RF GUN DRIVE YB/ND HYBRID LASER SYSTEM FOR SUPERKEKB PHASE III COMMISONING

Rui Zhang[#, A, B)], Xiangyu Zhou[A, B)], Hiroki Kumano[C)], Naoyuki Toyotomi[C)], Yosuke Honda[A, B)], Mitsuhiro Yoshida[A, B)]
[A)] High Energy Accelerator Research Organization (KEK)
[B)] The Graduate University of Advanced Studies (SOKENDAI)
[C)] Mitsubishi Electric System & Service Co., Ltd. (MSC)

Abstract

The first stage of SuperKEKB Phase III commissioning has finished in this July. The electron beam generated by RF gun is used for injection of High Energy Ring (HER). It is the first time to realize the full and continuous injection by RF gun at KEK. During these 4 months operation, any problem occurred in laser system and RF gun. Thanks to the reliable monitoring system in the current laser system, stable electron beam with low emittance is provided for HER injection with comparable low background. Meanwhile, the best laser injection status and electron beam generation status can be found by the precise control system. We demonstrated more than 5 nC electron charge by use of current laser system and RF gun. In order to realize high charge electron beam with low emittance and low energy spread, we will do temporal and spatial reshaping for laser in the following days. Another laser system is also under investigating for improving the quality of electron beam in the later stages of SuperKEKB phase III.

INTRODUCTION

The new peak luminosity record, 122.9 × 10^{32} $cm^{-2}s^{-1}$, is achieved during the SuperKEKB 2019 spring run [1]. The RF gun system at linac contributed a lot for this valuable achievement. The electron beam generated by the RF gun is injected into HER fully and continuously. Thanks to the comparable low emittance and low energy spread, low injection noise and low background are very helpful for this commissioning. Meanwhile, the RF gun drive laser system worked 4 months without any problem occurred, it plays an important role in smooth and long-term operation.

Basing on the operation experience of phase II requirements of phase III early stage, the Ytterbium (Yb) / Neodymium (Nd) hybrid laser system is used [2]. Some improvements have been done for realizing more stable and smoother laser operation. In addition, temporary laser beam reshaping equipment is also installed with the aim at decreasing the emittance and instability of electron beam. It has been demonstrated that all the improvements are effective and helpful in beam commissioning. About 1 nC stable electron beam is delivered at the end of linac for beam transporting line and HER injection.

Although high charge is not required in 2019 spring run, we tested high charge generation by full energy of laser. More than 5 nC is achieved successfully, it proves that the RF gun and drive laser system have the ability to generate qualified high charge electron beam for SuperKEKB. About 2.8 nC electron is achieved at the linac end. As to the high charge experiment, the emittance and energy spread of electron beam become bad due to space charge effect in the RF gun, as well as the wake filed effect inside the accelerating structure.

For generating high quality electron beam for latter stages of phase III commissioning of SuperKEKB, temporal and spatial reshaping for laser pulse will be done in the following days. All the experimental setup has been being preparing now.

RF GUN DRIVE Yb/Nd HYBRID LASER SYSTEM FOR 2019 SPRING RUN

Yb/Nd hybrid laser system is used in phase II commissioning. Although the gain width of Nd:YAG laser crystal is narrow (0.9 nm width when central wavelength is 1064 nm), it is good enough to generate qualified electron beam because the requirements for phase II was not strict. 1 nC electron with 150 μm emittance was acceptable. Similarly, the early stages of phase III commissioning don't require high charge and emittance of 20 μm, so the similar Yb/Nd laser system is decided to be used after necessary updating as transitional RF gun drive laser system.

Figure 1 shows the of the current Yb/Nd hybrid laser system which is used in 2019 spring run of SuperKEKB. The overall layout of the laser system is almost the same as the one used in phase II [2]. We used 3 oscillators for backup of smooth operation in 2018, two are Menlo commercial products, one is homemade ANDI type. But one Menlo oscillator is broken in 2018 winter, so the second Menlo oscillator is decided to be used as 1064 nm seed laser. Except this, the other components in fiber part are the same as before. Three stages of Yb doped single mode fiber (SMF) amplifiers are adopted. After the first stage of Yb SMF amplifier, one grating stretcher is installed to select the 1064 nm wavelength component from the seed laser due to the seed laser is broad bandwidth which is also used for 1030 nm laser system. Then, a semiconductor optics amplifier (SOA) is applied to reduce the repetition rate of seed laser from 114 MHz to 10.38 MHz. After all the fiber amplifiers, an electric-optical module (EO) is adopted as a pulse picker to reduce the repetition rate into desired one (1-25 Hz available).

#rui.zhang@kek.jp

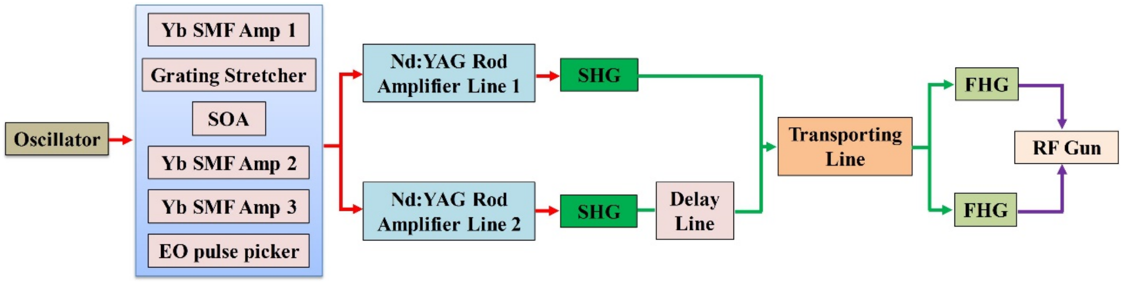

Figure 1: The layout of current Yb/Nd hybrid laser system for SuperKEKB 2019 spring run.

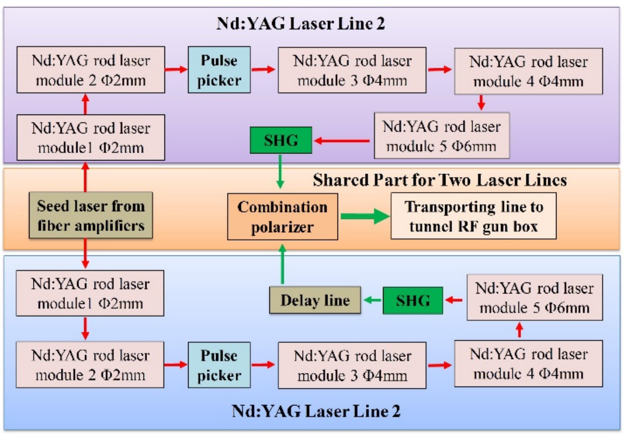

Figure 2: Structure of the Nd:YAG rod laser amplification part of current laser system.

After the fiber stage, a beam splitter is adopted to divide the seed laser into two equal parts for Nd:YAG rod amplification part, as shown in Fig. 2. The application of two parallel laser lines has many advantages. Firstly, it is possible to realize two laser beams injection into RF gun for higher charge generation and better emittance of electron beam. Secondly, each laser line can be used for backup line when problem occurred. This insures smooth and continuous commissioning of SuperKEKB. Every laser line has 5 stages of Nd:YAG rod amplifiers, a delay line is installed in the 2nd laser line for adjusting the laser phase and 2856 MHz RF accelerating phase. Pockels cell pulse pickers are inserted before the 3rd amplification stage for achieving double laser bunches or singe bunch operation. In the following stages, double bunch electron beam will be used for injection and collision, we will use the temporal pulse width of pulse pickers to operate. Achieving all the amplification, about 10 mJ 1064 nm lasers are generated separately. The green lasers are converted and combined by a polarizer, then they are sent from ground laser hut to tunnel RF gun box. Another polarizer is installed for dividing the two laser beams again. After converting into the UV lasers and spatial reshaping, the two UV laser impinge into RF gun from two windows. As to the two lasers injection design, details can be checked in reference 2.

After the commissioning of phase II, we improved the Nd:YAG rod laser part in 2018 summer maintenance [3]. Firstly, high dopant Nd:YAG laser crystals are installed in the modules. Higher gain is reached under lower driving currents. Thanks to this, lower thermal management is realized so that the stability of laser system is improved dramatically. Meanwhile, it reduces the risk of hardware problems under low driving current operation condition. Secondly, in order to realize higher charge generation, the fifth amplification stage is built in the 1st laser line. 10 mJ 1064 nm laser and about 4.5 mJ green laser have been gotten. The next, remote-control piezo mirrors are also applied before the two lasers combination. Fine adjustment is very necessary to correct the thermal distortion due to the temperature fluctuation. Finally, the RF gun box optical layout is improved totally, as shown in Figure 3.

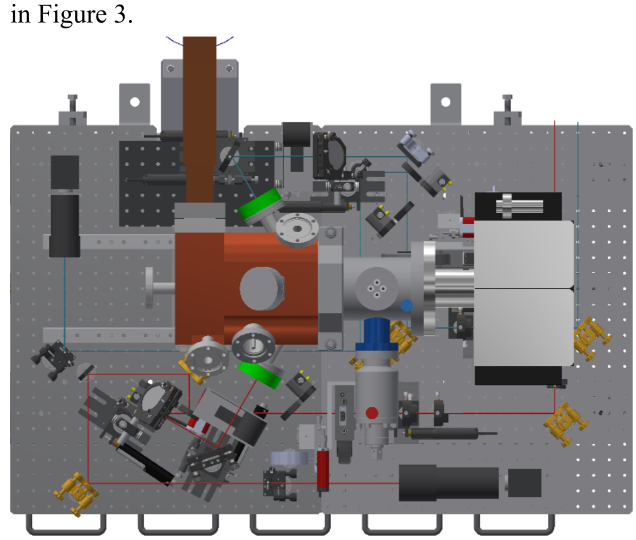

Figure 3: Top view of the RF gun box optical layout.

In order to realize comparable low emittance of electron beam, temporary spatial reshaping apertures are used for the UV lasers. A remote-control motorized wheel with 12 sorts of apertures is designed to reshape the UV laser beam. In addition, two CCD cameras are installed at the positions of virtual cathode. Together with the aperture, the UV laser beam profiles can be monitored with the aim of finding the best laser injection status for photocathode, as shown in Fig. 4. Besides this, two internet laser energy meters are set after the apertures, real time laser status can be monitored anytime for deceasing the injection noise and background. All of these improvements are helpful to achieve electron beam with low emittance and low energy spread. Most worth mentioning is the RF gun drive laser system had worked for 4 months continuously without any problems, and the electron beam generated by RF gun is used for HER injection full spring run. This achievement is being hailed as milestone in phase III commissioning of SuperKEKB.

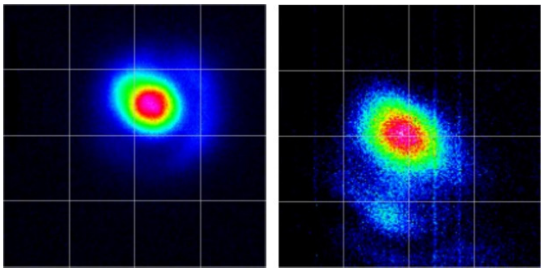

Figure 4: UV laser beam profiles of the 1st and 2nd line at the position of virtual cathode.

In order to investigating the pointing stability of laser beam, one laser beam position monitor is placed at the virtual cathode position. We collected more than 60,000 datum of laser beam pointing, the spatial fluctuations along x and y direction are about 150 μm, as shown in Fig. 5. In the following days, we will study the relationship of laser pointing stability and electron beam stability, and make feedback system for more stable electron beam generation.

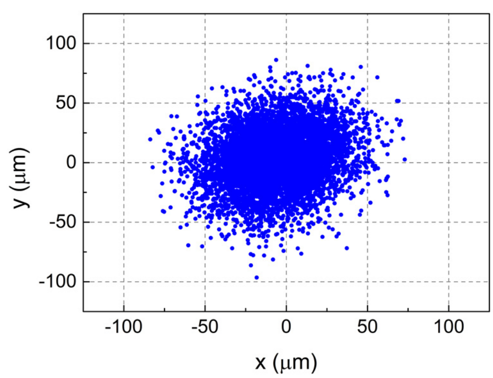

Figure 5: Laser beam pointing stability at the position of virtual cathode.

RF GUN STUDY RESULTS OF SUPEREKB 2019 SPRING RUN

High charge test has been done by use of full energy of two lasers, the orbit and electron charge are shown in Fig. 6. 2.8 nC electron charge is achieved successfully at the end of linac. Additionally, 5.3 nC electron charge is generated in RF gun by scanning the phase of 2856 MHz RF wave. Due to the strong space charge effect in RF gun, as well as the wake filed effect in accelerating tube, the emittance of high charge electron beam became worse. This is an important issue that needs to be studied and resolved in the follow days.

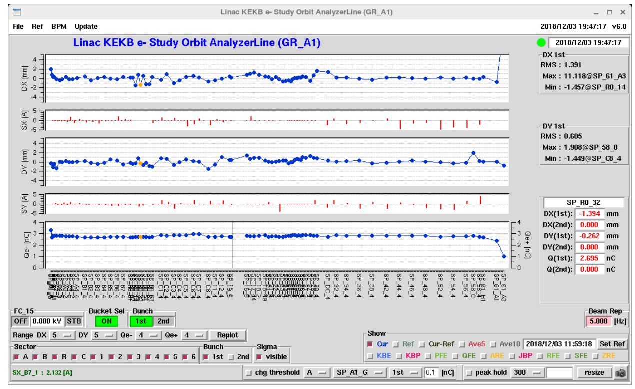

Figure 6: Electron charge orbit for high charge test.

As to the 2019 spring run of SuperKEKB, high charge electron beam is not required. Compared with the electron charge, better quality of electron beam and long-term stability is more important. Therefore, about 1 nC electron charge is generated with lower emittance for 4 months injection. The electron beam orbit is shown in Fig. 7. Accordingly, the horizontal and vertical emittance of B-sector are 12.6 μm and 11.2 μm respectively, which is measured by wire scanner. At 5-sector, the emittances are 65 μm and 58 μm.

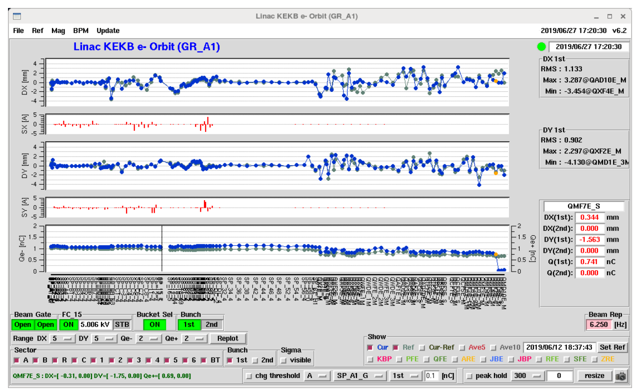

Figure 7: Linac and BT line electron beam orbit for HER injection in 2019 spring run.

CONCLUSION

By improving the Yb/Nd hybrid laser system after phase II commissioning, more stable and higher pulse energy RF gun drive laser system is achieved. It is used in 2019 spring run of SuperKEKB for 4 months full commissioning. Any problem occurred during this run for our laser system and RF gun. We achieved continuous and stable electron beam injection into HER with lower injection background and noise, which is generated by RF gun with low emittance. Higher electron charge experiment is also investigated by use of full laser energy. 2.8 nC electron charge is transported to linac end successfully. In addition, more monitoring setups are installed in current laser system for accomplishing the best status for electron generation and smooth operation.

In the following days, laser reshaping for temporal and spatial distribution will be done to improve the quality of electron fundamentally. We are planning to use pulse stacking technology for generating electron beam with low energy spread and low emittance to meet the requirements of SuperKEKB phase III later stages.

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