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LASER SYSTEM FOR SuperKEKB RF GUN IN PHASE III COMMISSIONING

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Abstract

In order to generate high quality electron beam with high charge in Phase III commissioning of SuperKEKB, some improvements have been done in Ytterbium doped fiber and Neodymium doped YAG (Nd:YAG) hybrid laser system. Spatial reshaping part for the 4th harmonic laser beam at 266 nm has been adopted to realize low emittance electron beam. In addition, for achieving continuous and stable laser operation, position feedback system has also been used to improve the pointing stability of laser beam. In 2021c commissioning of SuperKEKB, stable 2 nC electron beam is generated for HER injection. Meanwhile, we achieved the best emittance results at B-sector of linac injector and BT line for comparable low injection background and higher injection efficiency. With the aim of generating higher charge electron beam with good quality in the following commissioning, a perspective towards the next step update for current laser system is also introduced.

INTROCUTION

SuperKEKB phase III commissioning has been being operated from 2018. Highest luminosity achieved in 2022a commissioning is almost two times of KEKB luminosity record [1]. Study about the bunch number of fill pattern and the bunch current has been being done for achieving higher luminosity and more physics run before long short down 1.

From SuperKEKB phase II commissioning, RF gun has been used for electron beam generation source. The Ytterbium (Yb)/Neodymium (Nd) hybrid laser system is built for high charge electron beam generation. By using of two lasers injection method, 2.3 nC electron beam was generated for SuperKEKB high energy ring (HER) injection. Meanwhile, the highest generation charge was 5.3 nC under the full laser energy input case [2]. Basing on the operation experiences of Phase I and II, the Yb/Nd hybrid laser system is also used for the phase III commissioning after upgrading for the higher quality electron beam generation.

In order to generate low emittance electron for phase III commissioning, the laser spatial distribution should be reshaped from Gaussian distribution into flat-top distribution [3]. Diffractive optics element (DOE) has been introduced into the UV laser part before injection into the RF gun. Thanks to the contribution of DOE, the best emittance results have been measured by wire scanner method at B-sector of SuperKEKB linac under 2 nC electron charge condition. In addition, the discharge induced by the laser injection decreased dramatically thanks to the application of DOE.

Furthermore, the laser beam pointing stability affected the electron beam stability during phase II commissioning. Due to the long distance from ground laser hut to the tunnel optics system and RF gun, it is found that the temperature fluctuation affected the laser pointing stability. We designed a laser position monitor and made a feedback system by piezo mirror mounts for the stabilization of laser beam. It has been demonstrated that the laser pointing fluctuation has been suppressed to one-fifth of the previous value without this stabilization system.

Beside these, electron charge feedback system has been also developed for stable and continuous 2 nC electron beam generation. All of these improvements ensure our phase III operation smoothly from 2019. In this proceeding, all the improvements mentioned above will be introduced in details.

IMPROVEMENTS IN LASER SYSTEM FOR HIGH CHARGE & STABLE ELECTRON BEAM GENERATION

The ability has been demonstrated to generate high charge electron beam for our Yb/Nd hybrid laser system and RF gun in SuperKEKB commissioning phase II [2]. In order to realize more stable and effective injection in phase III, the high-quality electron beam with low emittance and high stability under high charge condition is necessary. Some research and development have been done for improving the current laser system. The details and latest operation results are introduced in this part.

Introduction of Current Yb/Nd Hybrid Laser System

The current Yb/Nd hybrid laser system is almost the same as the laser system used in Phase II. The overall layout of it is shown in Fig. 1. Two commercial mode-lock oscillators are used for smooth commissioning, both of them are synchronized with the 114 MHz. One 2*1 MEMS switch is applied to select one oscillator for the laser system operation. After one stage of Yb doped single mode fiber (SMF) amplifier and grating stretcher, one semi-conductor optical amplifier (SOA) is used. 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 half waveplate and a polarizer divide the seed laser into two equal parts, one is for the first Nd:YAG rod amplifier line, the other one is for the second line, both of them have 5 stages of Nd:YAG rod amplifier.

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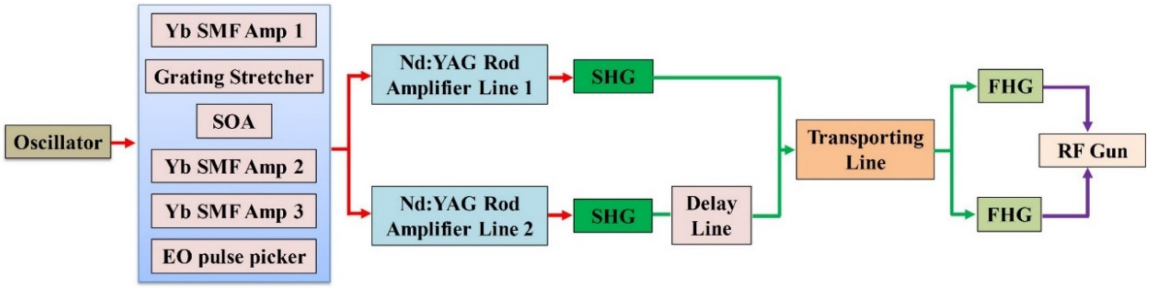

Figure 1: The layout of current Yb/Nd hybrid laser system for SuperKEKB commissioning.

To realize two laser synchronous injection for RF gun, a delay line is added in the second laser line to adjust the optical path. After this part, two laser beams are converged by a polarizer and transported to tunnel optics table by one transporting line. The 532 nm green laser beams are separated again and converted into ultra-violet (UV) lasers. Two lasers are injected into the RF gun separately from two windows. Before injecting into the RF gun, DOEs are inserted for laser spatial distribution reshaping, this will be introduced in the following part.

During the 2021 summer maintenance, two powerful modules with 10 mm diameter Nd:YAG crystals are applied in two laser lines for realizing higher laser pulse energy. Thanks to this upgrading, about 8 mJ 532 nm laser and 1 mJ UV laser energy are achieved in both laser lines. In addition, the pulse width of 532 nm laser is measured by a streak camera, the width is about 20 ps.

Laser Spatial Reshaping for Lower Emittance Electron Beam Generation

According to the previous simulation result, the laser beam with flat-top spatial distribution can generate electron beam with lower emittance comparing with the case of laser beam with Gaussian spatial distribution [3]. There are many methods to reshape the laser beam distribution, for example serrated aperture apodizer, super Gaussian mode overlap and so on. Take into account the laser energy loss and the complexity of setup, we decided to adopt DOE as our reshaping component. We purchased the DOE components from MARUBUN Corporation and the maker is SILIOS Technologies France.

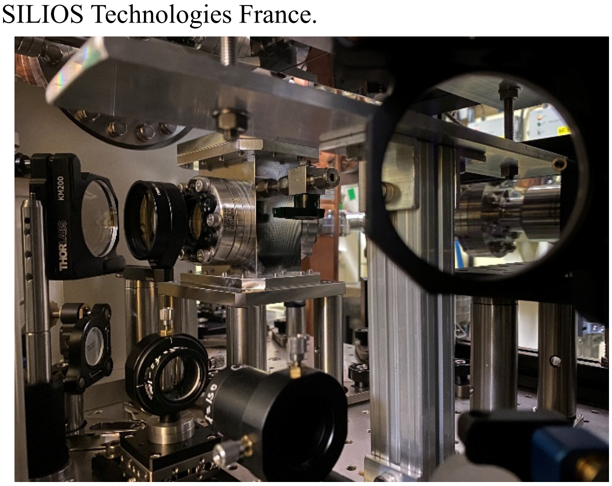

Figure 2: The DOE chamber in the 2nd laser line.

Consider according to the size of photocathode and the 60° incidence angle of laser beams, we designed to generate the flat-top laser intensity distribution with an elliptical 2D distribution (6 mm along long axis and 3 mm in short axis direction) so the cross sections of laser beams on the surface of photocathode are round shape. Due to the fine 3D structures on the surface of DOE, it is very weak at dusts. The environment in accelerator tunnel is not clean so we designed small vacuum chambers for the DOEs to prevent the dusts in ordinary air environment, as shown in the middle part of Fig. 2. Although the two windows of vacuum chamber introduced optical loss, the total transmission ratio is higher than 92%.

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. It is clear that 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.

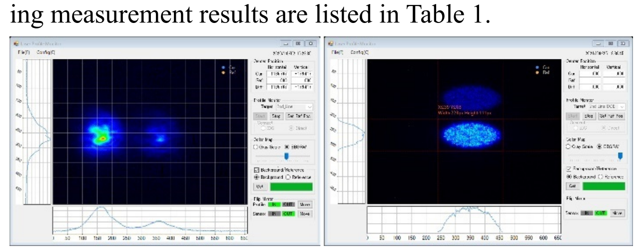

Figure 3: The UV laser beam spatial distributions without and with the application of DOE.

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

Application of Laser Position Sensor

As shown in Fig. 1, after generating the 532 nm lasers in ground laser hut, both of the 532 nm laser beams are sent to the tunnel laser optics table by the transporting line. Although vacuum tube is used for all the transporting line to

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prevent the airflow disturbance, due to the 11 meters length, the pointing stability of laser beam was not good enough because of the minor position drift introduced by the temperature fluctuation. One position monitor is placed in the position of virtual cathode, the recorded one-day laser beam positions in 2019a is shown in Fig. 4(a). We can see the horizontal and vertical fluctuations (4-σ) are about 135 μm and 150 μm respectively. This fluctuation of this magnitude affected the stability of electron beam seriously, frequent laser beam position adjustment and electron beam tuning were necessary before 2020a operation.

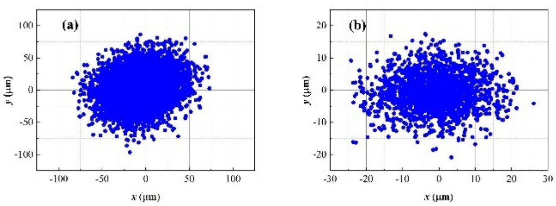

Figure 4: One-day position records of the UV laser beam at virtual photocathode position without and with laser position sensor and feedback system.

From 2020b operation, the laser position sensor and feedback system has been applied to our laser system. This system consists three parts. The first one is laser beam position monitor, which is placed behind the first mirror after the transporting line. We use commercial laser beam position sensor and developed the homemade driver module for pulsed laser availability. The real time position datum is changed into voltage information and record by an oscilloscope. Then all the datum is analysed in PC, the second part of this system. After processing the real datum, the program will calculate the difference between the current status and set value, then send the signal to the piezo mirror mount and controller, which are the last part of this system. The piezo mirror mount is used for the last mirror before the transporting line. The laser pointing instability induced by the minor position change is suppressed by use of this feedback system. As shown in Fig. 4(b), after introducing the laser position monitor and feedback system, the horizontal and vertical fluctuations (4-σ) are about 38 μm and 30 μm respectively. The vertical pointing fluctuation has been suppressed to one-fifth of the previous value, so it is no need to do complex laser adjustment and electron beam tuning during the continuous injection commissioning.

Latest Commissioning Results

As introduced in the former part, we have achieved the best emittance records at B-sector and BT line thanks to the laser beam spatial reshaping. Beside this, the continuous and stable beam injection is continued by use of the laser position monitor feedback system. Meanwhile, one electron beam charge feedback system is also applied to our laser system to maintain the 2 nC electron charge generation at inside RF gun. The current electron beam orbit of the Linac injector and the BT line is shown in Fig. 5. One collimator is adopted at the beginning of BT line to adjust the energy spread for better injection. Smooth electron beam injection for HER is continued from this January with comparable low injection background.

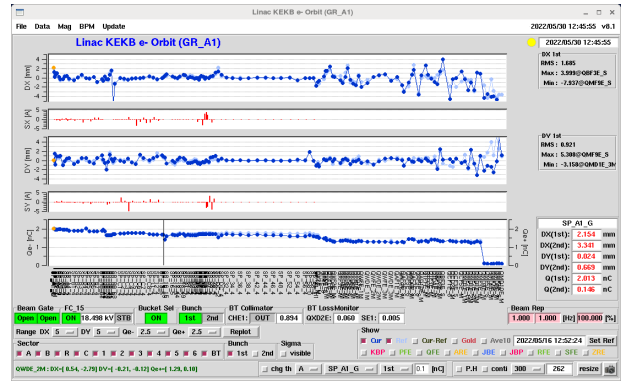

Figure 5: Current electron beam orbit.

FUTURE PLAN

In order to generate 4 nC electron charge for SuperKEKB requirement, it is necessary to upgrade the laser amplifier part. After 2022a commissioning, powerful amplifier modules will be applied to generate higher laser pulse energy. Secondly, for most effective injection for HER, low energy spread electron beam is essential. We will carry out the laser temporal reshaping for realizing high charge electron beam with low energy spread. Therefore, the Nd:YAG amplification part is not good enough to fulfil this. The new Yb:YAG laser system is under investigation. Thirdly, the degeneration of vacuum window of RF gun occurred during operation due to the discharge inside RF gun, better vacuum environment will be investigated from the next operation period.

CONCLUSION

Yb/Nd hybrid laser system is used in SuperKEKB 2022a commissioning. For generating low emittance electron beam, reshaping for laser spatial intensity distribution is done by the DOE. The best electron beam emittance records under 2 nC at B-sector and BT line have been achieved. Laser position feedback system is applied to obtain stable and continuous injection. Smooth, continuous and stable electron beam injection for HER is realized. It will be investigated to increase electron charge and decrease energy spread by temporal reshaping in the following days.

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