DEVELOPMENT OF LASER STABILIZATION FOR SuperKEKB RF GUN

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Abstract

Electron beam with high charge and low emittance is required for SuperKEKB high energy ring (HER) injection. After entering phase III commissioning of SuperKEKB, about 2.0 nC electron beam with comparable low emittance has been achieved successfully for injection. For continuous and stable injection and physics run, the stability of laser operation is extremely important. Due to the temperature fluctuation and long transporting line from laser hut to tunnel, the laser beam pointing stability was about 50 µm along horizontal and vertical direction. For improving the laser pointing stability, laser beam position sensor and piezo mirror mount feedback system have been developed and applied. By use of this system, the laser pointing stability has been improved dramatically. Furthermore, it is no necessary to adjust the laser beam position manually during the continuous injection and commissioning.

INTRODUCTION

SuperKEKB 2022ab commissioning has finished in June. New peak luminosity record has been achieved [1]. For continuous and stable commissioning, the stable electron beam is crucially important. In order to generate the stable and continuous electron beam for SuperKEKB HER injection, stable laser for the electron beam generation is necessary.

As to the current laser system, we developed some parts for improving the laser beam stability in the last few years. For example, adoption of beam pipe for the laser beam transporting line to separate the airflow disturbance. Except this, application of shield for laser system also improved the laser beam pointing stability to about 50 µm at the position of virtual photocathode [2]. However, distortion of the mirror mounts and the beam transporting line is still a serious subject for laser stability, which is induced by the temperature fluctuation in the laser hut and accelerator tunnel.

For realizing the further improvements to the laser pointing stability, we designed a feedback system which consists piezo-mirror mount, laser beam position sensor and software. By application of the feedback system, the laser pointing stability has been significantly improved. Meanwhile, diffractive optical element (DOE) is also applied to our laser system. Because of the diffractive overlap effect for laser beam profile spatial distribution, the spatial jitter is suppressed. Thanks to these developments, the laser pointing stability is dramatically improved, especially the vertical pointing fluctuation is suppressed to one-fifth of the previous value.

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LASER BEAM POSITION FEEDBACK SYSTEM

Thanks to the installation of beam pipe for laser beam transporting line and shield for the laser system, the laser pointing stability was improved than the previous status. Unfortunately, the instability introduced by the temperature was still unresolvable. Firstly, our laser hut is in klystron gallery, one part of the walls of this laser hut is the external wall of the klystron gallery. Because of this, the temperature inside laser hut is affected by the external temperature changes and heat influx. Although we installed the thermal insulation material to the wall, the temperature change inside laser hut is still not stable, as shown in Fig. 1. Associated with the temperature change of klystron gallery, temperature change inside laser hut is about 0.5 ºC per day. Although the temperature change of optical table is weaker because of the installation of table shield, the change is of 0.3 ºC per day. In addition, the laser beam transporting line is installed in the klystron gallery, the thermal distortion of fixed elements due to temperature change also seriously affects the laser pointing stability. In the summer days of SuperKEKB 2020ab commissioning, the laser position must be adjusted every day for electron beam generation.

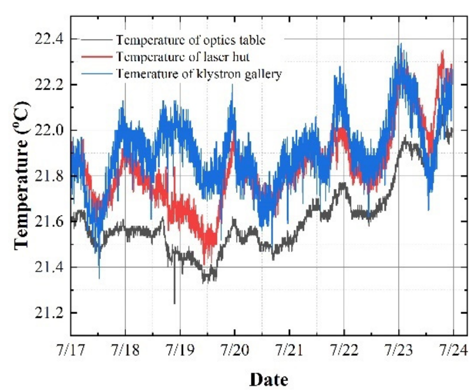

Figure 1: One week temperature history in the laser hut and klystron gallery at Linac.

In order to realize stable and continuous electron beam generation, we designed the laser beam position feedback system. The ordinary commercial laser position feedback monitor is available but there is one problem for our current laser system. For SuperKEKB commissioning, the repetition rate of electron beam and laser system is from 1 Hz to 25 Hz, but the commercial product is only for high repetition laser system. Some products were tested in our laser system, but the response action was not accurate. For solving this, we just bought a commercial laser position monitor and developed the position monitor driver unit and feedback system by ourselves. Thanks to the homemade parts, the response action works well, the feedback flow diagram is shown in Fig. 2.

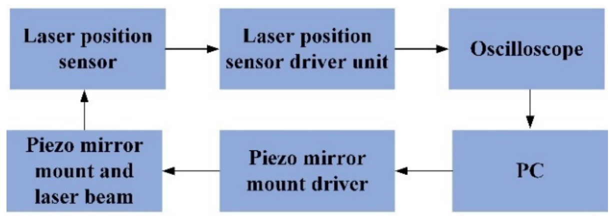

Figure 2: Feedback flow diagram.

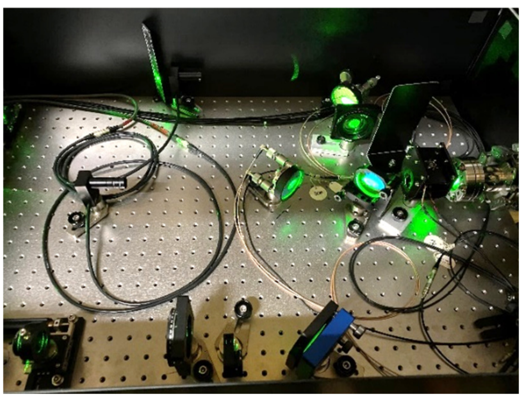

Figure 3: Laser beam position sensor.

The laser beam position information is recorded by the laser position sensor, which is installed behind the first high reflection mirror after the 11-meter-long laser beam transporting line, as shown in Fig. 3. Then the signal is gotten by the sensor driver unit and sent to the oscilloscope. After tracking the voltage information by PC and comparing to the setting value, drive signals are sent to piezo-mirror mount driver then the piezo-mirror mount can be adjusted until the current laser beam position is adjusted to the target value area, the feedback system working process is shown in Fig. 4. We apply the piezo mirror mount to the last reflection mirror before the laser transporting line. This feedback system was installed during the SuperKEKB 2020c commissioning. In the past two operations in summer, the laser pointing instability induced by the temperature change and thermal distortion has been compensated well, there is no need to do the additional manual adjustment as before. Additionally, a novel piezo mirror mount with wide range of adjustable displacement has been applied in the feedback system from 2021c commissioning. It can realize more flexible adjustment and compensation for our laser system.

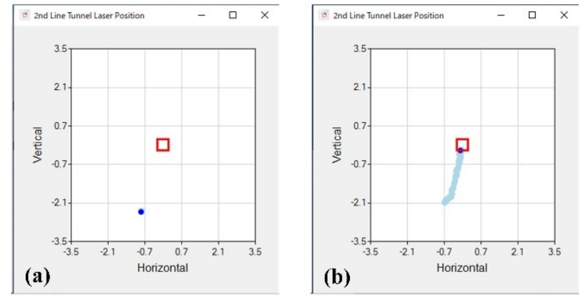

Figure 4: Feedback system working process for adjusting the laser beam position to the target value area.

DIFFRECTIVE OPTICAL ELEMENT

From 2020c commissioning, DOE has been applying in current laser system for achieving spatial reshaping of laser beam. 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. The principle of DOE is diffractive optics principle by the combination of lens and designed optical plate with micro-configurations. Every part on the surface of DOE can refract the laser beam that impinges on it into designed area at the imaging plane. Then the summation of the image is the patten which we want to get. For our case, we designed an ellipse flat-top distribution according to the shape and incident angle for the photocathode, the experimental result is shown in Fig. 5.

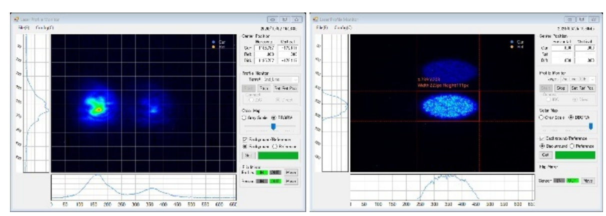

Figure 5: Reshaping for laser beam spatial distribution by the DOE and lens.

What we didn't expect was the application of DOE is also effective to the laser beam stabilization. The analysis revealed that thanks to the overlap function of the DOE and lens, the jitter of reshaped laser beam profile at the imaging plane is suppressed. In addition, the input laser beam size is much larger than the size of final beam profile. The divided laser beam by DOE is focused on the image plane through the lens, the determined optical path is helpful to decrease the instability.

EXPERIMENTAL RESULTS

One laser beam monitor is placed in the position of virtual cathode, the recorded one-day laser beam positions in 2019ab commissioning is shown in Fig. 6(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. Thanks to the application of laser beam position feedback system and DOE, the laser pointing stability record is shown in Fig. 6(b) which is measured in 2021c commissioning. 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.

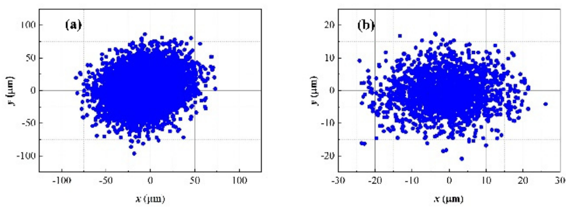

Figure 6: One-day position records of the UV laser beam at virtual photocathode position without and with laser position feedback system and DOE.

CONCLUSION

Laser position feedback system and DOE are applied in current laser system to realize stable and continuous electron beam generation for SuperKEKB commissioning. Thanks to these developments, the laser pointing stability is greatly improved. There is no need to do manual laser beam adjustment and electron beam tuning during continuous operation even the temperature fluctuation exists.

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