THE RF SYSTEM OF INFRARED FREE ELECTRON LASER FACILITY AT NSRL *

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Abstract

An infrared free electron laser light source (IRFEL) is being constructed at National Synchrotron Radiation Laboratory, which could be used in the study of far infrared detection, light dissociation and light excitation. The accelerator of IRFEL deliver an average current 300 mA electron beam at 15~60 MeV, the energy spread is less than 240 keV, and the emittance is less than 30 mm*mrad. IRFEL is consisted of two optical resonator system, which could create 2.5~50 um, 40~200um infrared laser respectively. The design of IRFEL RF system is introduced, the recent progress of prebuncher, buncher, frequency distribution, accelerator and DLLRF system are also present in this paper.

INTRODUCTION

RF system is main part of IRFEL linac, which is used to compress and accelerate the electron beam. The IRFEL linac is composed of prebuncher, buncher and two accelerating sections. The prebuncher is a single resonant cavity, and the buncher is a 1-meter travelling wave accelerating construct. The accelerating section is 2-meter constant gradient travelling wave accelerators. The pulse length of electron beam is 1 ns from the electron gun, and the charge quantity is 1.5 nC. At the end of linac, the pulse length is compressed to 10 ps, and the beam energy reaches 60 MeV. The layout of IRFEL RF system is shown in Figure 1.

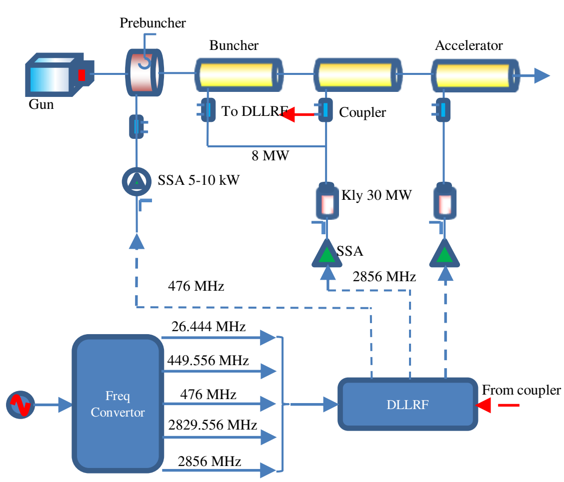

Figure 1: Layout of IRFEL RF system.

*Work supported by the National Science Foundation of China (11575181, 11605202)

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DESIGN OF IRFEL RF SYSTEM

Each section is fed by Toshiba E3729 klystron, which could offer 35 MW output power. The power for prebuncher is much less than buncher and accelerating section, so a 10 kW solid state amplifier is used as the power supply for prebuncher. The output of first klystron is divided into two-branch, one provides 8 MW for buncher, the other branch is 20 MW, which supplies power for the first accelerating section. According to this design, the energy of electron gain 30 MeV, by passing each accelerating section.476 MHz reference signal is produced by Keysight N5181B source. The frequency convertor system creates several signals, such as the clock signal, local signal, IF signal and excitation signal. The digital down conversion and acquisition is achieved by digital low level system. It also completes the complex feedback calculation, in order to maintain amplitude and phase in high stability.

Prebuncher and Accelerator

The prebuncher is a standing wave resonant cavity. Due to the high current, the beam loading effect is quite strongly. For purpose of reducing beam loading effect, lower Q factor and shunt impedance R is designed. Therefore stainless steel is used as cavity material. The simulation result of electric field in the cavity is obtained using CST code, as shown in Fig. 2. The cavity resonant frequency is 476.0031MHz, Q factor is approximately 3000, and shunt impedance is 440 kΩ. The dimension parameter of prebuncher is list in Table 1.

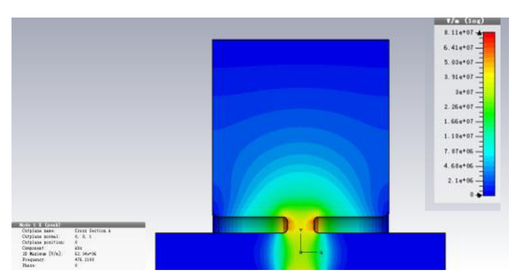

Figure 2: Simulation of E-field distribution in prebuncher.

ISBN 978-3-95450-182-3

Table 1: Dimension Parameter of Prebuncher

Parameter	Value (mm)
Cavity length	140
Beam channel length	89.5
Cavity thickness	10
Cavity radius	151.88
Nose length	59.5
Top nose radius	3
Bottom nose radius	5
Beam channel radius	30
Gap	21

We don't want a cumbersome prebuncher, but if the cavity thickness is too thin, plastic deformation may occur under atmosphere pressure, cavity resonant frequency may deviate from operating frequency, and the Q factor and shunt impedance would change a lot.

A simulation method combining ANSYS and SUPERFISH is used to calculate the cavity frequency and field distribution variation due to small deformation caused by atmosphere pressure [1]. As it is shown in Figure 3 and figure 4, cavity thickness is 10 mm, the frequency deviation is less than 5 kHz, and the plastic deformation would not occur.

It is hard to estimate the deformation cause by welding, so an aluminium prototype cavity is produced to accumulate experience. The frequency, Q factor, shunt impedance of prototype are quite agreement with the simulation. The cooling and supporting system are both shown in Fig. 5. The frequency deviation caused by argon arc welding is approximately 2 MHz. We also test the parameter of prebuncher, and the test result is shown in Figure 6.

The traveling accelerating structure technology is used in buncher and 2-meter accelerator. The main parameter is list in Table 2.

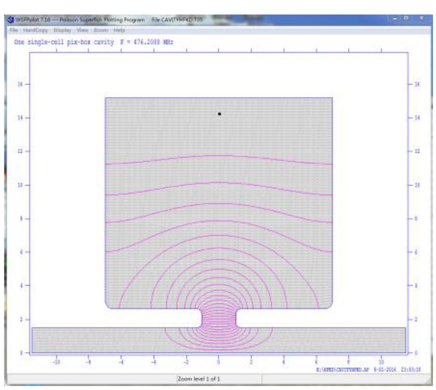

Figure 3: Simulation of frequency deviation by using SUPERFISH.

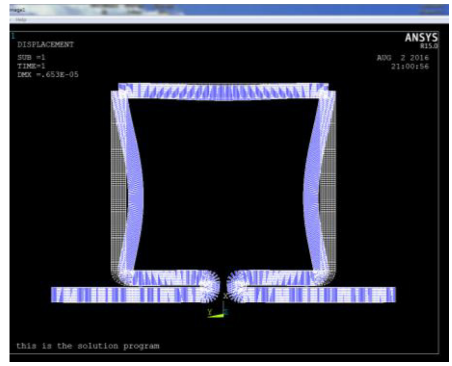

Figure 4: Simulation of deformation by using ANSYS.

Table 2: Parameter of Accelerating Section

Parameter	Value
Rs (MΩ/m)	55 - 63
α (Np/m)	0.12 – 0.34
τ (Np)	0.398
T_F (us)	0.6

Figure 5: Prototype of prebuncher.

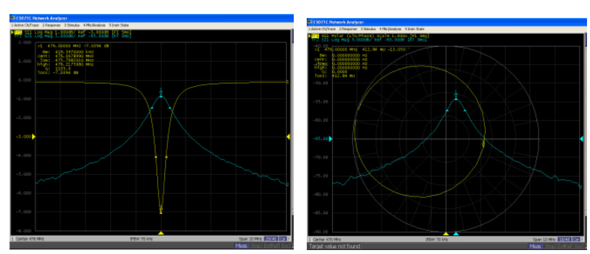

Figure 6: Test of prototype prebuncher.

Frequency Convertor and DLLRF System

Frequency synthesis technology is to create lots of different frequency signal by transforming reference signal, and the output signal has the same accuracy with reference signal.In general, frequency synthesis technology falls into three categories: direct frequency synthesis (DS), phase lock loop (PLL), direct digital synthesis (DDS). The performance comparison of each frequency synthesis technology is shown in Table 3.

Table 3: Performance Comparison of each Frequency Synthesis Technology

Parameter	DS	PLL	DDS
Stability		Depend on ref	
Clutter	Lower (Depend on filter)	Lower	Higher
Operation frequency	Higher	Higher	Lower
Volume	Biger	Smaller	Smaller
Phase jitter	Lower	Moderate	Higher
Phase nose	Much Lower	Moderate	Lower

The direct frequency synthesis generates the output signal by mixing, dividing, multiplying the same reference signal, so the output signal generated by DS has no phase shift in theory, and no accumulation of phase shift in long turn. The PLL and DDS are widely used in muti-frequency and muti-channel communication system. However, digital phase demodulator and phase lock loop may cause some phase jitter in DDS and PLL system. Based on a comprehensive consideration, the DS technology is selected for our frequency convertor system. The design of frequency convertor system is shown in Figure 7.

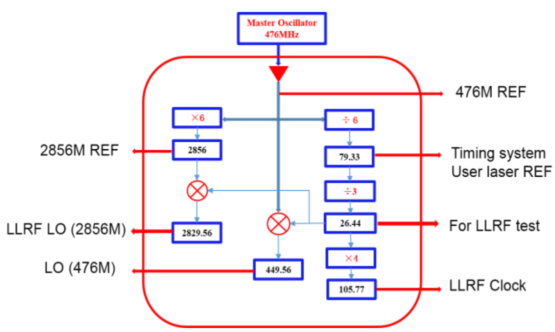

Figure 7: Design of frequency convertor system.

At present, the prototype of frequency convertor system has been manufactured and tested. Figure 8 is the prototype of frequency convertor system. Semiconductor thermoelectric cooler technology is used in this prototype to guarantee temperature stability. The short turn and long turn stability could be 0.0012°C and 0.002°C respectively. As it is shown in Figure 9, the phase noise is less 80 dBc, and phase shift is 1°/°C.

Figure 8: Prototype of frequency convertor system.

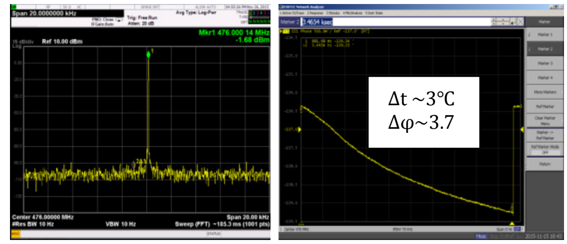

Figure 9: Test of frequency convertor system prototype.

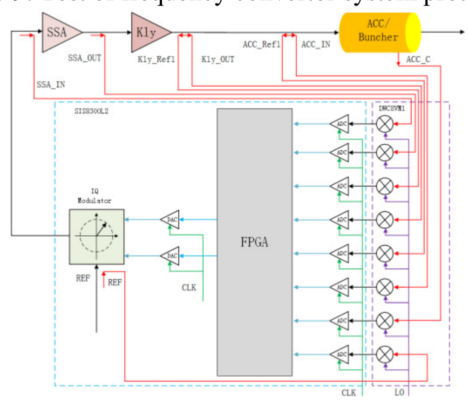

Figure 10: Diagram of LLRF.

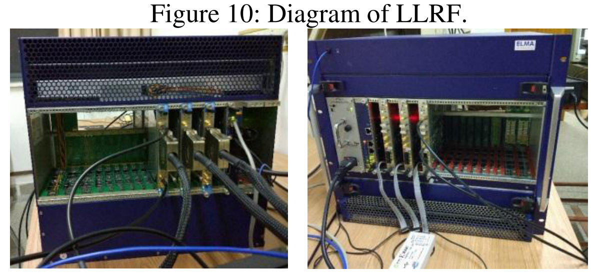

Figure 11: Picture of LLRF system.

Figure 10 shows the diagram of LLRF system. MTCA.4 system structure is used in the LLRF, which have the advantages of flexible backplane structure, better heat dissipating, reliability, openness and compatibility [2]. The RF board and the digital signal processing board is carried on the MTCA.4. 476MHz and 2856MHz signal are both down converted to IF signal of 26.44MHz by RF board. This board also have the function of IQ vector modulation output. The DSP board which carry FPGA is used to sample, IQ demodulate and control IF signal. LLRF system is shown in figure 11.

SUMMARY

In this paper, we present the progress of IRFEL RF system. The prototype of prebuncher, frequency convertor and DLLRF are all developed, both of the prebuncher and frequency convertor are tested. In next step, the DLLRF system would be tested offline.

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ISBN 978-3-95450-182-3