STRAIGHTNESS ALIGNMENT OF LINAC BY DETECTING SLOPE ANGLE*

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Abstract

Straightness measurement by detecting slope angle[1] was adopted for evaluating the aligning straightness of the 600-m-long KEK e-/e+ injector linac[2].

Here, the slope angles between the centers of the alignment base plates for the 71-m-long part of the linac could be detected with the standard deviation (σ) of 9 µrad by using Talyvel 4, a precise electronic level system. As a result, the straightness could be evaluated with the standard deviation of 26 µm fairly easily, which is hardly achieved by conventional methods.

The estimation based on our error propagation model shows that straightness evaluation with the reproducibility of 0.6 mm (2σ) for the distance of 500 m, sufficient for aligning the KEK linac, and that of better than 1 mm (2σ) for the distance of 10 km, expected for the linacs planed in the ILC project[3], can be achieved with this technique.

INTRODUCTION

The 600-m-long KEK e-/e+ injector linac is expected to be aligned with an accuracy of sub-mm or better in its mechanical alignment (primary alignment) for the future upgrade. The linac is composed of the 125-m-long straight section and the 483-m-long straight section connected with the 180-degree arc section, forming "J" shape. It follows that the aligning straightness of the 483-m-straight-section should be evaluated with an accuracy of sub-mm or better. We adopted a straightness measurement method using a level for evaluating the straightness, considering that it is hardly achieved by any other conventional methods (cf. figure 7).

Figure 1 shows its schematics. Here, the tangential angles of the profile corresponding to the differential of the straightness are obtained. The straightness is derived by integrating the angles without affected by error in the scanning straightness $e(x_i)$, as the detected angles were not affected by the error.

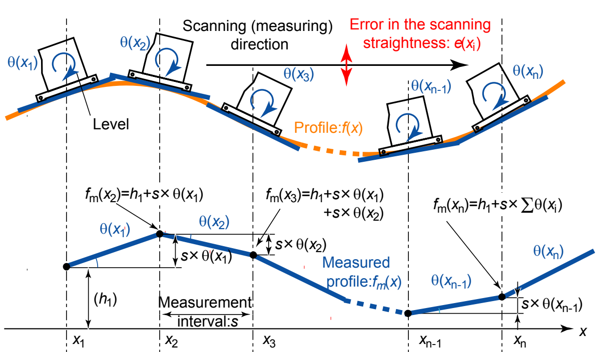

Figure 1: Straightness measurement using a level.

The straightness $f_m(x_n)$ at position x_n is derived as

$$f_m(x_n) = h_1 + s \times \sum_{i=0}^{n-1} \theta(x_i), \quad (1)$$

where h_1, s, $\theta(x_i)$ expresses an arbitrarily defined straightness of the start point, the measurement interval, and the measured slope angle at point x_i, respectively.

STRAIGHTNESS MEASUREMENT

The KEK linac is composed of 9.6-m-long accelerator units. Figure 2 shows one of the typical accelerator units. In each unit, accelerator components: 2-m-long S-band (2856 MHz) accelerator structures, magnets, and beam monitors, operating directly on particle beams, are typically mounted on a 9-m-long pipe-girder and magnet girders. They are mounted on the girders using alignment base plates made of 15-mm-thick machined stainless steel. Each top of the plates is used as a vertical position reference, while one sides of the alignment rails mounted on the plates are used as horizontal position references. They are aligned with the tolerance of ±0.05 mm for each unit prior to its installation.

We evaluated the vertical aligning straightness of the 38 base plates for the 71-m beginning part of the 483-m straight section. It follows that the average measurement interval was 1.9 m. The slope angles for between the neighboring base plates were measured sequentially with a precise electronic level system, Talyvel 4 (Taylor-Hobson), having ±600 sec (±3 mrad) of measurement range and 0.1 sec (0.5 µrad) of resolution.

Straight bars put on between the centers of the plates were adopted for ensuring the continuity of the

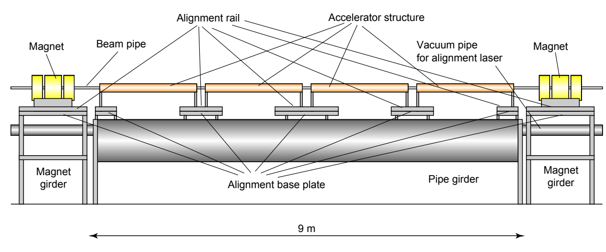

Figure 2: Side view of the typical accelerator unit.

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straightness between the discretely-aligned plates. Pairs of contact feet under both ends of the bars were also adopted for preventing distortions of the plates affecting the measurements. They are used as shown in figure 3.

We used three kinds of straight bars made of aluminum alloy considering periods and obstacles between the neighboring plates. Two of them were 25-mm-thick and 50-mm-wide rectangular-pipes with the pipe-thickness of 3 mm and the lengths of 1998 mm and 2306 mm, respectively. They were used with a pair of grass plates (optical parallels) with 2-mm-thick, 50-mm-wide, 50-mm-long, having the flatness of better than λ=633 nm as their contact feet. The other was a 25-mm-thick, and 50-mm-wide solid-bar with the length of 1640 mm. It was used with a pair of machined aluminum-cuboid-block with 50-mm-thick, 50-mm-wide, and 160-mm-long as its contact feet.

It is important to eliminate systematic errors in the measurements as they introduce large systematic error in the derived straightness through integration (cf. equation (1)). We eliminate the systematic error in the measurements by reversal measurement shown in figure 4. Here, the real angle to be detected θ_r is obtained without affected by the systematic error θ_0 as

$$\theta_r = \frac{\theta_m - \theta_n}{2}, \qquad (2)$$

where θ_m and θ_n expresses the measured angle for before and after the reversal measurement. They are expressed as $\theta_m=\theta_r+\theta_0$ and $\theta_n=-\theta_r+\theta_0$, respectively. The systematic errors θ_0 are considered to be caused by offset of the level, distortions of the straight bars and height differences between the each pair of contact feet.

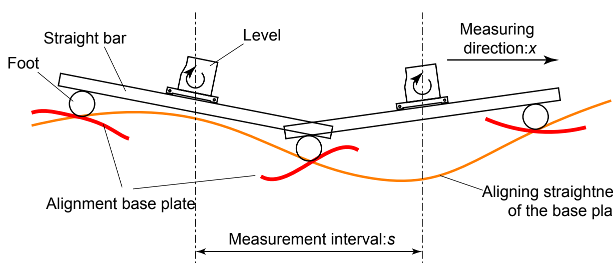


Figure 3: Straightness measurement using a level with straight bars and pairs of contact feet.

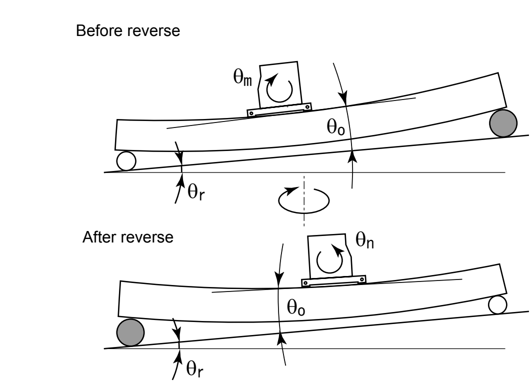
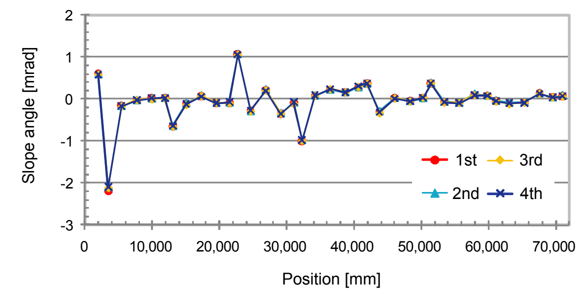
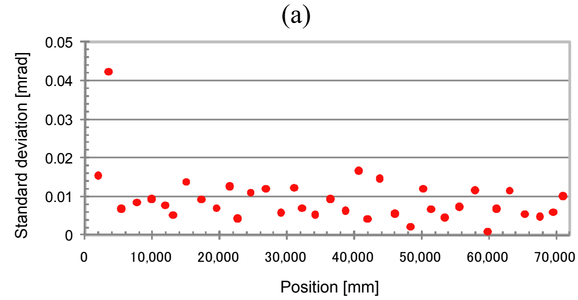


Figure 4: Reversal measurement of the level with a straight bar and a pair of contact feet.

As a result, slope angles between the neighboring base plates could be obtained with the standard deviations of 9 μrad (average) and 42 μrad (maximum), respectively. Figures 5 (a) and (b) express angles derived from the reversal measurements using equation (2) and their standard deviations. They are for four times of repeat measurements during successive three days. It took 2 to 4 hours for each measurement.

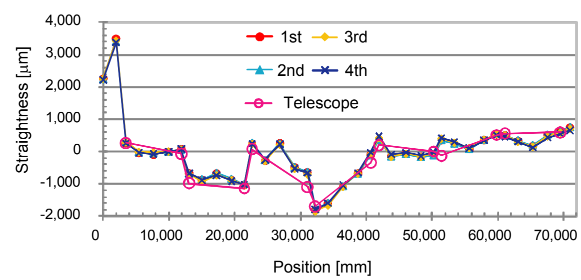


(a)

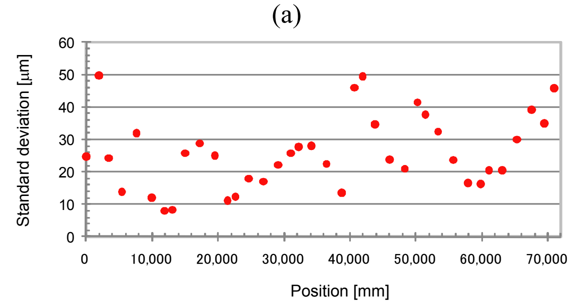


(b)

Figure 5 (a): Slope angles and (b): their standard deviations



(a)



(b)

Figure 6 (a): Straightness and (b): their standard deviations.

The aligning straightnesses of the base plates are shown in figure 6 (a). They are derived from the measurements shown in figure 5 using equation (1). They are normalized by their least square approximation lines. They agree well with those measured by standard telescope-based alignment technique. Figure 6 (b) shows the standard deviations of the derived straightness. They are 26 μm (average) and 50 μm (maximum), respectively.

DISCUSSION

Figure 7 shows accuracy in straightness as a function of measurement distance. Filled circles express those for the achieved here by the two standard deviation (2σ) (cf. figurer 6 (b)). It also shows those for conventional methods by using their definitions, in which TOF expresses for a system based on time of flight of the measurement light such as total station, GPS expresses for global positioning system, respectively.

By using our method, straightness with better accuracy than those for TOF and GPS could be achieved at longer measurement distance than those for straightedge and interferometer, which can hardly achieved by these conventional methods.

Figure 7 also shows estimated accuracies (errors) for two measurement intervals, s=1.9 m (open circles) and 20 cm (triangles), respectively. They are the two standard deviations (2σ) obtained by using equation (3) with σ_{ma}=9 μrad, that is the average standard deviation of the measured slope angles (cf. figure 5 (b)).

Error in the derived straightness σ_p can be estimated as

$$\sigma_p = \sqrt{s \cdot l} \cdot \sigma_{ma}, \quad (3)$$

assuming that error in each $\theta(x_i)$ is random and propagates to the error in derived straightness $f_m(x_n)$ as the error propagating rules (cf. equation (1)). Here, s, l, σ_{ma} expresses the measurement interval, the measurement distance, and the error in each slope angle measurement $\theta(x_i)$, respectively.

The achieved accuracy is approximately one third of the estimated one for s=1.9 m. The reason has not yet resolved; however, the tendency that achieved one is better than estimated one is not a problem in practical usage, considering it as a safety margin.

As shown in figure 7, straightness evaluation with the reproducibility of 0.6 mm (2σ) for the distance of 500 m, which is sufficient for aligning the KEK linac, can be achieved, using the measurement interval of 1.9 m. Moreover, straightness evaluation with the reproducibility of better than 1 mm (2σ) for the distance of 10 km, which is expected for aligning the 10-km-long linacs planned in the ILC project, can also be achieved, using the measurement interval of 20 cm.

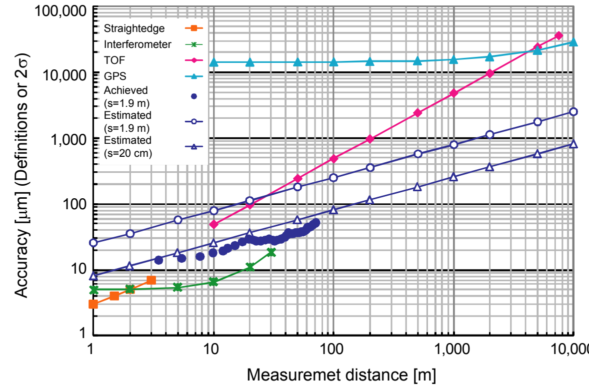


Figure 7: Accuracy in straightness as a function of the measurement distance.

CONCLUSION

Straightness measurement by detecting slope angle was adopted for evaluating the aligning straightness of the 600-m-long KEK e-/e+ injector linac.

As a result, slope angles with the average standard deviation of 9 μrad could be detected and consequently straightnesses with the average standard deviation of 26 μm could be obtained for the 71-m-long part of the linac.

Error estimation shows that straightness evaluations sufficient for aligning the KEK linac (0.6 mm-2σ for 500 m), and expected for aligning the linacs planned in the ILC project (better than 1 mm-2σ for 10 km) can be achieved with this technique.

ACKNOWLEDGEMENTS

Authors thank Yukinori Kobayashi and members of the Accelerator Division 7 in Accelerator Laboratory in KEK and Masahiro Katoh of Institute of Molecular Science for providing us Talyvel 4, and Yohsuke Iino, Kunihiko Sakai and members of Toyama co., ltd. and Mitsubishi electric system & service co., ltd. for providing us useful advices and supporting our studies.

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