IMPROVEMENT OF THE ALIGNMENT SYSTEM FOR THE KEK 2.5-GEV ELECTRON LINAC

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The alignment system for the KEK 2.5-GeV electron linac was improved regarding several points: replacement of the large gas laser (He-Ne) with a compact diode-pumped solid laser (Nd:YAG), the introduction of a single-mode, polarization-maintaining fiber between the laser and the light-injection point into the alignment vacuum duct, and the use of new optics for realizing a diffraction-limited beam along the entire linac length of 460 m. The new system works satisfactorily and serves as a light source of good quality. A preliminary measurement of the system resolution for the KEK 2.5-GeV electron linac is reported as well as the main points concerning the improvements. A new design of the linac alignment system for the KEKB injector linac is also proposed.

I. INTRODUCTION

The stable acceleration of a high-current electron beam of good quality is one of the common requirements for modern large-scale electron accelerators, including linacs for a large yield of positrons, linacs for FEL, and future linear colliders. For realizing stable operation, transverse wake-field effects of high-current beams, which could cause a beam instability and degrade the beam quality, must be minimized in various ways. It has been recognized that the precise alignment of the accelerators is one of the key issues concerning the prevention of a wake-field instability.

In the KEKB injector linac [1] it is required that a large amount of positrons be produced effectively, for which a high-current, single-bunched primary electron beam of more than 10 nano Coulomb must be stably accelerated up to the positron production target (4 GeV). The alignment tolerances due to the transverse wake field have been calculated [2]; the misalignment errors of the accelerator components must be less than 0.1mm.

We have so far used the laser alignment system that was constructed about 14 years ago when the linac was commissioned. Since in recent years it had some troubles regarding optical systems, including the light source, and did not give the required resolution of alignment measurements, we planned to improve the alignment system for the KEKB injector linac. The key items of the improvement are the following:

1. light source and optical system
2. position-detection system
3. automatic alignment measuring system

By carrying out item (1) the beam quality of light is to become better, and the resolution of position measurements will be improved. We describe here mainly the first item, which was successfully accomplished. Regarding items (2) and (3), a brief prospect is presented in connection with a practical design of the alignment system for the KEKB injector linac.

II. ALIGNMENT SYSTEM

Since the roundness effect of the earth is eminent in this kind of very long system, it is in principle impossible to align the system along the long beamline by the usual method using levels. A conceptual drawing of the laser alignment system is shown in Figure 1.

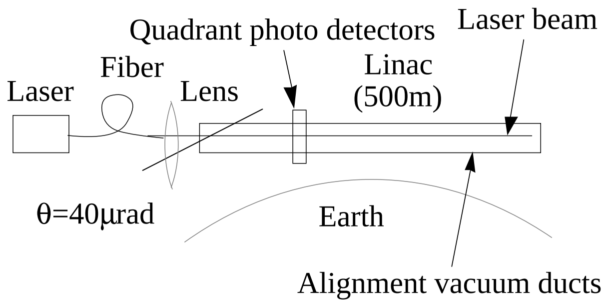

Figure. 1: Conceptual drawing of the laser alignment system.

A. Principle

The procedure of alignment is basically divided into two parts:

1. By using a laser beam as a reference line along the entire linac, the positions of each accelerator girder are measured with quadrant photo detectors set at the front and back ends of the girder. The light path is kept in a vacuum so that any index fluctuation effect on the laser beam can be avoided.
2. The accelerator girders are then aligned so that the positions become centered. The accelerator components are put on these girders with a mechanical precision of less than 0.1 mm.

This procedure signifies that the measurement resolution of alignment must be less than 0.1 mm, which satisfies the alignment tolerance calculated from the transverse wake-field effects. As a result, this alignment scheme should also work for the KEKB injector linac.

B. New Light Source

Since the laser beam is utilized as a reference line, it must be of good quality: the mode must have not only a good Gaussian profile, but also a shorter wavelength for accomplishing a smaller beam size of the diffraction limit. The laser used so far is a He-Ne gas laser at a wavelength of 633 nm, which essentially suffers instability problems due to the characteristics of the gas used. The recent progress of laser-diode pumped solid lasers is prominent; a good beam quality is easily obtained compared with that of gas lasers. Besides, utilization of non-linear optical materials allows an effective generation of a laser beam having a shorter wavelength. We have adopted a laser-diode pumped Nd:YAG laser with subharmonic generation at a wavelength of 532 nm as a new light source. The characteristics of the laser are shown in Table I.

Table I. Parameters of the laser for alignment: a laser-diode pumped Nd:YAG laser with subharmonic generation (single longitudinal mode) [3].

Wavelength (nm)	532
CW Output Power (mw)	>10
Transverse Mode	TEM_{00}
TEM_{00} Beam Diameter (mm)	0.32
TEM_{00} Beam Divergence (mrad)	2.2
Beam Pointing Stability (μrad)	±3 (measured@ 8hrs)
Stability of Output Power (%)	<±2 (8hrs)
Noise (10Hz-1GHz) (% rms)	<0.5
Polarization	linear
Inherent Line Width (kHz)	<10 (1ms)
Jitter (kHz)	<±500 (1s)

C. Fiber Optics

Although the laser shows a fairly good pointing stability of ±3 μrad over 8 hours, it is not sufficient for our alignment system, since this angular variation causes a beam-position fluctuation of ±1.5 mm at a distance of 500 m. In order to prevent this effect, we have introduced a single-mode polarization-maintaining optical fiber for transporting the laser beam from the laser to the alignment optical system. In this way, we could isolate the alignment optical system from the laser, so that it is not affected by the laser, itself. The pointing stability is improved by using a positioning system of high-precision and high-stability for the fiber output point. The mode shape is also improved by the mode-cleaning effect of the fiber, showing a good Gaussian form.

D. Alignment Optical System

Since the laser beam is used as a reference line, the beam size must be sufficiently small to permit the required measurement resolution. According to the characteristics of the quadrant photo detectors and the electric circuits, it has turned out that a beam size of less than 30 mm in diameter assures an alignment resolution of 50 μm. From calculations based on Gaussian beam optics, if a diffraction-limited beam is established and the beam waist is located at a distance of 500 m from the beam-injection point, the beam size would be about 15-20 mm for a wavelength of 532 nm, which is satisfactory for our system.

For accomplishing this, we made special optics for a beam-size transformation that enables a diffraction-limited beam along the entire linac. The experimental results show that a laser beam with an initial size of 30 mm in diameter at the electron gun girder is successfully transported to the end of the linac, where the beam diameter is measured to be less than 15 mm ($1/e^2$). As a result, an alignment resolution of less than 50 μm is expected.

III. PRELIMINARY MEASUREMENTS

In order to check the performance of the system, we carried out preliminary measurements of the alignment status of the KEK 2.5-GeV linac as well as a brief calibration of the measurements.

A. Calibration

Rough calibrations were performed at two representative points (first and last acceleration sections) in the linac in order to understand the position dependence of the calibration factors. By moving the quadratic photo detectors with a precision of 10 μm, the detector outputs were measured. The results are shown in Figure 2. The errors due to beam-position fluctuations were sufficiently small during the measurements. The measurement resolution was estimated to be less than 50 μm.

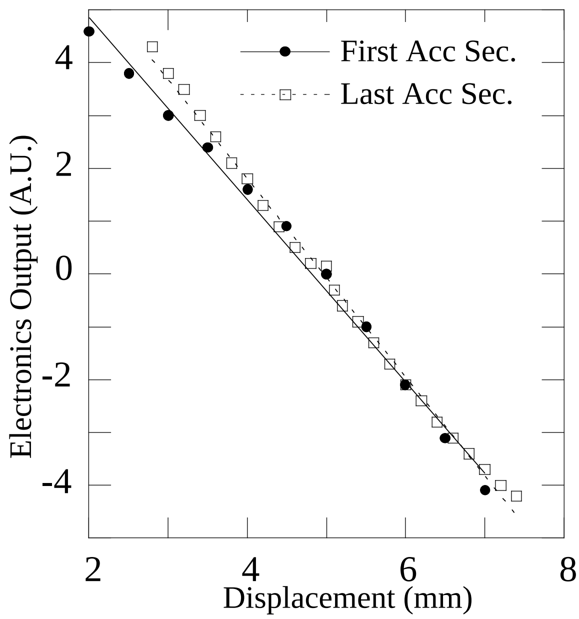

Figure 2: Calibration of the alignment system. The solid lines represent the linear fitting of the data.

The linearity is not bad in the measurement dynamic range of two or three millimeters, while the position dependence seems not to be large in this range of beam size. For a more precise calibration, however, it is necessary to measure at the same time the beam size at each calibration point. Therefore, the calibration factors obtained by the slopes of the fitted lines will have some errors due to the ambiguity of the beam sizes if they are used for positions other than the present calibration points.

B. Alignment Measurement

Figure 3 shows the alignment status of the KEK 2.5-GeV linac (preliminary). Since the calibration factors are not universal (as mentioned in the preceding section), the absolute amount of deviation seen in the graph will be revised. In any case, the results indicate that the linac is misaligned to some extent. We will therefore adjust the misalignment in the near future.

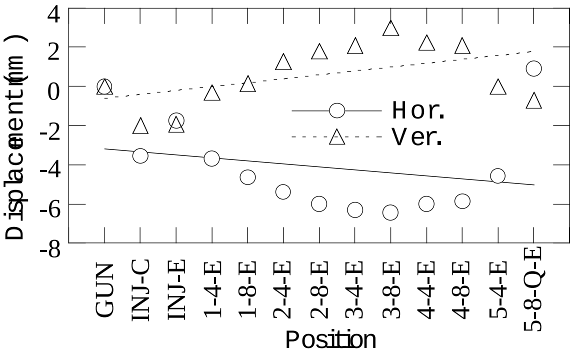

Figure 3: Alignment status of the KEK 2.5-GeV linac (preliminary).

IV. CONCLUSIONS AND DISCUSSIONS

The alignment measuring system of the KEK 2.5-GeV linac was improved regarding several points. A measurement resolution of 50 µm was achieved by installing a new laser and an alignment optical system comprising an optical fiber.

For further improvements, we plan to accommodate an automatic alignment measuring system, including an improvement of the position-detection system. This system would be especially useful for real-time monitors of the alignment status of the KEKB injector linac, since it would help figure out one of the causes in case that the stable operation of the linac is disturbed by some unpredictable phenomena, such as earthquakes.

In the KEKB project, the linac has an arc section in order to utilize the present positron generator linac for increasing the total energy of the linac. Therefore, the alignment must be carried out in three parts: the up-stream linac, the arc, and the down-stream linac (Figure 4). We plan to align the three parts as follows:

1. Align the down-stream linac using the present alignment system with a precision of less than 0.1 mm.
2. Transfer the height of two separate points of the down-stream linac to corresponding points of the up-stream linac with a laser trigonometry or some other methods. In the up-stream linac, we employ a laser alignment system identical to that of the down-stream linac by using the two transferred points as references. For the horizontal directions perpendicular to the beam line, we use the usual levels. As a result, the plane of the down-stream linac is transferred to the up-stream linac.
3. Align the arc section with the usual levels. This signifies that the plane of the arc section is inclined to the others with an angle of about 40 µrad (Figure 1 and 4).

V. ACKNOWLEDGMENTS

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VI. REFERENCES

[1] A. Enomoto et al., Proc. of the 1994 International Linac Conference, Aug. 21-216, Tsukuba, Japan, p. 184.

[2] Y. Ogawa et al., *ibid.* p. 535.

[3] ADLAS diode laser pumped solid state laser, 532 nm cw, Nd:YAG, model 105.

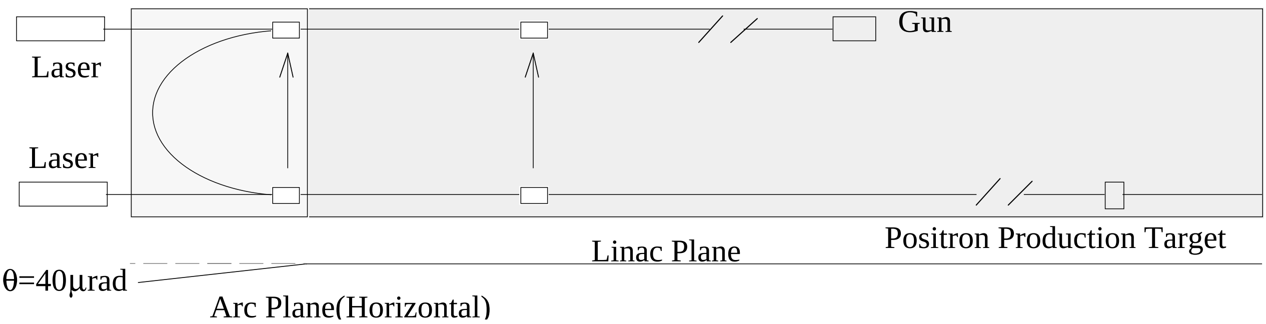

Figure 4: Alignment configuration of the KEKB injector linac.