LASER SYSTEM FOR SuperKEKB RF GUN AND ITS MULTI-FUNCTIONALIZED APPLICATION

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Abstract

Electron beam generated by RF gun is used for SuperKEKB high energy ring (HER) injection. Basing on the commissioning experience before, stable and continuous injection has been realized successfully. In order to generate high charge electron beam, upgrade of Nd:YAG laser amplification modules and amplification of powerful modules have been adopted in our laser system. Meanwhile, with the aim of generating high charge beam with low emittance, essential spatial reshaping of UV laser has been investigated. Diffractive optical element (DOE) is set in UV laser part for studying and operation. The best emittance measurement results in B-sector and BT part have been achieved for better HER injection. Finally, we also realized the multi-functionality of the 2nd laser line for HER electron beam generation and photocathode cleaning during SuperKEKB commissioning.

INTRODUCTION

SuperKEKB 2022ab commissioning has finished in June 2022. New peak luminosity record has been achieved [1]. For generating high quality electron beam with high charge, we achieved some upgrades from 2020c commissioning. Although the current Yb/Nd hybrid laser system cannot realize pulse reshaping (pulse stacking method) in time domain, it possesses the stability and simplicity for stable and continuous commissioning [2]. Hence the Yb/Nd hybrid laser is still adopted as the RF gun driven laser system to generate electron beam for SuperKEKB commissioning.

In order to generate 2 nC electron beam by use of current RF gun, the increasement of laser pulse energy is the first thing that should be upgraded. New powerful amplifier module as booster amplifier is accomplished in-house. Meanwhile, due to the problem of product life, some new purchased amplifier modules are installed in the laser system. About 700 µJ laser energy at 266 nm can be gotten by one laser line. Beyond this, two lasers incidence method is used for electron beam generation, so 2 nC electron beam generation is an achievable job. As the electron charge increases, the space charge effect becomes stronger. Excellent emittance result was gotten under 1 nC case, as to 2 nC or higher electron beam, it is difficult to achieve low emittance without additional development. According to the simulation results, it is possible to get high quality electron beam with low emittance and low energy spread by use of flat-top spatial distribution [3]. Therefore, the DOE are selected to reshape the original Gaussian spatial distribution to flat-top one. With all these upgrades, the best emittance results of 2 nC electron beam are realized at B-sector and BT line by wire scanner method in SuperKEKB operation history.

On the other hand, the 2nd laser line is reformed in 2021 summer maintenance for realizing the multi-functionality. As the application of DOE in laser system, the cleaning function of laser for photocathode became impossible because the UV laser telescope system cannot be installed. With the aim to keep the cleaning function of our laser system during operation, double-layer laser construction is investigated. Thanks to this design, we can achieve simultaneously the laser path with DOE for reshaping and the other path with telescope for laser cleaning.

CURRENT LASER SYSTEM AND RECENT UPGRADES

Current laser system is based on the Yb-doped fiber oscillator, Yb-doped fiber amplification part and Nd:YAG rod amplification part, as shown in Fig. 1. Two 114 MHz commercial Yb-doped fiber oscillator are installed. One oscillator is selected by a MEMS switch. The spectrum of oscillator is wide band from 1010 nm to 1070 nm, one grating is inserted for selecting 1064 nm component for Nd:YAG amplification part. The following semi-conductor optical amplifier (SOA) is for changing the 114 MHz repetition rate into 10.38 MHz, which is designed for SuperKEKB double bunch operation with 96 ns time interval. The 10.38 MHz laser pulse train at 1064 nm is amplified by three stages of Yb-dope fiber amplifier. Two EO modules are used in our laser system, one is for changing the 10.38 MHz repetition rate into 1~50 Hz, the other one is used to reduce the background noise for solid-state laser amplifiers.

After the Yb-doped fiber amplification part, the seed laser is divided into two equal parts, both are sent into two amplification lines separately. Both of the amplification line has 5 stages Nd:YAG rod amplification modules for reaching 10 mJ laser pulse energy. The first two stages use diameter of 2 mm Nd:YAG rod, the 3rd and 4th stage use 4 mm one. The last stage, boost amplifier stage, uses diameter of 8 mm Nd:YAG rod for decreasing nonlinear effect. After the second stage amplifier, one Pockels cell is used to choose one bunch operation or two-bunch operation for SuperKEKB HER injection.

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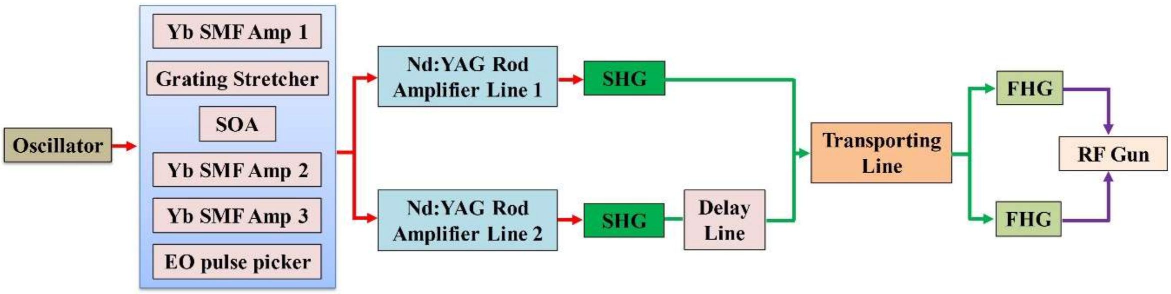

Figure 1: The layout of current Yb/Nd hybrid laser system for SuperKEKB commissioning.

Because all the Nd:YAG rod amplification modules were purchased about 10 years ago, some of them fail frequently during the operation due to the performance decay. From 2021 we started to replace the old modules by new products for smooth and stable electron beam operation. For increasing the laser pulse energy to be able to generate 2 nC electron beam, the 8 mm diameter Nd:YAG modules are made in-house as boost amplifiers. By upgrading, about 10 mJ laser pulse energy at 532 nm is obtained in Nd:YAG amplifier line 1, and 8 mJ in Nd:YAG amplifier line 2. Finally, 750 µJ and 700 µJ 266 nm UV laser are separately generated for electron beam generation.

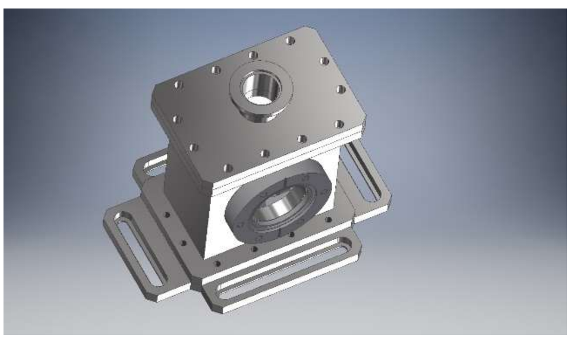

Figure 2: Installed DOE and compact vacuum chamber experimental setup in current laser system.

As introduced before, the space charge effect becomes stronger under higher electron charge situation. It has detrimental effects to the quality of electron beam. We investigated the application of DOE for our laser system from 2019. Considering the space in RF gun optics box, combination of lens with focusing length of 1 m and DOE plate is decided finally. The reshaped laser spatial distribution is designed as flat-top pattern with elliptical 2D shape at the imaging plane, which is the surface of photocathode. The long axis of ellipse is 6 mm along the vertical direction and short axis is 3 mm in the horizontal direction. All of these are decided by the incidence angle of laser with respect to the photocathode. Due to the surface micro-configuration of DOE plate, it is very weak at dust. A compact vacuum chamber is manufactured to provide a clean environment for the DOE plate, as shown in Fig. 2. Total loss of this setup is measured to be about 8% for the 266 nm laser. To the best of our knowledge, this is the first time to apply the DOE for UV laser reshaping in the world.

The UV laser beam spatial distributions are shown in Fig. 3. The left one is the measurement in 2020b commissioning without DOE application and the right one is in 2021b commissioning after application of DOE. The laser beam spatial distribution is reshaped as flat-top distribution with 2D elliptical cross section as designed. We applied the DOE components in both laser lines for two lasers injection from 2021b operation. By utilizing the flat-top laser beams, the best emittance records for 2 nC electron beam has been achieved at B-sector and BT line from the beginning of the SuperKEKB project. The corresponding measurement results are listed in Table 1.

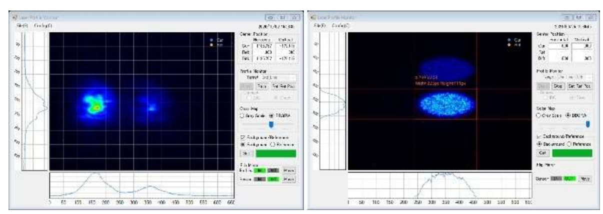

Figure 3: Reshaping for laser beam spatial distribution by the DOE and lens.

Table 1: Wire Scanner Results at B-sector and BT Line for 2 nC Electron Beam

	Horizontal	Vertical
B-sector	8.57 µm	8.89 µm
BT 2	20.95 µm	17.82 µm

MULTI-FUNCTIONALITY OF THE 2ND LASER LINE

Owing to the limited available space, the installation of DOE in the 2nd laser line was delayed. On the other hand, laser cleaning function of the 2nd laser line was decided to keep. It is impossible and incompatible to fulfil both functions at the same time by only one laser path layout. As to usual electron beam generation mode, the input laser beam size for DOE is larger than 10 mm (FWHM), and the final beam shape is ellipse with 6 mm long axis and 3 mm short axis. But for laser cleaning mode, the final beam size on the surface of photocathode should be small for high beam intensity. For solving this problem, double-layer laser construction is proposed. The block diagram of double-layer layout for the 2nd laser line is shown in Fig. 4. Because there is not enough space for building another laser path for the installation of DOE, two remote control flip mirrors are introduced to switch the laser propagation to the direction perpendicular to the optics table. In this way, the new laser path for DOE can be built directly above the current laser path that is for laser cleaning mode. These two flip mirrors are synchronized for both in and out. When they are inserted in, the 266 nm UV laser is reflected to the upper layer, and firstly expanded by a telescope then sent to the lens and DOE combination. Oppositely, the laser is in the lower layer as always and passes reduction telescope to be smaller beam size for photocathode cleaning when the two flip mirrors are out. One part of the double-layer experimental setup is shown in Fig. 5.

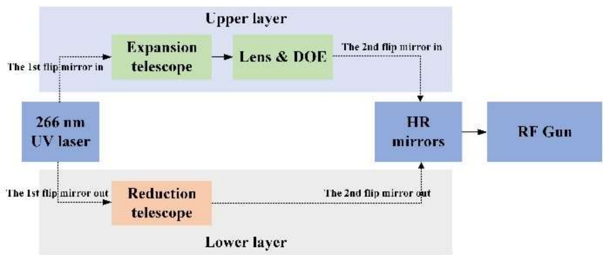

Figure 4: Block diagram of double-layer layout for the 2nd laser line.

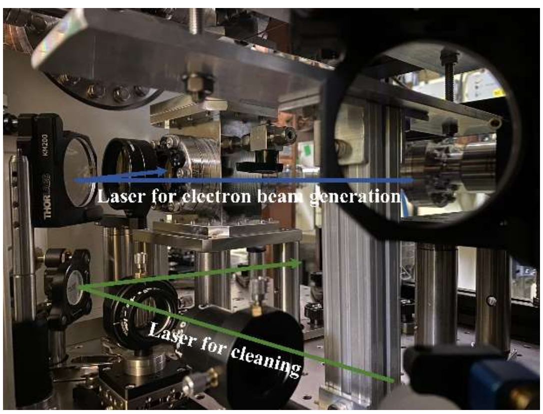

Figure 5: One part of the double-layer experimental setup. Blue line shows the laser for electron beam generation by passing the DOE; the green line shows cleaning mode laser.

By virtue of this method and upgrades of laser system, 2 nC electron beam with low emittance has been achieved, the electron beam orbit at Linac and BT line is shown in Fig. 6. Smooth and stable 5 months long 2022a commissioning is achieved after these upgrades and developments by current laser system.

Figure 6: The electron beam orbit for SuperKEKB HER injection in 2022a commissioning.

CONCLUSION

Upgrades of Yb/Nd laser system have been achieved from 2022 summer. By exchanging the Nd:YAG rod amplifier modules, higher laser pulse energy is realized for generation of 2 nC electron beam for SuperKEKB HER injection. In order to improve the quality of electron beam, DOE plates are installed in current laser system for getting flat-top spatial distribution of laser beam. We have achieved the best emittance measurement results for 2 nC electron beam in SuperKEKB history. In addition, double-layer configuration for the 2nd laser line is applied for multi-functionality. The 2nd laser can be used for electron beam generation and photocathode cleaning during commissioning.

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