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Yb/Nd DOPED HYBRID SOLID LASER OF RF GUN AND BEAM COMMISSIONING FOR PHASE-II OF SuperKEKB

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Abstract

SuperKEKB Phase II has been commissioning from this march. According to the demands for linac electron beam, an Yb/Nd hybrid solid laser system is achieved for RF gun to generate qualified electron beam for injection of High Energy Ring (HER). Compare with the laser system used in phase I, three mode-lock fiber oscillators and two independent Nd:YAG rod laser amplification lines are adopted for more flexible commissioning in phase II. Moreover, two RF guns are installed at the start point of linac for guaranteeing smooth and continuous injection and commissioning. 3.3 nC and 2.3 nC are generated successfully by one laser line and two laser lines separately. Electron beam of 2.4 nC is achieved at the end of linac for injection with required emittance and energy spread.

INTRODUCTION

For achieving SuperKEKB project phase II demands on electron beam, an Ytterbium (Yb) / Neodymium (Nd) hybrid laser system is 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 it is not necessary to do spatial and temporal reshaping for laser pulse for realizing low emittance and energy spread [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 (single bunch)	1.0 [nC]	0.5 [nC]

From the view point of laser, Nd:YAG laser medium with narrow gain width can be used as amplifier. Therefore, based 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 and RF gun are 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, another new cut disk structure (CDS) RF gun is installed in the summer of 2017. The first Nd:YAG laser line can be used for the old quasi-travelling wave (QTW) RF gun [4] and CDS RF gun. All of these selectivity can guarantee the smooth progress of SuperKEKB phase II commissioning. Beside these, 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 due to the stable and controllable laser operation.

By use of the current laser system, 3.3 nC electron beam is generated successfully by two lasers injection. Accordingly, about 2.3 nC electron charge are 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.

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

Figure 1 shows the current overall layout of the Yb/Nd hybrid laser system which is under using in SuperKEKB Phase II. The seed laser with 114 MHz 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

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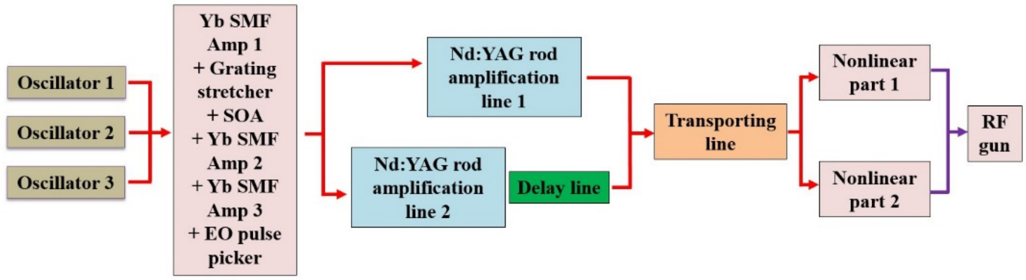

Figure1: The overall layout of current Yb/Nd hybrid laser system for SuperKEKB phase II commissioning.

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 divided 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 for the second line with 5 stages amplifier. To realize two laser synchronous injection for RF gun, a delay line 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 commercial 1064 nm mode lock laser, it has 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 rod amplifier, self-phase modulation (SPM) is adopted to generate the 1064 nm components. The generated spectrum with 1064 nm components (blue line) after the band pass filter whose central wavelength is 1047 nm.

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 Figure 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

By use of a polarizer, the seed laser from the fiber part can be divided into two equal parts with different polarization. For guaranteeing smooth and continuous injection and commissioning in phase II, two Nd:YAG amplification lines are built, the structure is shown in Figure 2. After amplification and second harmonic generated separately, two green lasers are combined together and sent to the RF gun optics box to generate UV laser for photocathode.

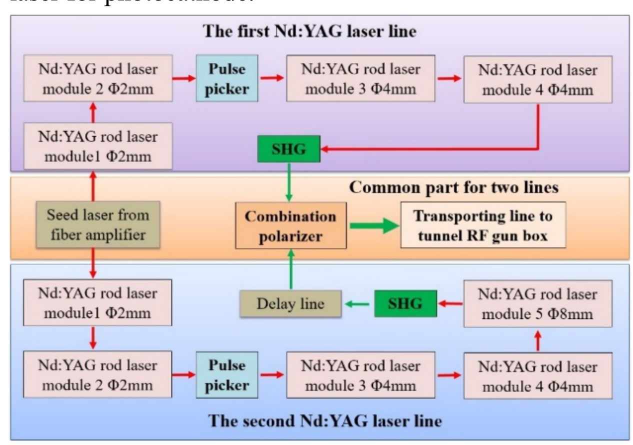

Figure 2: Structure of the Nd:YAG rod laser amplification part of current laser system.

Nd:YAG rod laser modules with 2 mm diameter are used in the first and second stages of the first and second line. 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 RF gun by only one laser line.

BBO crystals are applied to generate green laser for two laser lines. For the first laser line, about 2.8 mJ green

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laser is achieved. On the other hand, 4.0 mJ is generated in the second one. Aim to realize two laser beams synchronous injection in RF gun, a delay line is built in the second laser line, as shown in Figure 3. A roof mirror is placed on a step motor stage to adjust the optical path. By checking the laser phase and accelerator RF phase, adjustment of optical path can be done by the remote control system.

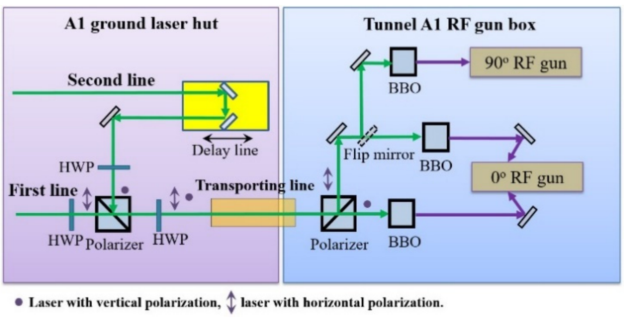

Figure 3: Delay line and transporting part in laser system.

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 can introduce 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 700 μJ are achieved by the first and second laser for photocathode.

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 this, 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. 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. Two lasers inject into RF from two opposite windows and impinge into photocathode with 60º degree.

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. The orbit and electron charge diagrams are shown in Figure 4. 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.

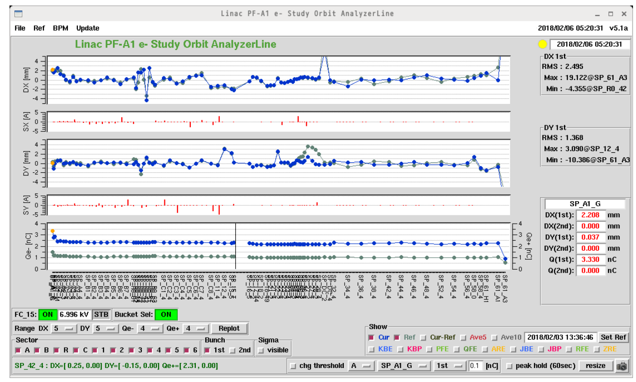

Figure 4: Orbit and electron charge diagrams under two laser beams injection mode at 5 Hz.

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

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. Meanwhile, another new RF gun is installed at linac A1 section. Beside these, remote control adjustment parts for laser system are adopted to realize high efficiency of electron charge generation.

By use of current 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.

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