SUPERKEKB PHASE II コミッショニングの RF 電子銃用 Yb/Nd ハイブリッドレーザーシステム

Yb/Nd HYBRID LASER SYSTEM FOR RF GUN IN SUPERKEKB PHASE II

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Abstract

SuperKEKB Phase II commissioning has finished in this July. According to the demands for linac electron beam, an Yb/Nd hybrid solid laser system is achieved and used for RF gun to generate qualified electron beam for injection of High Energy Ring (HER). Compare with the laser system used in phase I, multiple choice are prepared for fiber oscillator and solid state amplifier stage. Moreover, in order to realize more stable and reliable commissioning, monitoring system and remote controlling system are added for long time operation. In addition to these, improvements on synchronization RF monitoring and temperature control also make the laser and electron beam be much more stable than before. 3.3 nC has been realized successfully by two laser lines s. 2.4 nC electron beam is measured at the end of linac for HER injection with required emittance and energy spread. The electron beam generated by RF gun is injected into HER successfully in phase II commissioning.

INTRODUCTION

SuperKEKB phase II commissioning finished on 17th July. For achieving SuperKEKB project phase II demands on electron beam, an Ytterbium (Yb) / Neodymium (Nd) hybrid laser system was prepared for phase II commissioning. As shown in Table 1, the emittance for electron beam is not very as strict as the final requirements of SuperKEKB project, so Nd:YAG with narrow gain width is chosen as amplifier gain material without spatial and temporal reshaping for laser pulse [1].

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]

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Basing on the experience of phase I and requirements of phase II, phase II laser system for RF gun consists Yb-doped fiber oscillator, Yb-doped fiber amplifiers and Nd:YAG rod laser amplifiers. After all the amplifiers, ultra-violet (UV) laser can be generated by utilizing two stages of second harmonic generation for Iridium Cerium photocathode with high quantum efficiency inside the RF gun [2].

In order to guarantee smooth and continuous injection and commissioning in phase II, higher reliability of the laser system is necessary. Therefore, backup design are considered and prepared for different parts of our laser system before phase II. Firstly, three mode lock fiber oscillators are installed, two of them are commercial products and the other one is ANDI-type homemade oscillator [3]. One MEMS switch is adopted to change different seed laser for the following stages of Yb-doped fiber amplifier. This alternative operation can realize continuous operation if error occurred during commissioning. The second one, two independent Nd:YAG rod amplification lines are achieved. After fiber amplification part, the seed laser is divided into two parts for the first and second Nd:YAG rod amplification line. A delay line is inserted into the second laser line to adjust the optical path for realizing two laser synchronous injection into RF gun. It is optional to select one laser injection or two laser injection according to the commissioning requirements. Finally, new vacuum transporting line, the precise optics controllable injection part for the RF gun, as well as temperature monitoring system are used in current laser system. The electron beam with higher stability and quality can be generated thanks to the stable and controllable laser operation. Besides these, status monitor for mode lock oscillator and I/Q monitor for synchronization status of laser system with trigger RF has been adopted.

By use of the current laser system, 3.3 nC electron beam has been generated successfully by two lasers injection. Accordingly, about 2.3 nC electron charge are prepared for injection to HER. Meanwhile, one laser injection mode generates 2.4 nC electron charge in RF gun and 1.5 nC at the end of linac for BT line and HER injection. The most importing thing is the current laser system had been operated continuously more than 3 months. It demonstrates this solid laser system is very believable and practical.

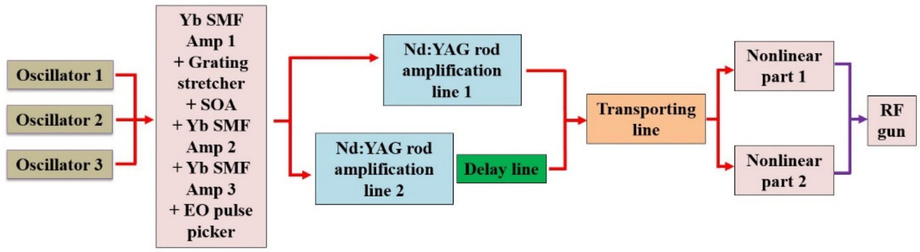

Figure1: The overall layout of current Yb/Nd hybrid laser system for SuperKEKB phase II commissioning.

Yb/Nd DOPED HIBRID LASER SYSTEM OF RF GUN FOR SuperKEKB PHASE II

Figure 1 shows the of the Yb/Nd hybrid laser system which is used in SuperKEKB Phase II. The 114 MHz seed laser is generated by an Yb-doped fiber mode lock oscillator which is synchronized with main trigger of accelerator. A MEMS optics switch is used to alter different fiber oscillator. Then the seed laser is amplified by the first Yb doped single mode fiber amplifier (SMF Amp). A transmission grating stretcher is used to select the proper wavelength. Then, the seed laser is amplified by one stage of semiconductor optical amplifier (SOA) and two stages of SMF Amp. After the SOA, the repetition rate of seed laser is reduced to 10.38 MHz from 114 MHz. An electric-optical module (EO) is adopted as a pulse picker to reduce the repetition rate into 25 Hz (1-25 Hz available). At the end of the fiber part, a polarizer is adopted to divide the seed into two equal parts, one is for the first Nd:YAG rod amplification line which has 4 stages amplifier, the other one is sent to the second line with 5 stages amplifier. Green lasers are generated by use of two BBO crystals in the first and second laser line separately. To realize two laser synchronous injection for RF gun, a delay line for green laser is added in the second line to change the optical path. After this part, 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 and converted into ultra-violet laser for the photocathode. The details are introduced in the following parts.

Fiber Part of Current Hybrid Laser System

As mentioned above, three oscillators are installed in our laser system. All of them are mode lock fiber oscillators that can generate serval hundreds femtoseconds laser pulse with 114 MHz. The first oscillator is homemade ANDI type 1064 nm Yb-doped fiber mode lock laser. It is almost the same as the one which is used in phase I commissioning [3]. The second oscillator is a commercial 1064 nm mode lock fiber laser, it has very stable output and compact size. The third one is a commercial 1030 nm mode lock laser. In order to generate 1064 nm seed for the following Nd:YAG amplifier stages, self-phase modulation (SPM) is adopted to generate the 1064 nm components. The original spectrum (red line) and generated spectrum with 1064 nm components (blue line) are shown in Fig. 2.

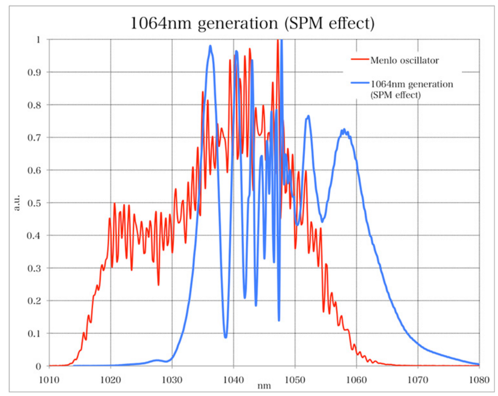

Figure 2: Spectrum of seed generated by SPM.

In order to realize stable and continuous laser operation, two commercial oscillators can be controlled by software in computer. The status of synchronization is monitored and recorded by an oscilloscope, we can achieve the recovery as soon as possible during problem occurred. In addition, the synchronization RF frequency is changed during optics adjustment during ring optics study. To avoid the oscillator stopping due to the change of RF frequency, a feedback is used to change the stepping motor and piezo position for adjust to the frequency change. Meanwhile, an I/Q module is added in the RF circuits part in this May. The best situation can be found easily for the phase matching between the accelerator RF and laser.

One MEMS switch is used to select the seed laser. After this switch, the seed laser is amplified by one Yb SMF Amp, as shown in the fiber part of Fig. 1. One grating stretcher is followed to serve as wavelength selector for picking up the seed laser centred at 1064 nm with FWHM 0.5 nm. Then, the seed is injected into the SOA part to for amplification. At the same time, the SOA is act as a pulse picker to change the repetition rate of the seed laser into 10.38 MHz. After this, the second stage of Yb SMF Amp is used. During the amplification, amplification of spontaneous emission (ASE) appeared. In order to get rid of it, another grating pair is adopted before the third Yb SMF Amp. At the end of fiber part, an EO module is inserted in to change the repetition rate in to the proper one (1-25 Hz) which is according to the accelerator.

Nd:YAG Rod Laser Amplification Part and New Transporting Line

Depending on polarization, the seed laser from the fiber part can be divided into two equal parts by a polarizer. For guaranteeing smooth and continuous injection and commissioning in phase II, two Nd:YAG amplification lines are built, the structure is shown in Fig. 3. After separate amplification and the second harmonic generation, two green lasers are combined together and sent to the RF gun optics box to generate UV laser for photocathode. One delay line is added in the second laser line to adjust the time delay for realizing two laser beams injection mode.

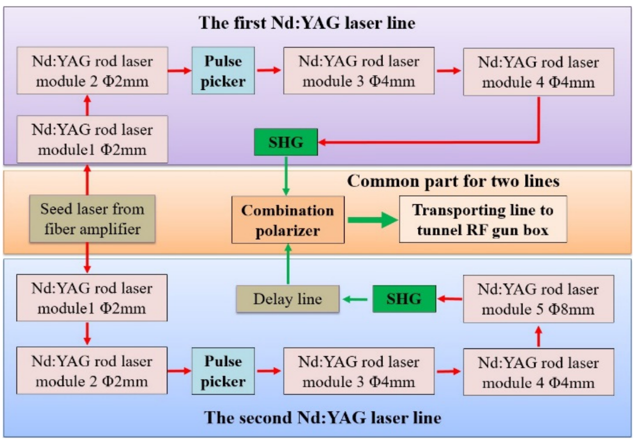

Figure 3: Structure of the Nd:YAG rod laser amplification part of current laser system.

2 mm diameter Nd:YAG rod laser modules are used in the first and second stages of the first and second laser line for high amplification efficiency. Vertical cavity surface emitting laser (VCSEL) pumped commercial modules are selected because they has high gain, long life time and stable operation. Before the third amplification stage, a Pockels cell pulse picker is used to set single bunch mode or double bunch mode. After the Pockels cell, the seed laser is amplified by the third and fourth stages by using of Φ4 mm modules. Different from the first line, an additional firth stage (Φ8 mm) is built in the second line to generate higher pulse energy for the RF gun by only one laser line.

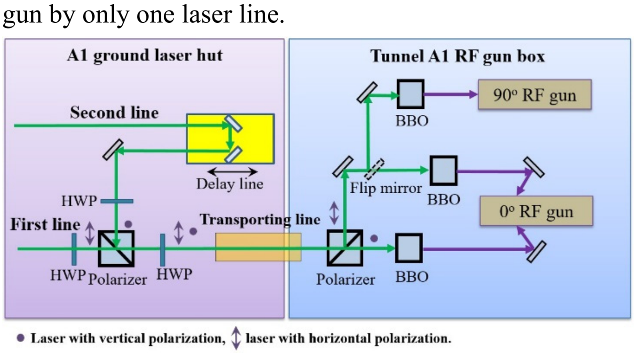

Figure 4: Delay line part and transporting part in current laser system.

BBO crystals are applied to generate green laser for two laser lines. For the first laser line, about 2.8 mJ green laser is achieved. On the other hand, 4.5 mJ is generated in the second laser line. Aim to realize two laser beams synchronous injection in RF gun, a delay line is built in the second laser line, as shown in Fig. 4. A roof mirror is placed on a step motor stage to adjust the optical path between the first and second line. By checking the laser phase and accelerator RF phase, adjustment of optical path can be done by the remote control system.

One polarizer is used to combine the first and second laser together for transporting line from the ground laser hut to tunnel RF gun box. According to the phase I operation experience, vacuum tube transporting line is built to isolate the air turbulence which introduces instability of the electron beam. At the exit of transporting line, another polarizer is placed to divide the two laser beams again for generating UV lasers separately and injecting into RF gun from different window.

Optics System inside RF Gun Box

After dividing by the polarizer, the two green lasers pass though the BBO crystals to generate the UV lasers for RF gun. 450 μJ and 800 μJ are achieved by the first and second laser for photocathode. The optics system is shown in Fig. 5.

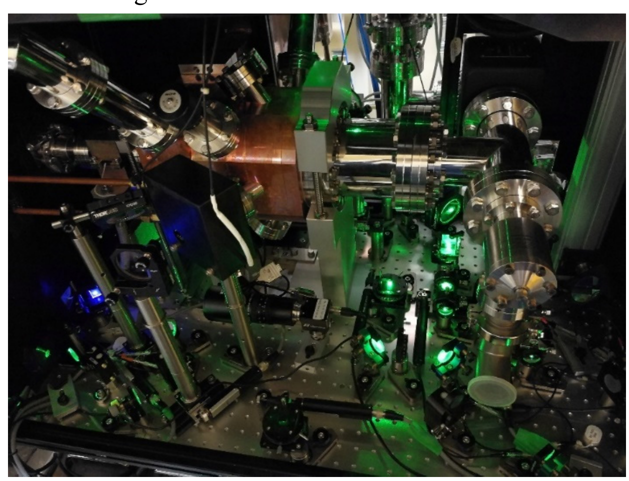

Figure 5: Optics system inside the RF box.

Compared to the optics system inside RF box, a lot of improvements has been made for more efficient laser injection into RF gun. Firstly, we installed 16 remote control actuators for laser fine adjustment by fully remote control. They can be used to adjustment the telescope systems, angles of the BBO crystals, the rotation of wave plates, UV laser horizontal and vertical positions, as well as the rotation angel of the mirrors before RF gun injection windows. Thanks to these, we can get the best condition to generate highest electron charge during RF gun study. Secondly, a beam profile monitor and laser energy meter are set in the first laser line to check the laser status. All the real-time data can be confirmed on internet anytime. The third, one remote controlled flip mirror is placed in the first laser line for changing the transmission direction to the 90 degree CDS RF gun which is installed in 2017 [4]. Two lasers inject into RF gun from two opposite windows and impinge into photocathode with 60° degree as shown in Fig. 4. In the future, both one laser injection mode and two lasers injection mode will be used for different purpose, such as SuperKEKB HER injection and PF or PF-AR injection.

RF GUN STUDY FOR SUPERKEKB PHASE II COMMISSIONING

SuperKEKB phase II commissioning has been being done from this march. In order to generate qualified electron beam by RF gun, the laser beam and RF gun study has been done. The laser beam monitoring system are also used to check the long term reliability.

By use of current laser system, 3.3 nC electron beam is generated successfully by use of two laser beams injection. Accordingly, about 2.3 nC electron charge is prepared for injection to HER. Meanwhile, one laser injection mode also generates 2.4 nC electron charge in RF gun and 1.5 nC at the end of linac for BT line and HER injection. The orbit and electron charge records are shown in Fig. 6.

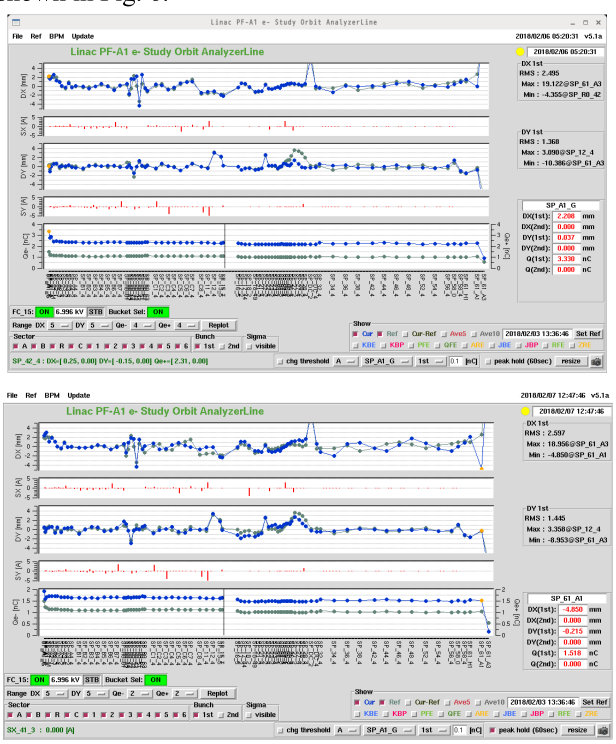

Figure 6: Orbit and electron charge diagrams. Above: two laser beams injection mode at 5 Hz; Below: one laser beam injection mode at 5 Hz.

The emittance of electron beam generated by RF gun is also measured at linac sector 5 by wire scan method, the result is shown in Fig. 7. We can see the horizontal and vertical emittance are 50 μm and 50 μm respectively. Both of them fulfilled the requirements of phase II for electron beam.

The electron beam generated by RF gun has been injected into HER successfully. The orbit diagram including the BT part is shown in Fig. 8. At the end of linac, about 1.5 nC electron charge is transmitted into the BT line for injection into HER, but the charge reduces to about 1.0 nC due to loss. The study about the beam loss in BT line is under investigating, and this is the most important task in the future.

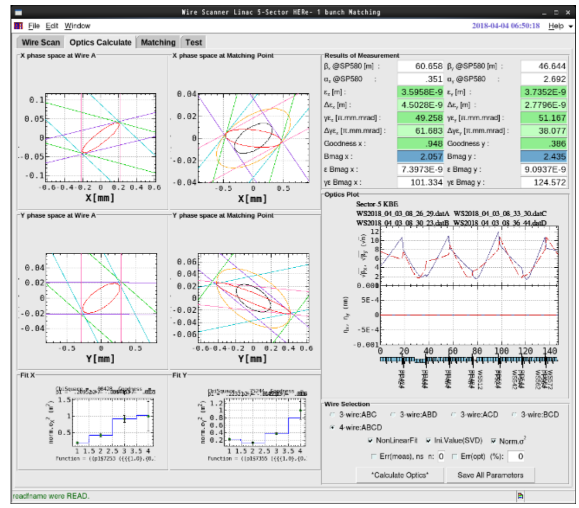

Figure 7: Wire scan measurement of electron beam at linac 5 sector.

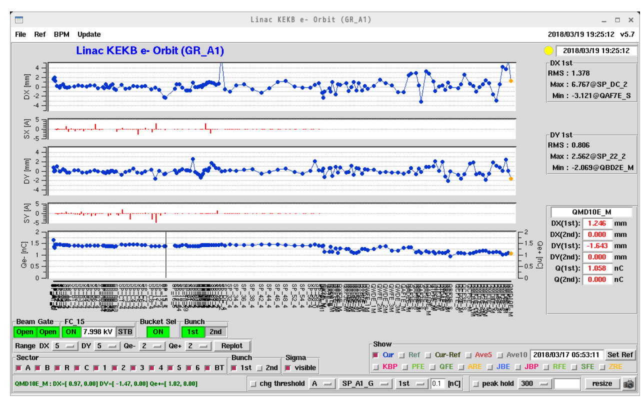

Figure 8: Linac and BT line electron beam orbit for HER injection in phase II commissioning.

CONCLUSION

An Yb/Nd hybrid laser system is built to generated qualified electron beam for SuperKEKB phase II commissioning. A lot of improvements have been done to increase the electron charge and decrease the emittance, as well as enhance the long term reliability of laser system.

To guarantee smooth and continuous injection and commissioning in phase II, three mode lock laser oscillator are installed. We also achieve two laser beam line for RF gun. One laser beam injection mode and two laser beams injection mode can be selected flexibly. Feedback between the laser and RF trigger is added for more solid operation during phase II commissioning. Meanwhile, another new RF gun is installed at linac A1 section. Besides these, the remote control optical adjustment parts for laser system are adopted to realize high electron charge generation efficiency.

By use of this hybrid laser system, 3.3 nC electron beam is generated successfully by using of two laser beams injection mode. And about 2.3 nC electron charge is prepared for injection to HER for SuperKEKB phase II commissioning. One laser injection mode also generates 2.4 nC electron charge in RF gun and 1.5 nC at the end of linac for BT line and HER injection.

REFERENCES

[1] M. Yoshida *et al.*, "SuperKEKB injector upgrade for high charge and low emittance electron beam", in Proc. IPAC'12, New Orleans, USA, paper TUPPD035.

[2] R. Zhang *et al*., "Improvements of the laser system for RF-gun at SuperKEKB injector", in Proc. IPAC'15, Richmond, USA, paper TUPWA071.

[3] X. Zhou *et al*., "Developing an Yb/Nd doped Hybrid solid state laser of RF Gun for SuperKEKB Phase II commissioning", in Proc. IPAC'17, Copenhagen Denmark, paper THPVA047.

[4] R. Zhang *et al*., "Study on stable and high output energy laser system for RF-gun at SuperKEKB injector", in Proc. PASJ'17, Sapporo, Hokkaido, paper WEP117.