LASER-BASED ALIGNMENT SYSTEM FOR THE J-PARC LINAC

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Abstract

A laser-based alignment system has been developed for the J-PARC linac. The total length of the linac is about 280 m, and the alignment goal is $\pm 50\mu$m transversely. In this paper, the outline of the alignment system is presented together with the feasibility test results with a 50 m test beam line.

INTRODUCTION

The J-PARC (Japan Proton Accelerator Research Complex) accelerator consists of a 400-MeV linac, a 3-GeV RCS (Rapid Cycling Synchrotron), and a 50-GeV synchrotron [1]. The linac is comprised of a 50-keV negative hydrogen ion source, a 3-MeV RFQ, a 50-MeV DTL, a 190-MeV SDTL (Separate-type DTL), and a 400-MeV ACS (Annular Coupled Structure linac). The total length of the J-PARC linac, which includes the straight section of the following beam transport line, is about 280 m. To avoid excess beam loss and beam quality deterioration, an accurate alignment of accelerator components is indispensable for the linac. From this point of view, the alignment goal along the linac is set to $\pm 50\mu$m transversely. In addition, it is essential to carefully watch long-term ground motion to maintain the alignment accuracy, considering that the J-PARC facility is to be built on a flimsy ground beside the Pacific Ocean. To meet these requirements, a laser-based alignment system has been developed. Trial-manufacturing of main components and feasibility tests with a 50 m test beam line have been performed. In this paper, the outline of the alignment system is presented together with some preliminary results of the feasibility tests performed with a 50 m test beam line. For detailed description of the system, please refer to the reference [2].

LASER-BASED ALIGNMENT SYSTEM

Concept and key components

The laser-based alignment system is designed based on the KEK-PF linac alignment system[3]. A conceptual drawing of the alignment system is shown in Fig.1. A light source is located at the upstream end of the linac. We adopt a 532-nm DPSS (Diode-Pumped Solid State) laser for the light source. An optical system is placed on a laser stage to make a parallel beam, and we have no other optical component downstream. The laser beam axis is set 700 mm horizontally away from the proton beam axis, and surrounded by an airtight duct to ease the sway by air turbulence. The inner diameter of the airtight duct is 80 mm. While a vacuum-tight duct is adopted in the KEK-PF linac alignment system, we plan to adopt an airtight duct for easy handling and manufacturing. A feasibility study of the alignment with the laser path in the atmosphere is now underway, using a 50 m test beam line as described later.

The J-PARC linac consists of accelerator components, such as rf cavities, quadrupole magnets, beam monitors, etc. Generally, several accelerator components are placed on an accelerator stand. The relative alignment among these components, which are placed on the same accelerator stand, is performed with the usual optical alignment method using an alignment telescope. Then, accelerator stands are aligned using the laser beam as a reference line. Each accelerator stand has two laser targets at the upstream end and the downstream end. For the laser target, we use quadrant silicon photo-diodes with a diameter of 30 mm. This diameter is larger than the expected diameter of the light spot after propagation length of 280 m.

Each laser target is installed in a box we refer to as a "*laser target box*". The laser target box has a driving mechanism to turn the laser target away from the laser axis. This feature is essential to enable downstream measurements, because laser targets are supposed to be attached to each accelerator stand. Precise position reproduction is required for the driving mechanism. Four target boxes have been manufactured by way of trial, and position reproduction of less than $\pm 5\mu$m has been achieved.

The box is attached to an accelerator stand by an arm. As an example, Fig.2 shows the case where the laser target box is attached to a DTL tank. The laser target position is adjusted using templates as a reference before we install the tank into the accelerator tunnel. Once the target position is adjusted, we can lock the position of the laser target box with respect to the tank. The template is a steel bar

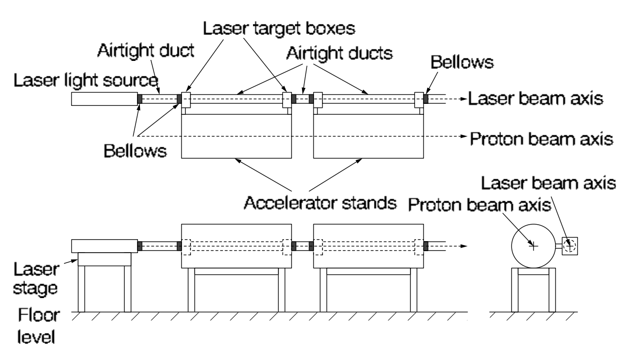

Figure 1: Conceptual view of the laser-based alignment system.

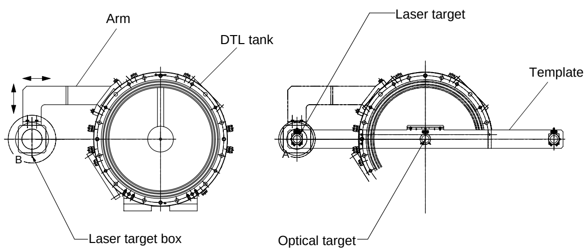

Figure 2: Attachement of a laser target box to a DTL tank.

on which we can mount an optical target and a laser target. These targets are removable with accurate mounting position repeatability. Using two laser targets mounted on two templates attached to the upstream and downstream ends of a DTL tank, we set the reference laser axis for the position adjustment of laser target boxes. An optical target can be mounted on the template, which is used for a relative alignment between a tank and the drift tubes. The attachment of laser targets to other parts, such as SDTL and ACS, is performed in a similar way. The rotation of an accelerator stand around the laser beam axis is avoided by using a level.

In principle, we leave the laser targets attached during beam operation, which enables us to watch the ground motion for a long period of time. However, the laser target can be easily put on and taken off with accurate mounting position repeatability. This feature is required because radiation damage of photo-diodes may be significant in some part of the linac.

After a long period of beam operation, it is necessary to perform re-alignment due to ground motion. As the floor on which the laser stage is placed also moves, the light direction also changes after a long period of time. Then, to enable re-alignment, the stage for the light source should have a mechanism to adjust the light direction to the designated one. The required resolution for the direction control mechanism is extremely high, namely, around 0.1 μrad. To realize the high-resolution direction control, we have adopted a deformation method. In the laser stage, the optical system is placed on a stack of four aluminum plates, and each plate has a narrow part about which we can bend the plate easily. We elastically deform the plates to change the light direction by pushing the plates with stepping motors. Figure 3 shows a photo of the laser stage installed in the JHF linac accelerator tunnel at KEK. Research and development of the laser stage is now underway.

Setting up the laser axis

This direction control system is expected to be useful in the initial alignment also, because the laser axis should be determined in consistent with the downstream alignment. The downstream beam transport line, to which we refer as L3BT, has arc sections. We plan to use a laser-tracker for the alignment after the first arc section of L3BT. Therefore,

Figure 3: Photo of the laser stage.

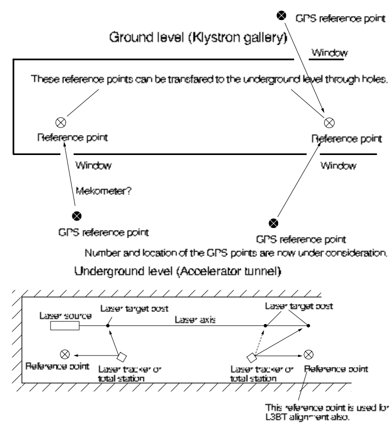

Figure 4: Determining of the laser axis.

we need a connection scheme between these two alignment systems. In addition, we plan to have two reference points in the accelerator tunnel, above which we have penetration holes to enable GPS measurement of the reference points. Using these reference points, we measure the relative position of the linac to other J-PARC facilities, such as the 3-GeV RCS and the 50-GeV Main Ring. We are setting up a GPS measurement network around the J-PARC facility for this purpose. To determine the laser axis using these reference points, we plan to have three secondary reference points (one of them is auxiliary), to which we refer as "*laser target post*", in the accelerator tunnel. By setting up these laser target posts with a laser-tracker, we can connect two alignment systems consistently. The procedure to determine the laser axis is schematically shown in Fig.4.

EXPERIMENTAL RESULTS WITH A TEST BEAM LINE

To check the feasibility of the laser-based alignment system, we have performed a long-range experiment with a 50 m long test beam line placed in the JHF linac accelerator tunnel at KEK. The main aim of this experiment is to examine the effect of air turbulence.

Before proceeding to the long-range experiment, we per-

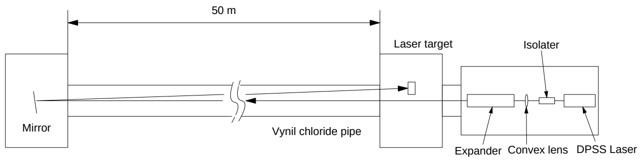

Figure 5: Conceptual view of the experimental setup.

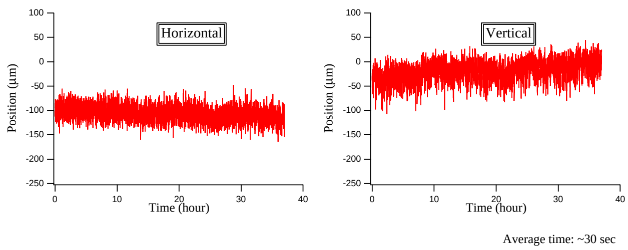

Figure 6: Time evolution of the photo-diode readout in a 50 m experiment.

formed a experiment with much shorter beam propagation length of around 0.3 m to check the fundamental characteristics of the system. In the experiment, we concluded that the spatial resolution of 5 μm can be achieved with the photo-diode, and the effect of the long-time drift of the A/D converter is around $\pm 5\mu$m.

Figure 5 shows the experimental set up of the long-range experiment. At the upstream end, a laser source and an optical system are placed on the laser stage. The optical system used in the experiment is simplified one which consists of a beam expander and an optical isolator, and neither collimator nor optical fiber is included. The laser pathway is surrounded by a temporal air-tight duct made with vinyl chloride to ease the sway by air turbulence. At the downstream end, we have an optical stand on which we place a laser target for 50 m measurements, or a mirror for 100 m measurements. The tunnel is air-conditioned and a cooling-water system for the linac is operated during the measurements. No temperature control is applied for the laser source.

Figure 6 shows the result of a 50 m measurement, in which measured laser-spot position is shown as a function of time. The result for 100 m measurement is shown in Fig.7. It is seen in these figures that the output signal is composed of relatively fast sway component whose period is around or shorter than a few minutes, and slow sway, or drift, component whose period is longer than a few hours. The relatively fast component can be reduced with averaging. In Fig.6, the output signal is averaged over 30 sec, and 2 min in Fig.7.

DISCUSSIONS

We have found in the experiment that the amplitude of the fast sway is roughly proportional to the path-length in this setup, and that we need three- to four-times longer av-

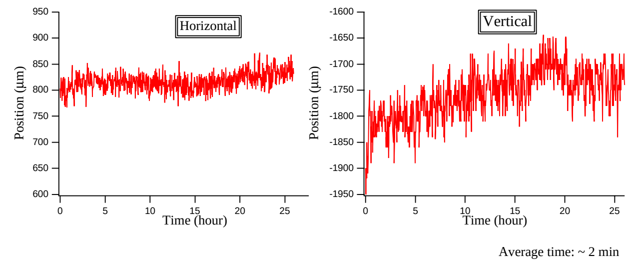

Figure 7: Time evolution of the photo-diode readout in a 100 m experiment.

eraging time to reduce the amplitude to half. It is seen in Fig.6 and Fig.7 that the measurement resolution of less than 50 μm can be achieved except for the vertical direction in the 100 m measurement. We suspect that the 100 m measurement is affected by some instability of the optical stand on which a mirror is placed, because the large-amplitude turbulence suddenly arises in 100 m cases. Because even a slight tilt of the optical stand can affect the measurement in this setting, the system is very sensitive to the stability of the optical stand in the 100 m measurements. To have more conclusive results in 100 m measurements, we need to improve the optical system at the 50 m point.

As mentioned earlier, the fast component of the sway can be reduced by averaging. Contrary, it is difficult to reduce the slow sway or drift component. While the slow component observed in the experiment is within a tolerable level, that in the actual alignment can be more significant considering that the path-length is much longer and the stability may be strongly dependent on the tunnel environment. Therefore, it is urgent to perform further investigation on the cause of the slow component and find a way to reduce it.

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