


Figure 3: The 3-db hybrid coupling.

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

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

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.

Table 2: Parameters of the 3-db coupler

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

The results of simulation by CST are shown in Fig. 4.

Mode Converter

Many modes are concentrated around the target TE0.1.nmode 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 TE_{01}nmode cavity, so that a mode converter is applied between the 3-db coupler and the cavity to reduce unnecessary modes. The mode converter is shown in Fig. 5.

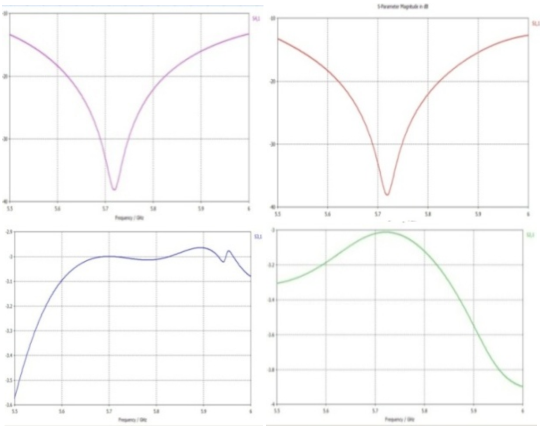


Figure 4: The simulation of the 3-db hybrid coupling.

The simulated S-parameters of the mode converter shows that the transmission coefficients of the other inconvenient modes become lower that 0.1 as S_{11}.

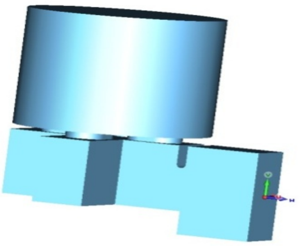


Figure 5: Mode convertor

Table 3: Parameters of the Mode Convertor

Rectangular:	BJ48, l=31.25mm
Cross rectangular:	l=80mm h=35mm
Cylindrical:	R=40mm,l=65mm
Coupling hole: Coupling height	h=4mm,a=22.18mm,b=16mm
Simulation	S_{11}<-30dB; S_{21}=0dB

The results of simulation by CST are shown in Fig. 6.

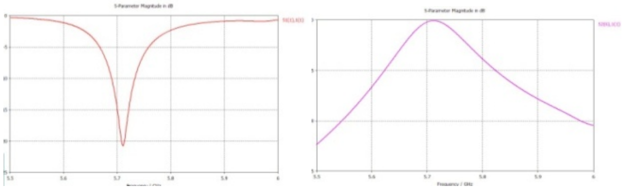


Figure 6: The simulation of the mode convertor.

CONCLUSION

In this paper we designed c-band pulse compression use TE_{0115} mode for the soft the SINAP SXFEL, and it will be fabricated in the future. And also some components for the c-band pulse compression are also designed. The low mode RF pulse comression cavity is fabricated in the SINAP.

REFERENCES

[1] Fang W C, Gu Q, Tong D C et al., Design optimization of a c-band traveling-wave accelerating structure for a compact X-ray free electron laser facility, Chinese Sci. Bull, 2011,56(32):3420-3425

[2] Z.D. Farkas, H.A. Hogg, G.A. Loew and P.B.Wilson, SLED:A METHOD OF DOUBLING SLAC's ENERGY, SLAC-pub-1453, June 1974

[3] XIAO Ou-Zheng, ZHAO Feng-Li, HE Xiang, Design and simulation of a c-band pulse compressor, CPC,2012,36(4):360-363

[4] Mitsuhiro Yoshida, Ph.D Thesis, The Research and Development of High Power C-band RF Pulse Compression System using Thermally Stable High-Q Cavity