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HYBRID Yb/Nd LASER SYSTEM FOR RF GUN IN SuperKEKB PHASE II AND PHASE III COMMISSIONING

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Abstract

SuperEKKB phase II commissioning has been finished in the summer of 2018. By use of Ytterbium doped fiber and Nd:YAG hybrid laser system, 2.3 nC electron beam with low emittance has been achieved at the end of linac, which is generated by RF gun. The electron beam is injected and stored in High Energy Ring successfully. Basing on these operation experiences, the Nd:YAG laser system will be used for the early stages of SuperKEKB phase III commissioning. After the update of laser system during 2018 summer maintenance, about 5.3 nC electron charge is generated by RF gun. Beside this, the laser spatial and temporal reshaping experiment has been being done in order to realize the electron beam with low emittance and low energy spread. Meanwhile, a perspective towards the next step Yb:YAG laser system is also introduced in this paper.

INTRODUCTION

For realizing high luminosity, high charge electron beam and positron beam with low emittance and energy spread are required in SuperKEKB, as listed in Table 1. Although thermionic gun can generate high charge electron beam, the emittance is bad without damp ring. As to the linac of SuperKEKB, one damp ring is built for the positron beam [1]. In contrast, RF gun is adopted to generate high charge electron beam with low emittance and energy spread [2].

Table 1: Phase III Requirements for SuperKEKB Linac

	Positron	**Electron**
Energy	4 GeV	7 GeV
Normalized Emittance $\gamma\beta\varepsilon_x/\gamma\beta\varepsilon_y$	100/50 μm	40/20 μm
Energy Spread	0.16%	0.07%
Bunch Charge at Injection Point	2 nC	3 nC

In order to generate stable and qualified electron beam for SuperKEKB high energy ring (HER), a RF gun drive Ytterbium (Yb)/Neodymium (Nd) hybrid laser system is adopted from SuperKEKB phase II commissioning in 2018 [3]. Although just three weeks HER injection is achieved by the RF gun during phase II commissioning, stable continuous electron beam injection with comparable low emittance is realized. Meanwhile, much cleaner injection background is demonstrated for Belle II Detector by use of RF gun injection mode compared with the case of injection by the existing thermionic gun. All of these results demonstrate that our Yb/Nd hybrid laser system can be used as RF gun drive laser system for early stages of SuperKEKB phase III. According to the operation experience in phase II, some improvements are made for current laser system in 2018 summer maintenance. More stable and higher charge electron beam has been achieved and adopted in phase III commissioning from this March. And the RF gun is decided to be the unique electron source for SuperKEKB HER injection [4].

By use of current laser, 5.3 nC electron charge is generated from RF gun, this demonstrates that the laser system and RF gun can generate high charge electron beam for the final aim of SuperKEKB phase III, as shown in Table 1. In the following days, the priority is to promote high charge electron beam with higher quality. Transverse and longitudinal reshaping of laser pulse for photocathode will be done with the aim of purchasing much lower emittance and energy spread. Meanwhile, Yb:YAG laser system is also under discussion because the Yb:YAG laser crystal has the ability to generate much shorter laser pulse for the pulse stacking stage. Flat top temporal laser pulse can be realized by pulse stacking method for reducing the emittance of electron beam.

RF GUN COMMISSIONING RESULTS IN SuperKEKB PHASE II

SuperKEKB phase II commissioning has been accomplished in last July. The Thermionic gun was used as main electron source because the requirements of phase II for emittance was not very strict. The RF gun is used for HER about three weeks. In contrast with injection mode by the thermionic gun, injection by the RF gun made much cleaner background. Meanwhile, the luminosity was increased at the same storage current level. Although it is just three weeks that the HER storage injected by the RF gun, the drive hybrid laser system had been being operated all the time during phase II. Solid and stable hybrid laser system guarantees smooth and continuous injection and commissioning in phase II. As a result, 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 emittance and energy spread are much lower than the case of thermionic gun injection.

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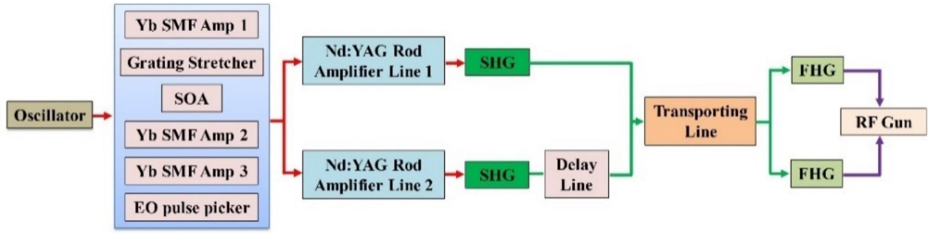

Figure 1: The layout of current Yb/Nd hybrid laser system for SuperKEKB phase III commissioning.

Yb/Nd Hybrid Laser System

The Yb/Nd hybrid laser system has been introduced in IPAC 2018 [3]. The overall layout of this laser system is shown in Figure 1. Three oscillators are adopted for smooth commissioning. Two of them are commercial products are one is homemade Andi-type Yb doped fiber mode lock laser. All of them are synchronized with 114 MHz. A MEMS switch is used to select one oscillator. After one stage of Yb doped single mode fiber (SMF) amplifier and grating stretcher, one semi-conductor optical amplifier (SOA) is adopted. Meanwhile, the repetition rate is changed into 10.38 MHz. An electric-optical module (EO) is used 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 divides the seed laser into two equal parts, one is for the first Nd:YAG rod amplifier line which has 4 stages amplifier, the other one is for the second line with 5 stages amplifier. To realize two laser synchronous injection for RF gun, a delay line is added in the line 2 to adjust 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 (UV) laser for the photocathode. Two lasers injection mode and one laser injection mode are available in phase II commissioning.

RF GUN COMMISSIONING IN SuperKEKB PHASE III

SuperKEKB phase III commissioning has been being done from this March. Due to the excellent performance of the hybrid laser system and RF gun, the RF gun is decided to be used as the premier electron source for HER injection. According to the operation experiences of SuperKEKB phase II, some improvements are made for the Yb/Nd hybrid laser system during 2018 summer maintenance. Laser pulse energy are increased so higher charge is generated successfully. Furthermore, temporary spatial shaping equipment is inserted for the UV laser in order to increase the quality of generated electron beam.

Improved Yb/Nd Hybrid Laser System

The current layout of Yb/Nd hybrid laser system is almost the same as the laser system which is applied in phase II commissioning. Especially, the fiber part of the laser system is unmodified in maintenance. In order to generate high charge electron beam for fulfilling the requirements of SuperKEKB phase III, higher UV laser energy is necessary. Therefore, we focused on improving the Nd:YAG amplifier stage after phase II. As shown in Fig. 2, another 5 stages Nd:YAG rod laser amplifier is added in the line 1, so both of lines possess 5 Nd:YAG amplification stages. In addition, for increasing gain and amplification efficiency, we chose high neodymium ions dopant Nd:YAG rod crystals for the first and second stages. Meanwhile, the Nd:YAG rod crystal with diameter of 6 mm is used to replace the crystal with diameter of 8 mm. Benefit from these, higher pulse energy is generated under much lower LD pump power. The harmful thermal effect is also decreased so that the stability of whole laser system is improved obviously. 700 µJ UV laser pulse energy of each laser line is gotten for photocathode.

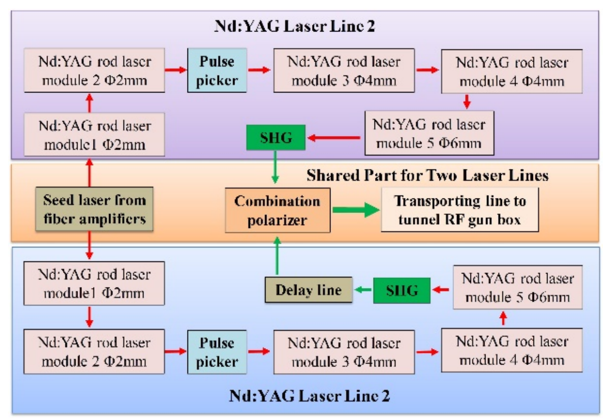

Figure 2: Configuration of the Nd:YAG rod laser amplification part of the current laser system.

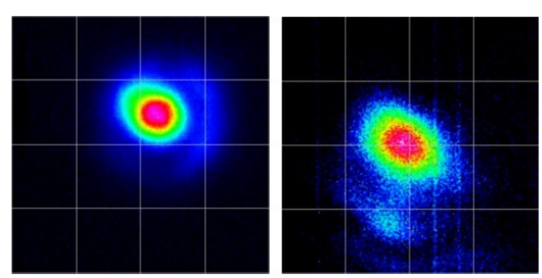

Figure 3: UV laser beam profiles of line 1 and line 2 at the position of virtual photocathode.

For the purpose of increasing the quality of electron beam generated by RF gun, the transverse and longitudinal reshaping of laser pulse will be done from the summer. During last summer maintenance, as a temporary solution, a pinhole set for UV laser is installed to improve laser beam quality. 12 sorts of pinholes are installed in a motorized wheel. Although laser pulse energy is reduced, depending on the physical cutting of pinhole, better laser beam profile is realized. The UV laser beam profiles of line 1 and line 2

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at the position of virtual photocathode are shown in Fig. 3. At the same time, comparable stable laser pulse energy for photocathode is done by the pinholes so that more stable electron charge is generated.

As so to realize smooth commissioning, more monitors and laser energy meters are installed in the laser system for monitoring the laser status. Any problem can be found out as soon as possible and recovered. Moreover, the laser hut temperature is affected by the Klystron gallery temperature, more stable mirror mounts are used to improve the stability of laser system. In addition, water cooling for optics table will also be used from this year.

RF Gun Commissioning Progress in Phase III

By use of the improved hybrid laser system, 5.3 nC electron charge by RF gun is generated successfully. This the highest record until now at linac. For phase III commissioning of this year, instead of high charge, better emittance electron beam is necessary. Therefore, 1.2 nC electron charge is generated after using the pinholes and 1.0 nC electron charge is transmitted to the BT line, as shown in Fig. 4. The emittance of electron beam is measured at linac sector 5 by wire scan method, the result is shown in Fig. 5. We can see the horizontal and vertical emittance are 55 µm and 67 µm respectively. This electron beam is used for phase III commissioning of this year.

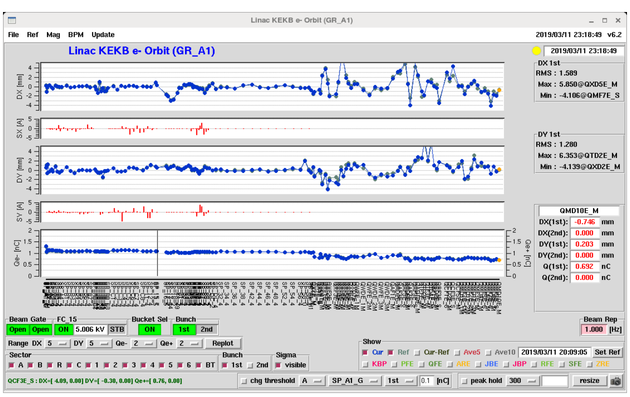

Figure 4: Electron orbit in phase III commissioning HER injection.

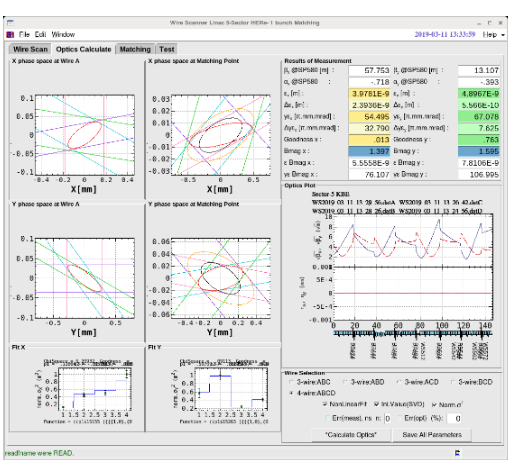

Figure 5: Emittance of electron beam at linac sector 5.

IMROVEMENTS AFTER THIS COMMISSIONING

Depending on current laser system, we demonstrate it has the ability to generate high charge for the final requirement of SuperKEKB, as listed in Table 1. We will focus on generating high charge electron beam with high quality after this commissioning. For the purpose to generate low emittance and low energy spread, it is necessary to make reshaping for laser pulse from gaussian to rectangular shape [2].

In order to realize a transverse rectangular shape, pulse stacking method will be introduced. By utilizing the birefringent effect of crystal, a laser pulse with temporal rectangular shape can be generated after pulse stacking of a few shorter laser pulses. Sharp edges of the reshaped laser pulse are very helpful in reducing the emittance of electron beam. Meanwhile, phase mask component is also under investigating for longitudinal reshaping of UV laser. We will set the phase masks before the RF gun to get spatial rectangular distribution laser pulse for the photocathode. This will also play an important role in reducing the emittance and energy spread.

Furthermore, another Yb:YAG laser system is also under discussion. Unlike Nd:YAG laser crystal, the Yb:YAG laser crystal has broader spectral bandwidth so narrower laser pulse can be gotten. By use of narrower laser pulse and pulse stacking method, it is possible to realize much flatter top and sharper edges of transverse laser pulse. In addition, higher quantum efficiency is helpful in reducing thermal effect and increasing stability of laser system and electron beam.

CONCLUSION

Yb/Nd hybrid laser system is built and adopted in SuperKEKB phase II commissioning. Qualified electron beam is generated by RF gun and injected in HER successfully. It demonstrated this laser system is suitable for long-term and stable commissioning. After improvement in 2018, more stable and powerful Yb/Nd hybrid laser system is achieved for early stage of phase III commissioning. 5.3 nC electron charge is generated successfully. Stable electron beam with low emittance and energy spread has been being used for injection now. Smooth, continuous and stable commissioning is realized by the current laser system and RF gun. The priority is to promote high charge electron beam with higher quality in the following days for the latter stages of SupreKEKB phase III.

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