S-BAND HIGH POWER RF SYSTEM FOR 10 GeV PAL XFEL*

W.H. Hwang#, Y.D. Joo, Y.J. Park, S.H. Kim, H.G. Kim, H.S. Lee, H.S. Kang, J.Y Huang
Pohang Accelerator Laboratory, Pohang 790-784, Korea

Abstract

In PAL, we are undergoing a 10 GeV PxFEL project. The output power of the klystron is 80MW at pulse width of 4 μs and the repetition rate of 60 Hz. In high power operation, it is important to decrease the rf electric field to break-down in high power components. To obtain the maximum beam energy, we must reduce the phase difference between waveguide branches including accelerator structure and minimize the environment influences. This paper describes the waveguide system and high power rf components for the PxFEL.

INTRODUCTION

Pohang Accelerator Laboratory, PAL, is under constructing a FEL Machine. The PxFEL is a 4th generation light source to produce a coherent X-ray free electron laser. This machine is designed with a S-band rf linear accelerator to obtain a 10 GeV electron beam. The linac design parameters for the PxFEL are shown in Table 1. The rf stability is a key issue to get stable beam for the PxFEL. The specifications of the beam energy spread and rf phase are 0.05 % (rms) and 0.05^{o} (rms) respectively. RF stability influences the electron beam energy and the beam energy spread. The long-term drift caused by environmental condition can be corrected by the rf phase feedback system. The short-term variations can be corrected by a stable modulator system.

Table 1: Linac Parameters for the PxFEL

Parameters	Specification
Main Accelerating Structure	Quasi-sym. type
Beam Energy	10 GeV
Beam Energy Spread	<0.05 %
Beam Emittance	<0.5 μm-rad
Beam Current	>3.0 kA
Operating Frequency	2856 MHz
No. of Klystrons	46
No. of SLED	46
No. of Acc. Columns	174
Modulator Voltage Stability	<50 ppm rms
RF Phase Stability	$<0.05^{o}$ rms

The major components of PxFEL are shown schematically in Figure 7-1. There are 46 S-band high power klystrons, 46 SLED-type pulse compressors, and 174 S-band constant gradient accelerating sections to obtain 10GeV beam energy. A short X-band rf section, operating at 11.424GHz, provide 4th harmonic correction to the energy gradient along the bunch before it passes through the first bunch compressor chicane[1].

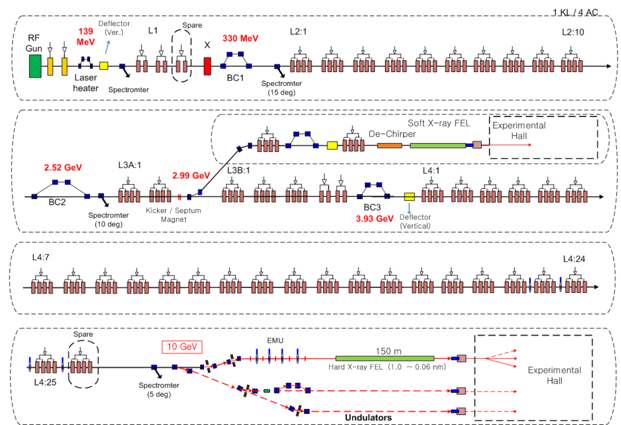

Figure 1: Schematic diagram for the PxFEL.

HIGH POWER RF SYSTEM FOR PXFEL

The high power waveguide system in one module consists of a s-band klystron, a SLED-type pulse compressors, and four constant gradient accelerating sections.

Design of Waveguide System

The distance between the RF input ports of the accelerating sections is 31 λ_o or 32 λ_o. The phase difference among branches of the high power waveguide network must be adjusted within 1 degree. The cooling temperature of the waveguide system is controlled within 30 ± 0.02 °C. A SLED will be installed in tunnel to minimize environment temperature perturbation as shown in Figure 2 and Figure 3.

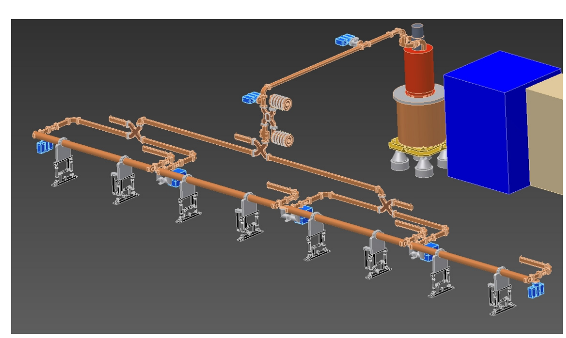

Figure 2: Layout of one klystron module.

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hohwang@postech.ac.kr

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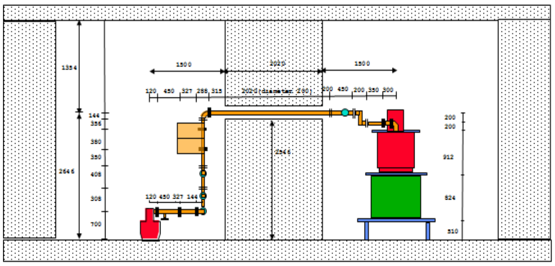


Figure 3: Waveguide network.

Accelerating Structure

There are 174 accelerating sections in the main linac, which are SLAC-type constant gradient structures as shown in Table 2. S-band accelerating section operated with 2π/3 mode is 3138mm long and has conflate flanges for easy installation and maintenances. The attenuation of an accelerating section is about 4.9 dB. The rf feeding coupler is used the quasi-symmetry type to minimize the beam kicking as shown in Figure 4. The maximum accelerating gradient of the S-band structure is 30MV/m. A X-band structure requires a modest power source to operate at 37 MV/m over a length of 0.6m to generate the needed 24MV of X-band rf [1].

Table 2: Specification of Accelerating Structure

Parameters	*S-band*	*X-band*
Frequency (MHz)	2856 ±0.5	11,424
Mode	2π/3	2π/3
Q	13,000	7,000
Shunt Impedance (Mohms)	53	~67
Attenuation Constant	0.57	0.52
Filling Time(μs)	0.83	0.1
Water Temperature(°C)	30 ± 0.02	
Coupler Type	Quasi-Sym.	
Total Length(mm)	3138	750

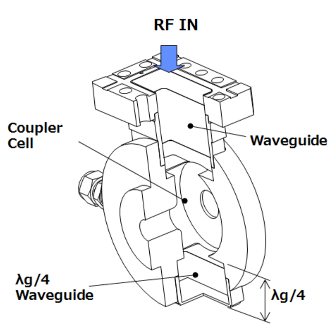


Figure 4: Quasi-symmetric type coupler.

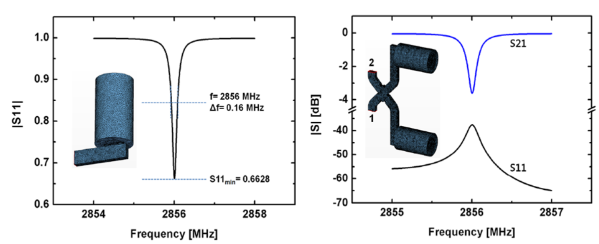
Design of SLED

A pulse compressor can increase the peak power of microwaves instead of reducing the input pulse width. We will use an rf pulse compressors to get a high energy gain in the accelerating sections. The rf pulse compression system, called as SLED (SLAC Energy Doubler), was first developed in 1970' [2, 3]. The parameters of SLED for PxFEL are shown in Table 3. When the rf phase reverse at 3.17 μs after the rf pulse turns on, the power gain is higher than 7 dB. The SLEDs will be installed in the tunnel to prevent the affect by room temperature variation.

Table 3: Specification of SLED

Parameters	*S-band*
Frequency (MHz)	2856 ±0.5
Input Peak Power (MW)	80
Cavity Mode	TE_{015}
Unloaded Q	10^5
Coupling Coefficient	5.0
Input Pulse Width (μs)	4.0
PSK Time (μs)	3.17
Water Temperature (°C)	30 ± 0.02

For SLED design, it is important to reduce the filed strength at iris in cavity and in 3-dB coupler. We are under designing a pulse compressor with dual iris coupler to reduce field strength at iris of cavity. The full three-dimensional FDTD (Finite-Difference Time-Domain) simulation, Microwave Studio (MWS) [4], is carried out to design the characteristic of the SLED with bi-planar 3 dB coupler [5] and dual iris cavity.



(a) Dual iris coupling (b) SLED with 3 dB hybrid

Figure 5: SLED with dual iris coupling.

The simulation result of the designed bi-planar 3 dB coupler is -50dB of return loss, 3dB of power ratio, and 90 degrees of phase difference between two ports. The simulated maximum peak electric field is about 700 V/m, which is half of that of original 3-dB coupler. And the high field at the coupling iris between waveguide and cavity leads to serious breakdown and radiation safety hazards, so that limits the maximum power of SLED in practice. It is reported that the concept of two port side-wall coupling irises is a good solution [5, 6]. We designed a SLED with dual iris cavity. The MWS simulation is carried out to find the Q-factors and coupling coefficient. As shown in Figure 5(a), the S11 value at the resonance is about 0.668 and the coupling coefficient is calculated as about 4.93. The half maximum frequency difference is about 0.16 MHz, which means the Q factor is about

106000. The simulated return loss and insertion loss of the SLED with bi-planar coupler is -40dB and -5 dB respectively as shown in Figure 5(b). The calculated maximum electric field strength of the dual-irises cavity is just two of thirds of that of single-iris cavity.

Design of SiC Dummy Load

A 50 MW SiC load at 1.0 μs was developed with indirect cooling pipe by Dr. Matsumoto in KEK [7]. Also IHEP developed a same type dummy load. We measured the dielectric constant and loss tangent of IHEP SiC rod by using network analyser with Agilent 85070E dielectric probe. The dielectric constant and loss tangent of IHEP SiC rod was 15.6 and 0.14 respectively. We simulated the SiC load with measured data by using MWS as shown in Figure 6. The simulated return loss at 2856 MHz is 35 dB and is less than 1.1 of vswr as shown in Figure 7. The simulation result is nearly same as measure results.

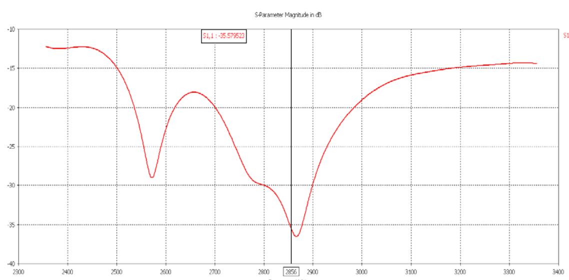


Figure 6: Simulated results of SiC load.

Design of Directional Coupler

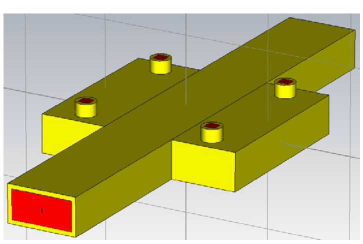


Figure 7: Simulated results of SiC load.

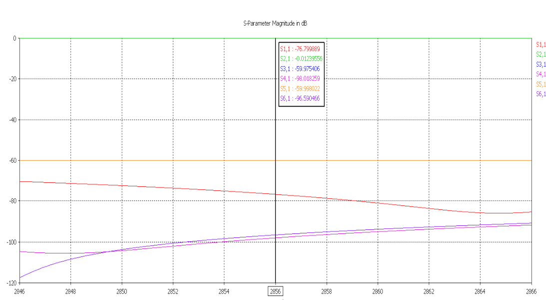


Figure 8: Simulated results of SiC load.

A directional coupler with good directivity is important to measure the power and phase accurately. The designed directional coupler is shown in Figure 7. The simulation results of the directional coupler are 70 dB of return loss and 37 dB of isolation in Figure 8.

SUMMARY

The newly proposed 0.1 nm SASE FEL at the PAL are employed in conjunction with the S-band rf linear accelerator to produce the 10 GeV electron beam. Among several possible options, we choose a layout which consists of a conventional normal conducting S-band rf linear accelerator. The input of accelerating structure is a quasi-symmetric coupler to minimize the beam kicking. When a 60 MW klystron drives four accelerating sections, the S-band rf linac combined with SLED can provide a maximum 19.3 MV/m accelerating gradient. As a result, the total length of the linac is about 720 m. We designed a new SLED system with the bi-planar 3 dB coupler and the dual side-wall coupling using MWS simulation to reduce the field strength at SLED. The designed SLED system will be effect to break loose from the rf breakdown in the high power operation. For the new 3 dB power splitter, the maximum electric field is reduced to the half of original one. The electric field at the coupling irises is also reduced to two of thirds of original one by using dual iris.

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