LASER-BASED ALIGNMENT SYSTEM AT THE KEKB INJECTOR LINAC

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Abstract

Towards the Super-KEKB project, the accurate alignment of the accelerating structures and magnets is strongly required for the delivery of the small emittance beam to the storage ring. For this purpose, a new laser-based alignment system has been developed at the KEKB injector linac. The new system comprises two convex lenses with different focal lengths, six flat mirrors, and a flat-parallel glass plate. By using this system, the 230-m-long laser propagating is successfully tested. In this paper, we present the overview of the new alignment system and experimental results in detail.

INTRODUCTION

The 600-m-long KEKB injector linac continuously provides 8 GeV electron and 3.5 GeV positron beams for the KEKB rings. For the higher injection efficiency and stable beam operation, the precise alignment of accelerating structures and magnets is strongly required since the large misalignment causes the serious beam quality deterioration like a large beam orbit displacement and an emittance growth.

Although the original laser-based alignment system has been constructed at the KEK linac more than thirty-years ago, this system was partially developed in the energy upgrade toward the KEKB project in 1995 [1]. The alignment measurements of KEKB injector linac were actively carried out up to 1998, and however, since then, any measurements have not been performed because of a lack of easiness for adjusting the laser beam propagation.

In this decade, the alignment of KEKB injector linac could be worse due to ground subsidence and/or other reasons. Toward the next generation B-Factory project [2], the higher injection efficiency and lower emittance beam transport are strongly required because of the much shorter beam life time and small injection aperture in comparison with the KEKB rings. For these reasons, the precise alignment of linac components is inevitable, and a new laser-base alignment system was developed.

SYSTEM DESCRIPTION

Outline of Alignment System

A schematic layout of the KEKB injector linac is shown in Fig. 1. It consists of 8 sectors (A to C and 1 to 5) in total. A 100-m-long and 500-m-long straight sections are connected by a 180-degree arc section. In a typical sector with a length of 76.8 m, there are eight accelerator units with a length of 9.6 m. One accelerator unit consists of four 2-m-long accelerating structures which are mounted on an accelerator girder with a length of 8.4 m. The quadrupole magnets are basically installed on a magnet girder between two successive accelerator units.

The accelerator girder is composed of a cylindrical tube with an outer diameter of 508 mm made of stainless steel as shown in Fig. 2. The four accelerating structures are mounted on five separated stainless-steel plates fixed on the accelerator girder, and reference guide rails fixed on the plates align the four successive accelerating structures. A cylindrical laser pipe made of stainless steel with an inner diameter of 115 mm has been welded to the upper inner surface of the girder. Such coaxial structure has been originally designed in order to reduce the convective air flow. The inner surface of laser pipe has been coated with a black paint basically comprised of acrylic resin for suppressing any unnecessary reflections and scatterings of the laser beams.

At both ends of the laser pipe, the quadrant-segmented photodiodes (PDs) are installed. The PD with a diameter of 10 mm (OSI Optoelectronics, Model SPOT-9D [3]) is attached to the PD chamber, which is connected to the flange of the laser pipe. When the laser beam hit the PD, the photocurrent signals are sent to a detector, and the detection electronics measures two-dimensional intensity centroids of the laser beam. Its measurement result means the displacement of the accelerator unit with respect to the reference straight line by the laser propagation. Before installation of the accelerator unit, the relative position among the centres of PD, accelerating structure, and the reference guide rail surface has been aligned well. For this reason, when we align the centers of PDs, all the accelerating structures and magnets can be consequently

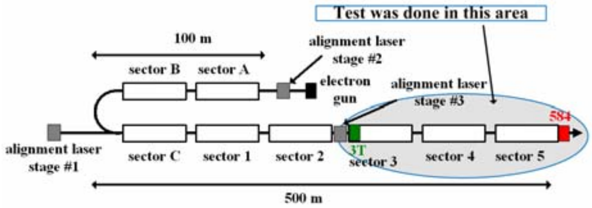

Figure 1: Schematic drawing of the KEKB injector linac.

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aligned.

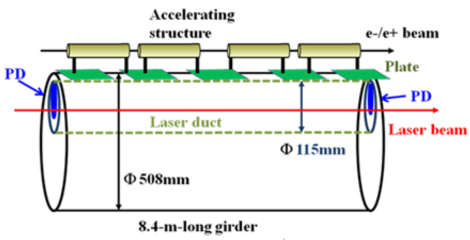

Figure 2: Schematic drawing of the typical accelerator unit in the KEKB injector linac.

Laser-based Alignment System

We adopted a He-Ne laser with 633 nm wavelength as a new laser source instead of a laser diode since He-Ne laser has a good axially-symmetric Gaussian beam profile in comparison with any other laser sources. A schematic layout of the new laser and optical system is shown in Fig. 3.

The new system comprises a He-Ne laser, two convex lenses with different focal lengths, six flat mirrors, and a flat-parallel glass plate. The focal lengths of Lens#1 and #2 are 300 mm and 1500 mm, respectively. The He-Ne laser and all optical components are mounted on the stable optical breadboard. In addition, the whole breadboard is covered with the acrylic case for avoiding the influence of air-fluctuation. The flat parallel glass plate is used for the fine adjustment of the laser position. Lens#2 mounted on piezo-controlled stage is used for the fine adjustment of the laser angle. The new system was installed at the laser stage #3 in Fig. 1.

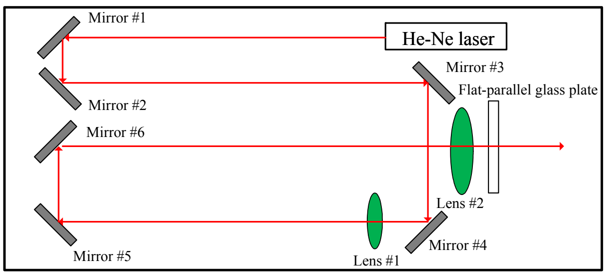

Figure 3: Schematic drawing of the laser and optical system. Its dimension is 600x1500x112 mm (WxDxH).

EXPERIMENT

Setup

The laser-based alignment experiment was carried out at sector 3 to 5 in Fig. 1. The total length of the laser propagation is about 230 m. The room temperature in the accelerator tunnel was kept within 23±0.1°C. Furthermore, the laser source along with the optical system was entirely surrounded with acrylic case and heat reserving material for avoiding the local temperature drift and unnecessary air flow around the optical system.

In this experiment, the total volume of the laser pipes was 2492.9 L. A vacuum port was attached to a middle point of the laser pipe installed at the middle of sector 3. It was connected with an oil-free scroll pump with a pumping speed of 1000 L/min. Nine Pirani gages were distributed at almost regular intervals up to the end of unit 584. The pressure inside of laser pipe was kept less than 10 Pa during the experiment. An inlet (outlet) vacuum window was used for laser injection (ejection) from atmosphere (vacuum) to vacuum (atmosphere) with transmittance of ~95% at λ = 660 nm. They are comprised of synthetic quartz (Shin-Etsu Quartz, SUPRASIL-P20 [4]) with a thickness of 20 mm for the inlet and outlet windows.

Laser Beam Size Measurement

First of all, we measured the laser beam size since the signal output of PD depends on the incident laser beam size. The beam sizes were measured with a CCD camera (OPHIR, USB L11058 [5]) at the location of most upstream and downstream in atmospheric pressure.

Figure 4 shows the measured and fitted beam size of 4σ along sector 3 to 5. In this figure, the solid lines denote the beam sizes fitted by the function

$$w_z = w_0\sqrt{\left\{\left(1+\left(\frac{\lambda(z-z_0)}{\pi w_0^2}\right)^2\right)\right\}}, \qquad (1)$$

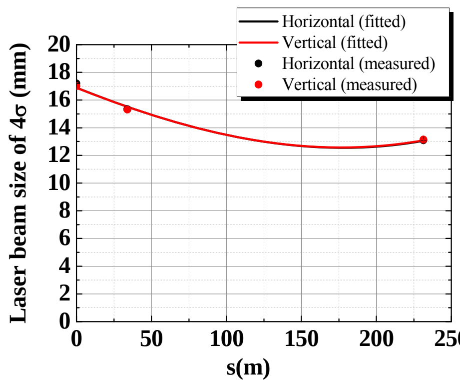

Figure 4: Measured (dot) and fitted (solid line) beam sizes along sector 3 to 5 as a function of the distance from the laser source.

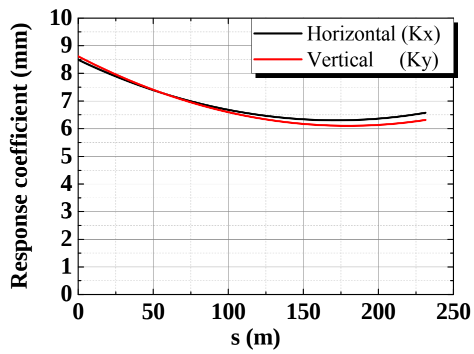

Figure 5: Calculated response coefficients for horizontal and vertical directions as a function of the distance from the laser source.

where z, z_0, w_z, w_0, and λ are beam position, beam waist position, beam radius at position z, beam waist radius, and wavelength of laser, respectively. The measured beam size in atmospheric pressure shows a good agreement with that of the fitted in both beam sizes of horizontal and vertical.

The detector readouts can be converted to the laser centroid position on PD by using the Eqs. 2 and 3 for the horizontal and vertical directions, respectively.

$$x = k_x \frac{(V_1+V_4)-(V_2+V_3)}{\sum_{i=1}^{4} V_i} \quad (2)$$

$$y = k_y \frac{(V_1+V_2)-(V_3+V_4)}{\sum_{i=1}^{4} V_i} \quad (3)$$

Here, k_x and k_y are the response coefficients for horizontal and vertical directions, respectively. Figure 5 shows the response coefficients calculated by the fitted beam sizes as shown in Fig. 4.

Alignment Measurement

The alignment measurements were finally carried out at each location of PD under vacuum condition. Before the alignment measurements, the laser line was corrected by tuning the positions and angles ejected from the optical system with the parallel-glass plate and Lens#2 mounted on piezo-controlled stage for making a straight line connecting two points which are at the front end of unit 3T and the other is that at the end of unit 584 as shown in Fig. 1. The laser beam centroids on PDs were calculated

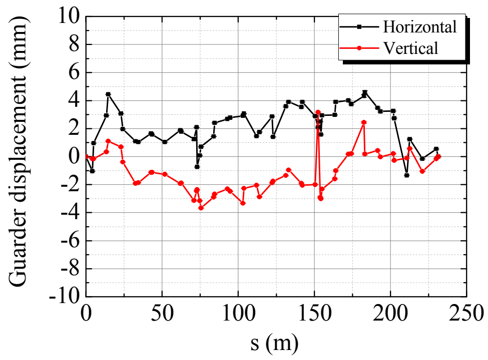

Figure 6: Measured guarder displacement averaged over twice measurements.

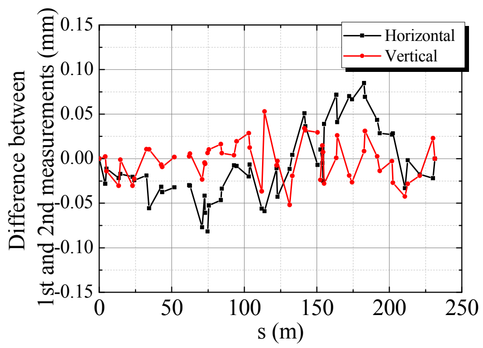

Figure 7: Difference between 1st and 2nd measurements.

by formulae of Eqs. 2 and 3. For the measurement of each PD, the data was averaged over 1000 times with a digital oscilloscope. The horizontal and vertical readouts measured at each PD location were transformed to the corresponding position displacements with each response coefficients as shown in Fig. 5. The measurements through 3 to 5 sectors were performed twice on different days.

Figure 6 shows the obtained results in the horizontal and vertical directions. The result is converted from the PD measurement results to the guarder displacement. The maximum displacements are obtained to be around ±4 mm. The differences between 1st and 2nd measurements in both directions are within ±0.1 mm at maximum as shown in Fig. 7. The horizontal and vertical standard deviations of differences are 40 μm and 20 μm, respectively. This result shows that the measurement was stably performed with good repeatability.

SUMMARY

The new optical system and laser source were developed at the KEKB injector linac. The alignment experiment was successfully carried out along a 230-m-long beam line under middle-level vacuum condition. The experimental results show that the displacements of the accelerator units can be measured with a resolution of less than ±0.1 mm in both the horizontal and vertical directions at maximum. It shows the good repeatability of measurements. In the near future, we will carry out the whole 500-m-long alignment measurement for the Super-KEKB project.

ACKNOWLEDGMENTS

The authors would like to thank Professors K. Furukawa and A. Enomoto of the Accelerator Laboratory at KEK for their continuous support over the duration of this study. The authors would like to express their gratitude to Mr. Y. Mizukawa, Mr. S. Kusano, Mr. T. Kudou, and Mr. K. Hisazumi of Mitsubishi Electric System & Service Co. for their assistance with the experimental setup.

REFERENCES

[1] K. Akai et al., Nucl. Instrum. Methods Phys. Res. **A499** (2003) 191.

[2] M. Masuzawa, "Next Generation B-factories", in Proceedings of IPAC'10, Kyoto, Japan, pp.4764-4768 (2010).

[3] http://www.osioptoelectronics.com

[4] http://www.sqp.co.jp/e/index.htm

[5] http://www.ophiropt.com