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, 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 the straightness evaluation with the reproducibility of 0.6 mm (2σ) for 500 m, sufficient for aligning the KEK linac, can be achieved.

It also shows that the straightness evaluation with the reproducibility of better than 1 mm (2σ) for 10 km expected for the linacs planed in the ILC project[3] can be achieved.

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 its future upgrade. The linac is composed of a 125-m-long straight section and a 483-m-long straight section connected with a 180-degree arc section, forming "J" shape. Therefore, it is necessary to evaluate the 483-m-section, the longer straight section with sufficient accuracy (sub-mm or better) in order to align the whole linac. We adopted straightness measurement using a level for evaluating the aligning straightness of the two straight sections, estimating that it is hardly achieved by any other conventional methods.

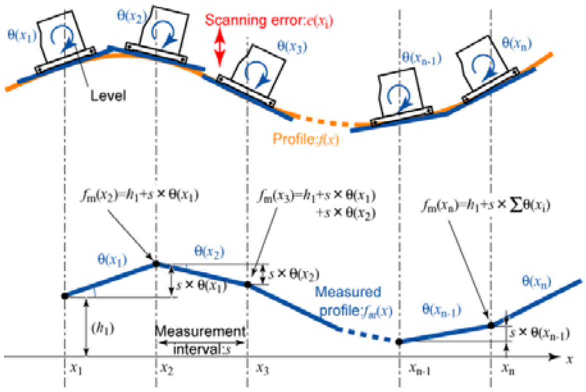

Figure 1: Straightness measurement using a level.

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

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 arbitrarily defined straightness of the start point, measurement interval, and 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 a typical accelerator unit. In each unit accelerator components: 2-m-long S-band (2856 MHz) accelerator structures, magnets, and beam monitors, operating directly on particle beams, are mounted on a 9-m-long pipe-girder and magnet girders. They are mounted on the girders using the alignment base plates made of stainless steel. Each top of the plates is used as a vertical position reference, while one side of the two alignment rails mounted on the plates is used as a horizontal position reference. They are aligned with the tolerance of ±0.05 mm for each unit prior to the 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 of measurement range and 0.1

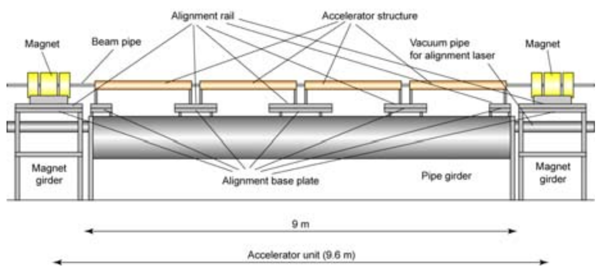

Figure 2: Side view of the typical accelerator unit.

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sec of resolution.

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

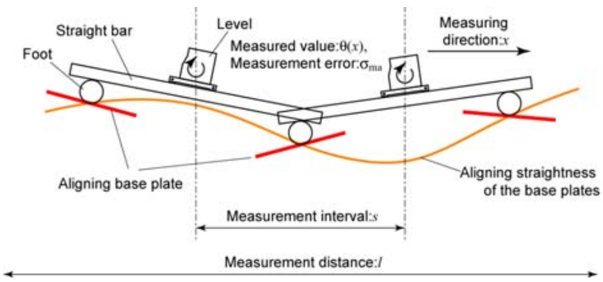


Figure 3: Straightness measurement using a level with straight bars and pairs of contact feet.

We used three kinds of straight bars considering periods and obstacles between the neighboring plates. They are made of aluminum alloy. 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 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.

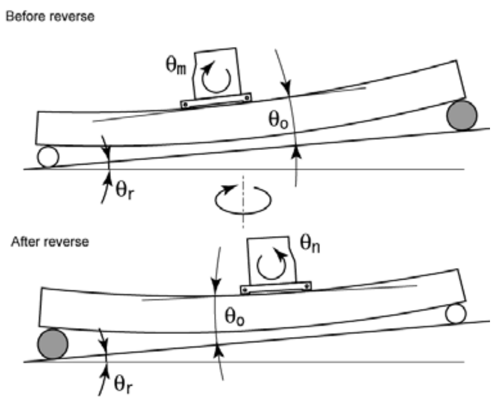
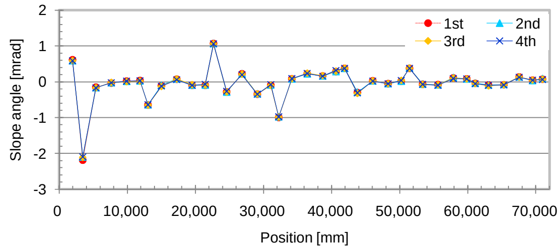


Figure 4: Reversal measurement of the level with a straight bar and a pair of contact feet.

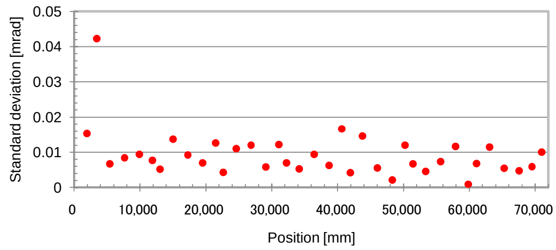
It is important to eliminate systematic errors in the measurements as they introduce large systematic error in the derived straightness through integration (cf. Eq. (1)). We eliminate the systematic error in the measurements caused by offset of the level, distortions of the straight bars and height differences between the each pair of contact feet by reversal measurement as 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.

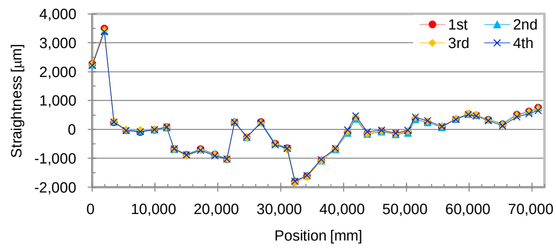


(a)



(b)

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



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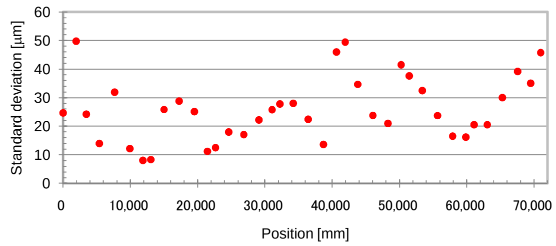

(b)

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

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. Figure 5 (a) expresses angles derived from the reversal measurements using the equation (2) and figure 5 (b) expresses their standard deviations. They are for the four times of the repeat measurements during successive three days. It took 2 to 4 hours for each measurement. The temperature of each accelerator component is controlled to be 30±0.1 deg by water cooling system. The room temperature is also controlled to be around 23 deg. They prevent the linac distorted by temperature fluctuations or distributions.

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 accuracies for the straightness as a function of measurement distance. It shows those of the achieved by filled circles with those of the conventional methods, in which TOF expresses for the systems based on the time of flight of the measurement light, such as the total station and GPS expresses for the global positioning system. It expresses that the straightness with better accuracy than those for the TOF and GPS could be evaluated at longer measurement distance than those for the straight edge or interferometer, which can hardly achieved by these conventional methods.

Assuming that error in each measurement which is the error in each $\theta(x_i)$ for equation (1) is random and that it propagates to the error in derived straightness $f_m(x_n)$ as error propagating rule, the error σ_p in the derived straightness can be estimated as

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

where s, l, σ_{ma} expresses measurement interval, measurement distance, and error in each measurement, respectively.

Figure 7 also shows those for the estimated using equation (3) with σ_{ma}=9 μrad, that is the average standard deviation obtained. They are for the two measurement intervals, s=1.9 m (open circles) and 20 cm (triangles), respectively. The achieved is approximately one third of the estimated for s=1.9 m. The reason has not yet resolved; however, the tendency that the achieved is better than the estimated is not a problem in practical usage, considering it as a safety margin.

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

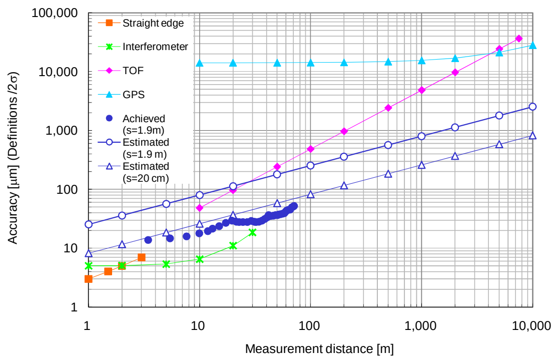

Figure 7: Accuracy in straightness as a function of the measurement distance.

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, and expected for aligning the linacs planned in the ILC project can be achieved with this technique.

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