DESIGN OF COLLIMATED LASER BEAM OPTICS FOR THE KEKB INJECTOR LINAC ALIGNMENT SYSTEM

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Abstract

A new laser-based alignment system is under development in order to precisely align accelerator components along an ideal straight line at the KEKB injector linac. The new alignment system is strongly required in order to stably accelerate high-brightness electron and positron beams with high bunch charges and also to keep the beam stability with higher quality towards the next generation of SuperKEKB project.

The new laser-based alignment system consists of the laser diode (LD) mounted on the auto stages, the vacuum ducts, the quadrant-segmented photodiodes (PDs) and the detection electronics. In order to eliminate the laser beam size-dependent response variation of PD, the collimated laser beam as small size as possible should be propagated along the linac. In this paper, we will report the design of collimated laser beam optics and preliminary experimental result for the KEKB injector linac alignment system in detail.

INTRODUCTION

The 600-m-long KEKB injector linac continuously provides the 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 are 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. Toward the next generation B-Factory project [1], 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 original KEKB rings. For these reasons, the precise alignment of linac components is strongly required, and a new laser-base alignment system is now under development. In the new system, we adopted a new laser source with axially symmetric Airy beams generated by two consecutively aligned circular apertures [2].

SYSTEM DESCRIPTION

Outline of Laser-based Alignment System

A schematic layout of the KEKB injector linac is shown elsewhere [3]. It consists of 8 sectors (A-C and 1-5) 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 (S-band) 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. 1. 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 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.

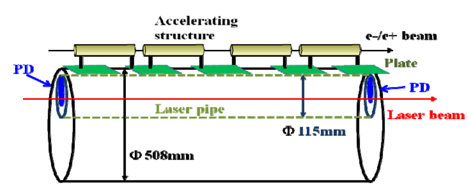

Figure 1: Schematic drawing of the typical accelerator unit in the KEKB injector linac.

At both ends of the laser pipe, the PDs are installed. The PD with a diameter of 10 mm 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 centre of PD, accelerating structure and the reference guide rail surface has been aligned well. For this reason, when we align the centers of all PDs, all the accelerating structures and magnets can be consequently aligned.

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Optical System

A schematic layout of the new optical system is shown in Fig. 2. The LD (Mitsubishi Electric, ML101J27) output is coupled into a single-mode optical fiber with a diameter of 3.5 µm. In this way, we could isolate the alignment optical system from the laser source so that it is not affected by the pointing stability of the laser itself. The output power (CW) of laser with a wavelength of 660 nm is 120 mW at maximum, whereas the final laser power injected into the laser pipe is about 1 mW because of the fiber coupling loss and the insertion loss of optical system.

The exit end of fiber is fixed on an optical system plate with a size of 162 mm x 340 mm. A flat and spherical mirror are also mounted on the same plate. The spherical mirror is aluminum-coated with a diameter and focal length of 152.4 mm. This optical system is mounted on a four-axis motorized stage. The position and angle of laser beam output are adjustable with the horizontal, vertical positions and the elevation and azimuthal angles. The emitted laser light is transmitted through two successive circular apertures with a diameter of 10 µm and 1 mm for generating the Airy beam without diffraction fringes. Only the central Airy disk beam can be transmitted since the second aperture with a 0.1 mm diameter truncates the side lobes generated by the first aperture.

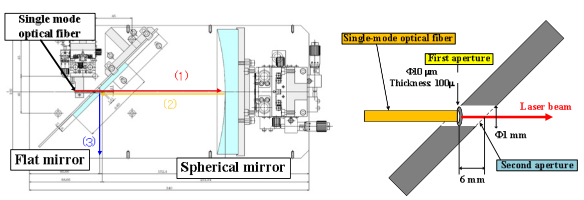
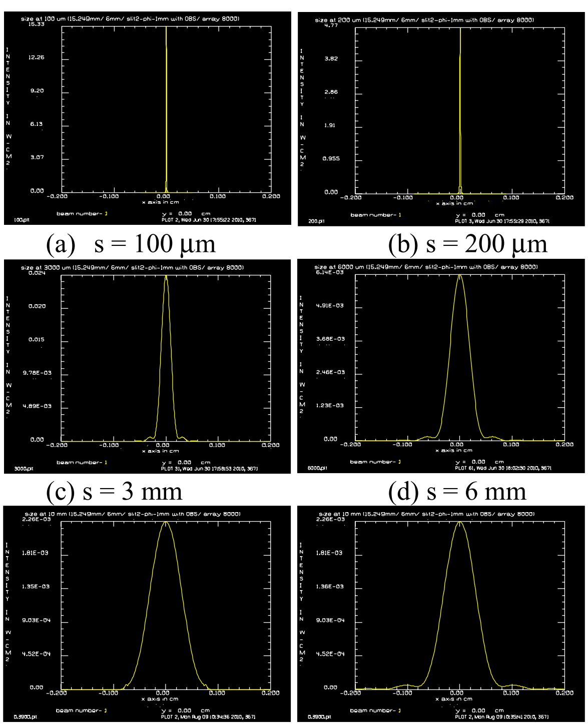


Figure 2: Schematic drawing of the whole optical system (left) and enlarged drawing of the flat mirror (right).



(a) s = 100 µm (b) s = 200 µm

(c) s = 3 mm (d) s = 6 mm

(e) s = 10 mm (f) s = 10 mm (without second aperture)

Figure 3: Simulation results of the horizontal beam profile. Here, s denotes the distance from the laser source.

Figure 3 shows the simulation results of horizontal laser beam profile from fiber exit to 10 mm. We used the simulation code of GLAD Ver. 5.5 for all of the beam profile calculations in this study. At 3-mm position, the first aperture with Φ10 µm truncates the side of laser beam, and the Airy beam is generated and propagated toward downstream. At 6-mm position, there is the second aperture with Φ1 mm which cut the side lobes of the beam. Figures 3-(e) and 3-(f) show the profile of 10-mm position with and without the second aperture, respectively. From these results, the second aperture can truncate well the side lobes of laser beam diffracted by the first aperture.

LASER PROPAGATIOIN EXPERIMENT

The 80-m-long laser propagation experiment was carried out in the tunnel of KEKB injector linac. Firstly, we tested the laser propagation of the waisted beam by adjusting the distance between the laser source and the spherical mirror to 15.29 mm. The room temperature in the accelerator tunnel was kept within 23±0.1°C. The beam profile was measured with a CCD camera (OPHIR, USB L11058) in atmospheric pressure. Figure 4 shows the measured beam size of horizontal (white squares) and vertical (blue-filled squares) as a function of the distance from the laser source. In the same figure, the black dots denote the calculated beam size of horizontal and vertical. Here, the beam size is defined by the 4-sigma width assuming Gaussian power distribution. The measured beam sizes of horizontal and vertical are not in agreement very well. This result can be explained that the laser beam is oblique incident to the center of the spherical mirror. Figures 5 and 6 show the measured and calculated

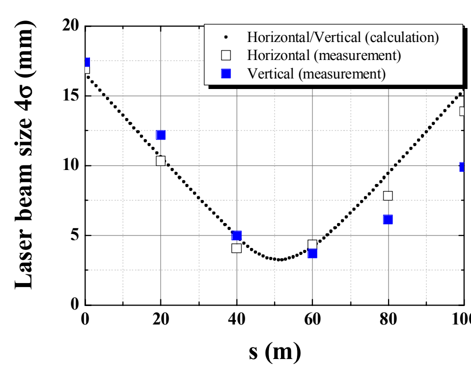


Figure 4: Variations of the horizontal (white squares) and vertical (blue-filled squares) beam sizes in vacuum condition as a function of the distance from the laser source. Calculated beam size is also shown (black dots).

beam profile at the position from 20 to 80 m, respectively. The measured profiles are in good agreement with the calculated profiles. The laser beam can be successfully propagated without diffraction pattern after 20-m downstream of laser source. By using the waisted laser profile, the preliminary alignment measurement was carried out, and its detailed result is described in Ref. [4].

Secondly, we carried out the laser propagation test of the collimated beam by adjusting the distance between the laser source and the spherical mirror to 15.249 mm. Figures 7 and 8 show the measured and calculated beam profile in the collimated beam, respectively. In the calculated result, the bam profile is propagated with the Gaussian power distribution. On the other hand, the power distribution is almost constant in the measured profile. The reason of disagreement between the measured and calculated results are now in investigation. We are planning the more precise simulation including the aberration effect due to a spherical mirror since these simulation results are calculated by using only the diffraction effects.

SUMMARY AND FUTURE PLAN

For the alignment system of the KEKB injector linac, we developed the new optical system comprising of a flat mirror with a circular aperture and a spherical mirror. The laser propagation experiments in atmospheric presser were successfully carried out along the 80-m-long line of the injector linac, and its results were compared with the simulation results. In the near future, we will carry out the full-length laser propagation test and alignment of the KEKB injector linac.

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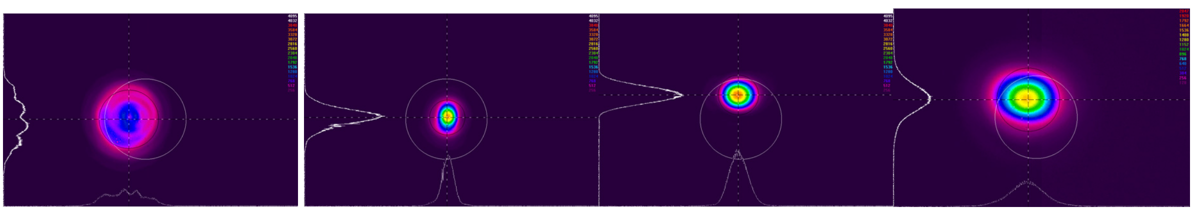
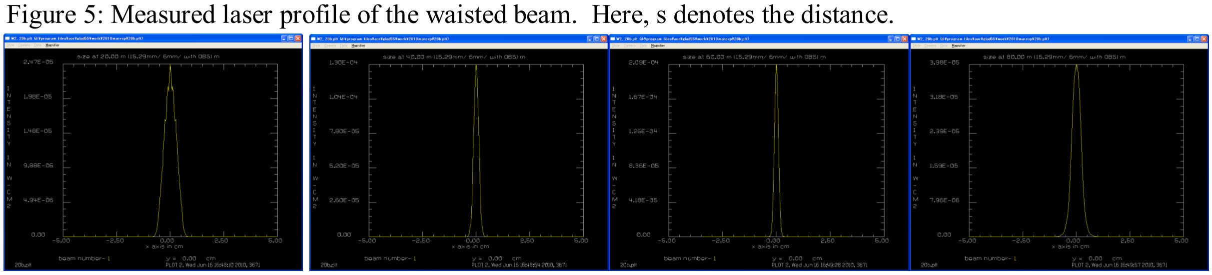


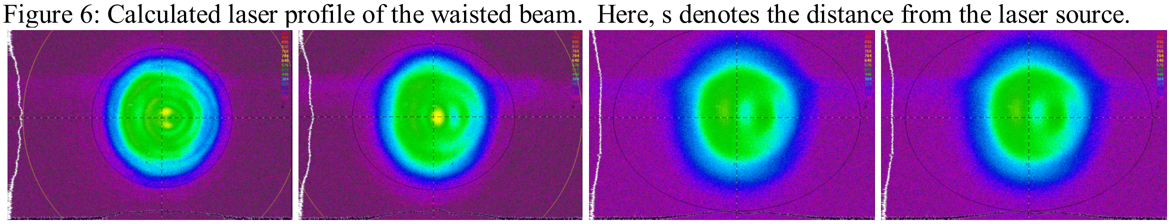
(a) s = 20 m (b) s = 40 m (c) s = 60 m (d) s = 80 m

Figure 5: Measured laser profile of the waisted beam. Here, s denotes the distance.



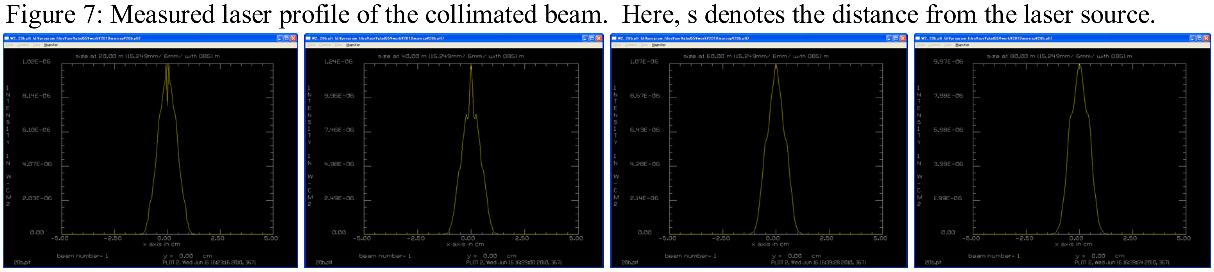
(a) s = 20 m (b) s = 40 m (c) s = 60 m (d) s = 80 m

Figure 6: Calculated laser profile of the waisted beam. Here, s denotes the distance from the laser source.



(a) s = 20 m (b) s = 40 m (c) s = 60 m (d) s = 80 m

Figure 7: Measured laser profile of the collimated beam. Here, s denotes the distance from the laser source.



(a) s = 20 m (b) s = 40 m (c) s = 60 m (d) s = 80 m

Figure 8: Calculated laser profile of the collimated beam. Here, s denotes the distance from the laser source.