THE DEVELOPING OF THE BEAM INJECTION SECTION WITH LASER SOURCE AND S-BAND ELECTRON RF GUN FOR SUPERKEKB PROJECT

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Abstract

For the beam injection at Linac accelerator of the SuperKEKB project, the s-band RF gun needs to provide low-emittance high-charge electron bunches. A photocathode RF gun system with an advanced RF cavity structure (quasi-travelling side-coupled structure, cut disk structure), a new photocathode material (Ir_5Ce cathode) and a hybrid laser system (Yb fiber and Nd:YAG hybrid system) have been developing in the SuperKEKB injector Linac. Furthermore, many monitors and remote controls program were built to increase the stability of operation. By the injection system, the required charge and emittance for Phase-II commissioning were achieved.

INTRODUCTION

KEK injector Linac has delivered electrons and positrons source for high energy accelerator research, particle physics and photon science experiments for more than 30 years. Then, KEKB is being upgraded towards the SuperKEKB which is an asymmetric energy of 7-GeV electron and 4-GeV positron double-ring collider [1]. Full-energy, high-charge and low-emittance beams are necessary in order to achieve a design luminosity of 8×10^{35} $cm^{-2}s^{-1}$ for the study of the flavour physics of elementary particles. The injector continues to deliver various beams to SuperKEKB and light source rings such as PF and PF-AR.

In the positron beam, new Flux Concentrator (FC) and capture section was developed for efficient positron generation. Since generated positron beam has large emittance, new damping ring (DR) has been constructed to reduce beam emittance. Therefore, the thermionic electron gun was reinstalled for positron beam generation with the charge of 10 nC [2].

For the injector upgrade, the electron beams with a charge of several nC and a normalized emittance of less than 10 μm are expected to be generated in the electron gun. A thermal cathode DC gun had been used for KEKB. Because the DC gun could not make low-emittance beam, a quasi-traveling wave side couple (QTWSC) RF gun which has two side coupled standing wave field was developed [3]. This gun has a strong focusing field at the cathode and the acceleration field distribution also has a focusing effect. In addition another cut disk structure (CDS) RF gun was installed to 90 degree injection line. These guns have been used for electron beam study.

A multi-crystalline iridium cerium (Ir_5Ce) compound is used as a photoemitter of a high charge and low emittance RF gun [4]. The quantum efficiency (QE) is approximately 9.1×10^{-4} with 219 nm laser source at room temperature, which has the long lifetime (>LaB_6).

For the laser source, an Ytterbium-doped (Yb-doped) fiber and Ytterbium-doped YAG (Yb:YAG) hybrid laser system was development. 30 ps, mJ-class, 257 nm ultraviolet (UV) pulse was provided and injected to the photocathode [5].

The Phase I beam commissioning successfully ended in the June of 2016. The electron beam and positron beam with the bunch charge of around 0.7 nC is successfully delivered to the end of beam transport line.

Table 1: Requirements for Linac in SuperKEKB Phase II

	Electron HER 7 GeV	Positron LER 4 GeV
Normalized emittance $\gamma\beta\varepsilon_x$ / $\gamma\beta\varepsilon_y$	150 / 150 [μm]	200 / 40 [μm] with damping ring
Energy spread σ_δ	0.10 [%]	0.16 [%]
Bunch charge at injection point	1.0 [nC]	0.5 [nC]

Towards Phase-II beam commissioning, the high-charge and low-emittance beam development is going on for the higher requirement (Table. 1). The mainly improvement is the laser source. An Ytterbium/Neodymium (Yb/Nd) hybrid laser system was developed. With the synthetic crystalline material Neodymium-doped YAG (Nd:YAG), high reliability of the laser source is realized. The layout of the electron guns and laser system is shown in Fig.1. The transport line between the laser and RF gun was restored with the backup line and remote control system.

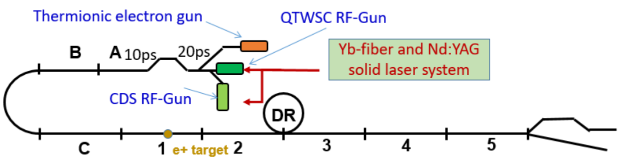

Figure 1: Layout of Linac.

Yb/Nd DOPED HIBRID LASER SYSTEM OF RF GUN

Based phase-I commissioning, the laser system for RF gun consisted Yb-doped fiber oscillator, Yb-doped fiber amplifiers and Yb:YAG thin-disk laser amplifiers. Yb:YAG crystal has large absorption bandwidth to reduce thermal management requirements for diode lasers, a longer upper-state lifetime, three to four times lower thermal loading per unit pump power, which is more suitable

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for diode-pumping for high power diode-pumped lasers. Yb:YAG Thin-disk regenerative amplifier system was employed in phase-I commissioning. Compared with the Yb:YAG crystal, commonly used Nd:YAG rods with high optical homogeneity, high damage threshold, consistent performance and high processing accuracy. Although the pulse shaping of Nd:YAG is difficult to be adjusted because of the narrow spectrum gain, the structure of the Nd:YAG is simple, that means reliable convenience and less maintenance. The Emission wavelength of Yb:YAG and Nd:YAG are around 1030 nm and 1064 nm with the bandwidth of ~3.0 ns and ~0.5 ns, which contained in the spectrum of Yb-doped fiber oscillator. Therefore, the Yb-doped oscillator and Yb-doped fiber amplifier also can be used with Nd:YAG amplification. For higher reliability requirement of the Phase-II commissioning, Nd:YAG are appropriate candidate for laser amplifier system [6].

Therefore, the laser system upgraded, consists Yb-doped fiber oscillator, Yb-doped fiber amplifiers and Nd:YAG rod laser amplifiers. The detail of laser part that shows in Figure 2.

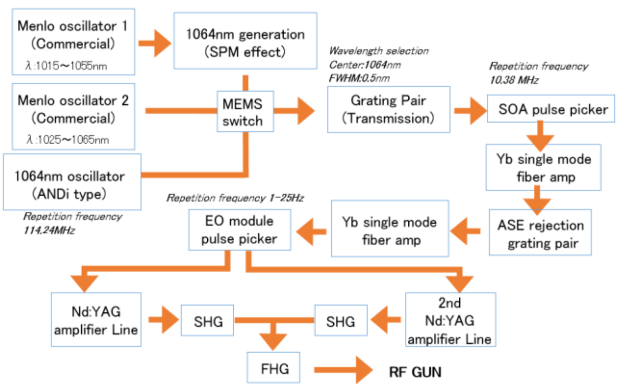

Figure 2: Layout of laser system.

Yb-doped Fiber Part

The laser system starts with three 114 MHz mode lock Yb-doped fiber oscillators. Two of them are commercial products (Menlo system), the other one is homemade cavity with the all normal dispersion (ANDi) structure. One MEMS optics switch is adopted to select oscillator for the following amplifier stages. A transmission grating pair stretcher was employed to expend pulse to ~10 ps and select the spectrum width of 0.5 nm with the centre wavelength of 1064 nm. The weak pulses reduced repetition rate to 10.38 MHz by a semiconductor optical amplifier (SOA) pulse picker, which was driven by a ~5 ns 100 mV electrical pulse at 10.38 MHz amplified through a high power RF amplifier. To compensate the energy loss of the gratings and SOA, two stages Yb-doped single mode fiber amplifier was employed. Because the amplified spontaneous emission (ASE) easy to be amplified with the weak seed pulse by strong pump power, an additional transmission grating was used to separate and cut the noise by a slit. After fiber amplifier, an Electro-optic module (E.O.) adopted as a pulse picker is used to pick out the 1-25 Hz signal from a sequence of pulses of 10.38 MHz [7].

Nd:YAG Amplifier Part

In order to guarantee the injection and commissioning reliably, two beam lines were prepared. At the end of the fiber part, the signal was separate to two equal parts (first beam line and second beam line) by a polarizer.

The first line which has 4 stages Nd:YAG rod amplifiers is proposed to provide the stable laser pulses with high quality. 2×79 mm Nd:YAG rod crystal are used in the first and second stages for high amplification efficiency. A Pockels cell pulse picker is insert to switch the single/double bunch mode. After the Pockels cell, the third and fourth stages amplify the pulse energy up to the 4.0 mJ by using of 4×93 mm Nd:YAG rod crystal. Then the green pulses of 532 nm were generated by using a frequency-doubling stage with 5 mm thickness beta barium borate (BBO) crystal. As the Figure 3, more than 1.8 mJ second harmonic generation (SHG) pulses was obtained with the good beam profile and 17 ps pulse width that measured by the streak camera.

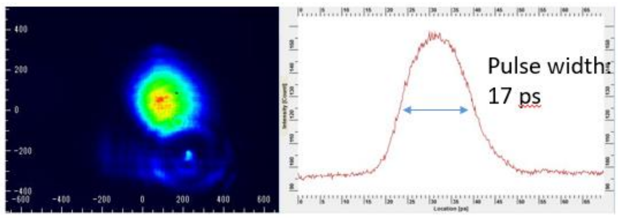

Figure 3: Beam profile and beam width of laser source.

Different from the first line, an additional fifth Nd:YAG amplifier stage (Φ8 mm) is built in the second line to pursue higher pulse energy. The amplified pulse energy is up to 8.0 mJ. And more than 3.8 mJ pulse energy of SHG beam is obtained during the frequency-doubling stage.

TRANSPORTING LINE

There is about 12 m distance from the laser clean room to the underground RF gun. The transport line is focus to reduce the energy loss and jitter in the air. Therefore, vacuum tube was built to isolate the air turbulence between the laser room and RF box. Two laser beams are converged by a polarizer and transported to RF gun box by one transporting line. Inside the RF gun box, the laser beams are separated again by another polarizer. The transport rate can be up to 80%. UV pulses were generated by BBO frequency-doubling stages. 450 μJ and 800 μJ are achieved by the first and second laser line to RF gun. The optics system is shown in Figure 4. The total efficiency of the ω-4ω is more than 10%.

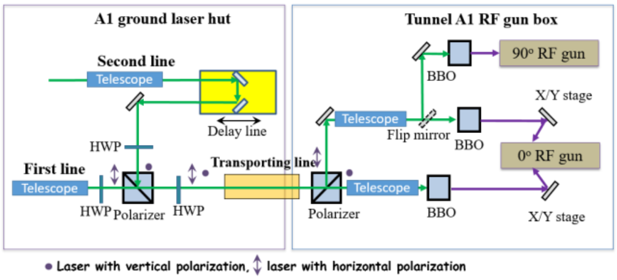

Figure 4: Transporting line.

The QTWSC RF gun could be irradiated by each laser sources with 60 degree, and another laser source works with the backup line. Furthermore, it is optional to select two laser injection with both sides. A delay line is inserted into the second laser line to adjust the optical path for realizing two laser synchronous injection into RF gun.

Also, a flip mirror is placed in the first laser line for changing the transmission direction to the 90 degree CDS RF gun.

MONITORING AND REMOTE CONTROL SYSTEM

Since the electron beam with high stability and quality are required in Phase-II commissioning, the status of laser system and RF cavity are monitored and recoded.

In oscillator, the stepping motor and piezo that adjust the frequency in the cavity is controlled to synchronize RF frequency signal. Status monitors and I/Q monitor are employed for detect the mode-lock and synchronization. When the RF frequency is drift, the laser frequency can be auto-adjusted immediately.

The temperature of the laser room and RF gun cavity and all the current of the power supply are monitored and recorded. Furthermore, the pulse output power of the every stages and the pulse shaping of the every pulse pickers are also monitored by photo diode detectors. The long term reliability of laser are recorded, and any unusual changes will be alarmed by monitoring system.

The optics system inside RF gun box is set near the electron gun. A beam profile monitor and laser energy meter are set in the first laser line to oversee the laser status. The real-time data can be confirmed on internet anytime. For optimize the laser source in the commissioning study, lots of adjustment unit were insert, such as telescope lenses distance, BBO crystal angle, X/Y stage and rotation stage. All of these units are adjusted by fully remote control. Thus, we can get the best condition to generate highest electron charge during beam study.

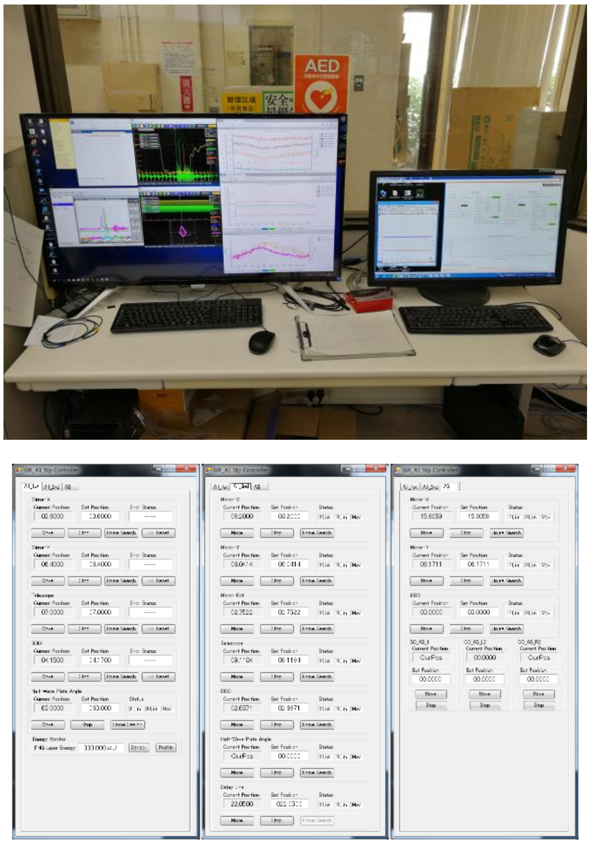

Figure 5: monitoring and remote control panel.

Figure 5 shows the monitoring and remote control system panel by windows-PC. Thanks to the monitoring and remote control system, the all beam injection section is continuously working during the Phase-II commissioning.

RF GUN STUDY FOR PHASE-II COMMISSIONING

SuperKEKB phase II commissioning has been performed since March to July 2018. The injection sector beam study has also performed. By use of first line laser source, 1.4 nC electron beam is generated, and the 1.1 nC electron charge is remained at end of the Linac. The beam orbit, energy were carried out without any significant issues. In contrast, 2.4 nC is obtained at end of the Linac by use of the second beam line. By the both side lasers irradiation, 3.3 nC electron beam is delivered successfully. Accordingly, about 2.3 nC electron charge is prepared for injection to High energy ring (HER) of the ring accelerator. The orbit and electron charge records are shown in Fig.6.

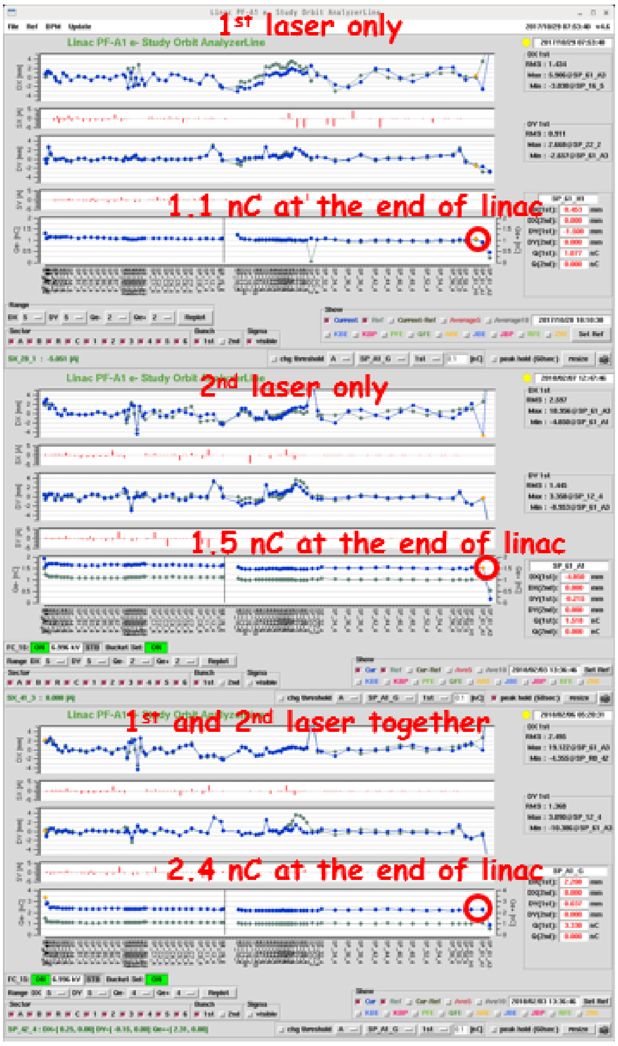

Figure 6: Orbit and electron charge by laser source.

The emittance of electron beam generated by RF gun is also measured by wire scan method. At Linac sector B, the end of the RF gun, the horizontal and vertical emittance $\gamma\varepsilon_x$=24.958, $\gamma\varepsilon_y$=18.640 was obtained respectively. Then the high bunch low emittance electron beams are transporting the Linac include the J-arc section. The horizontal and vertical emittance are less than 50 µm at the sector 5 (Figure 7). Low emittance and high charge achieved, and its performance is enough for the Phase-II commissioning.

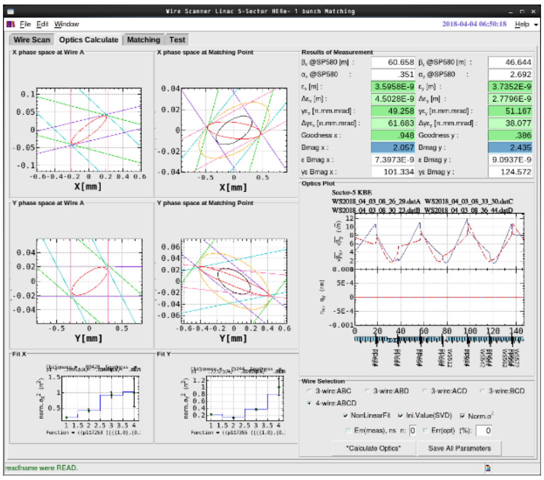

Figure 7: Wire scan measurement of 5 sector.

CONCLUSION

An Yb/Nd hybrid laser source is upgrade to deliver qualified electron beam by QTWSC RF gun and Ir5Ce cathode for SuperKEKB phase-II commissioning. Three laser oscillators and two beam lines were created. A lot of improvements of the monitoring and remote control system have been done to increase the reliability of the injection department. Electron charge of 2.4 nC and emittance of 50 µm fulfilled the phase-II requirements.

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