Alignment Issues of the SLC Linac Accelerating Structure*

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Introduction

The accelerating structure of the Stanford Linear Collider (SLC) is required to be aligned to 100 - 200 μm rms. Alignment at such a level will reduce transverse wakefield effects sufficiently so that only a small emittance enlargement of the beam is expected during acceleration to 50 GeV with up to 7×10^{10} particles per bunch. This report describes many aspects of the alignment including global alignment, local alignment, construction of the accelerating cavities, active controls of the structure alignment, external constraints, temperature and airflow effects, and alignment stability.

Laser Alignment System

The accelerator is globally aligned (every 12 m) using a laser system [1], which is housed in a 24 inch evacuated pipe which supports all the accelerator components. This system has sub-units 12 m long, called girders, with floor and wall supports and a flexible bellows at each end. A schematic view of a girder is shown in Fig. 1. A laser at one end of the accelerator illuminates Fresnel lenses which are inserted one at a time at the alignment positions. The laser spot is viewed at the other end of the accelerator. The transverse position of the laser focus indicates the position of the lenses. Local jacks are then used to correct the girder positions. The resolution of this system is about 50 - 75 microns but calibration transfer errors up to 1 mm have been seen. This system is very useful in measuring relative changes. For example, during 15 seconds of the October 1989 earthquake, settling of the accelerator occurred as well as a transverse displacement (~1 cm) of the downstream end of the accelerator [2]. See Fig. 2. The slip was fixed by placing a gentle s-bend in the accelerator over a distance of several hundred meters. A "beam based" alignment technique, discussed below, is less prone to calibration error and is used for finer girder alignment.

Telescope Alignment System

The alignment of components internal to a 12 m girder is performed using a telescope and targets mounted in 'optical' tooling holes. The holes in the thick end supports of the girder are the fiducial marks and the telescope is mounted in one of them. A target is inserted in the plate at the other end. The line between them is the survey reference for all internal components with tooling holes.

The tooling holes are part of the internal supports for the quadrupole, the aluminum strong back supporting the

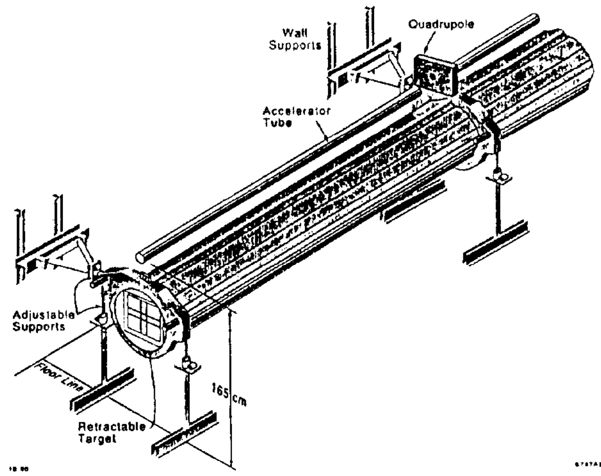

Fig. 1 Support girder for the SLC Accelerator

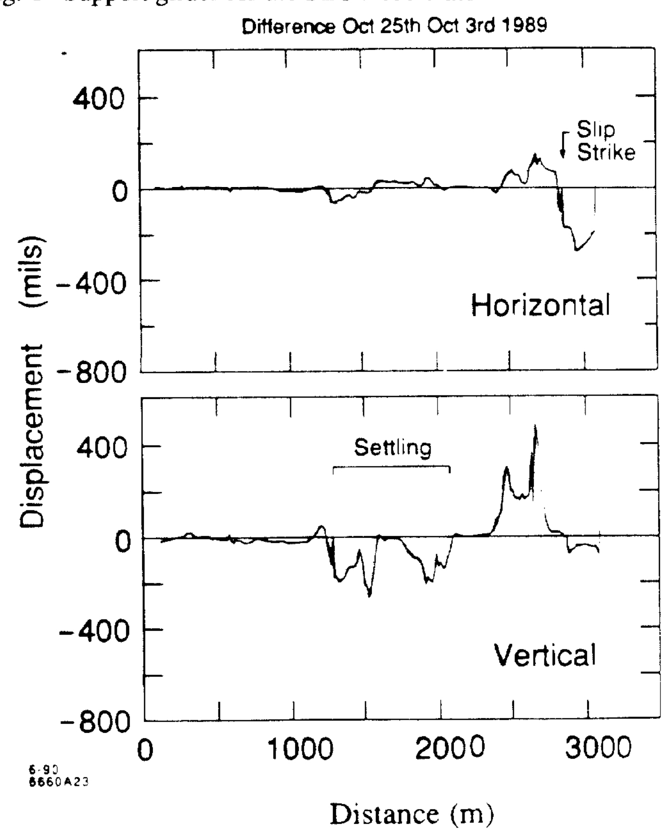

Fig. 2 Observation from the laser alignment system of the settling and shifting of the accelerating structures from the October 1989 earthquake.

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accelerator, and any beam diagnostics on that girder. The tooling holes were aligned relative to the waveguide center in the shop during the construction of the devices and pinned. The accuracy of the machined parts and alignment in the shop is quite good: 50 to 100 μm. However, this secondary reference system has the negative feature that many measurements, machining errors, clamping errors, and the like add to determine the absolute error in the placement of a component in real space. For example, aligning the copper structure with the tooling holes involves over twenty errors [3]. None of the errors are above 127 μm, but the quadratic sum is about 290 μm. Similar assembly errors arise for the quadrupoles and beam position monitors.

Beam-Based Alignment

Measurements of the trajectory of the beam along with the associated strengths of the quadrupoles and the dipole correction magnets (taken at several quadrupole settings) can be used to extract the magnetic offsets of the quadrupoles and the electrical - mechanical offsets of the position monitors [4]. The offset for each position monitor is relative to the nearby quadrupole and for each quadrupole is to the two nearest quadrupoles. With beam position monitor reading errors of order 25 μm, local offsets of 100 μm rms for quadrupoles and 80 μm rms for position monitors have been achieved. Fig. 3 shows the resulting errors of the SLC quadrupoles in the vertical plane (the horizontal plane is similar). It is difficult for this technique to remove long wavelength errors in the accelerator of the order of hundreds of meters [4]. However, the beam is expected to be insensitive to these errors.

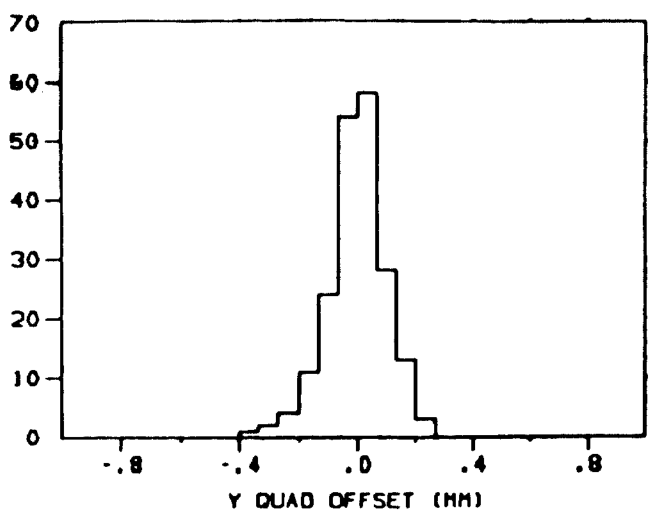

Fig. 3 Vertical residual quadrupole offsets after beam-based alignment.

Accelerator Structure Alignment

The copper accelerating structure is supported on a strongback at intervals of 1 m. These supports were adjusted 25 years ago to be straight. Some changes and settling between supports have occurred since. To align the structure, a theodolite and optical level must be used in the tunnel and many measurements taken. A typical example of the alignment data of a 12 m structure on one girder is shown in Fig. 4. The measurements took over an hour to acquire (without the complication of adjustments. (In addition, the tunnel conditions are difficult for surveyors and surveying [hot and dry]). The offsets at the supports (vertical lines in Fig. 4) can be adjusted with wrenches. Between supports, a bending device was fabricated and has been used but it's cumbersome. Less than 50 m of the 3 km linac have been realigned in this way. However, the spatial frequencies of these misaligned girders are very high (much higher than the betatron frequency) and do not contribute significantly to wakefields as positive and negative errors cancel. Whole girder offsets are the most important, because the statistical component at the betatron frequency is most harmful.

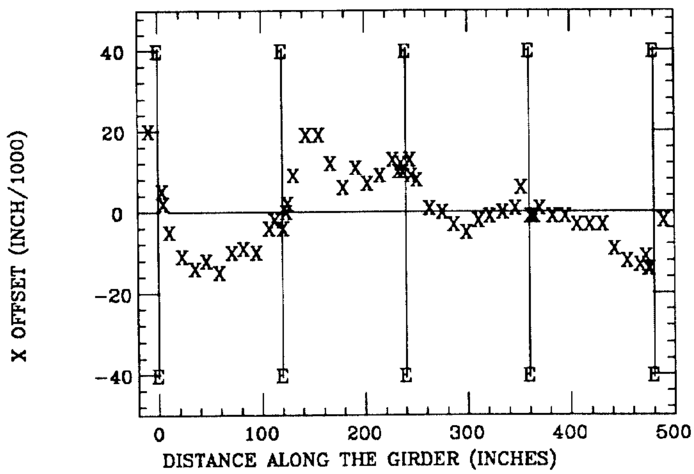

Fig. 4 Measured displacements of an accelerator structure measured every 30 cm. The symbols 'E' refer to the ends of the 10 ft assembly sections.

Active Structure Alignment Correction

A technique to actively control the accelerator offsets at the girder level has been devised [5]. Small movers are attached to the center of the girders to produce external movements of up to +/- 1 mm. The ends of the girder are held rigidly so that the quadrupoles and position monitors do not move. Small bows in many adjacent girders spaced at the betatron wavelength can easily drive wakefields in the beam. Cosine and sine like mover combinations can be devised to cancel the natural errors which affect the beam. A search is underway for an inexpensive hardware design.

Temperature and Airflow Effects

The accelerating structure is maintained internally at 113 degrees F in order to provide proper RF phasing from cell to cell. Since the structure is not insulated, heat flows from the structure towards the walls through several paths: radiant heat loss, conduction through the supports, and air convection. As a consequence, there are temperature gradients in the tunnel. The gradients have been measured [6,7] and generally give the temperature values illustrated in Fig. 5. One consequence of the temperature gradient is the refraction of the light used by the alignment telescopes. The gradient of 0.32 degrees F per 6 inches causes an unintentional vertical bow of about 20 μm in the center of the girder [7,8].

The temperature in the tunnel varies diurnally with a small air exchange from outside the tunnel. Measured temperatures over a week are shown in Fig. 6. Externally, the accelerator, H_2O piping, and the RF waveguide remain at about 111 to 113 degrees F as they are regulated. There is a relatively good thermal contact between the accelerator and its support (the strongback) which dampens the temperature variations of the strongback. The laser light pipe is not strongly coupled to the strongback and follows the variations of the surrounding air more closely. However, the lightpipe is rigidly connected to the strongback mechanically. Thus differential expansion causes bowing, checked both theoretically (ANSYS) (Fig. 7) and measured in the tunnel (Fig. 8). The bowing is 150 μm / degree F difference. Maintaining temperature conditions during alignment is very important. Alternatively, girder clamps, which hold the lightpipe center fixed, are under investigation. Also, air flow patterns from normal convection and from the nearly 600 tunnel penetrations are under study.

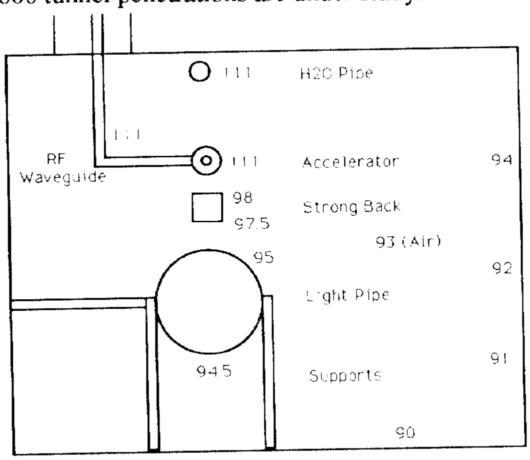

Fig. 5 Typical temperature measurements in the Linac tunnel.

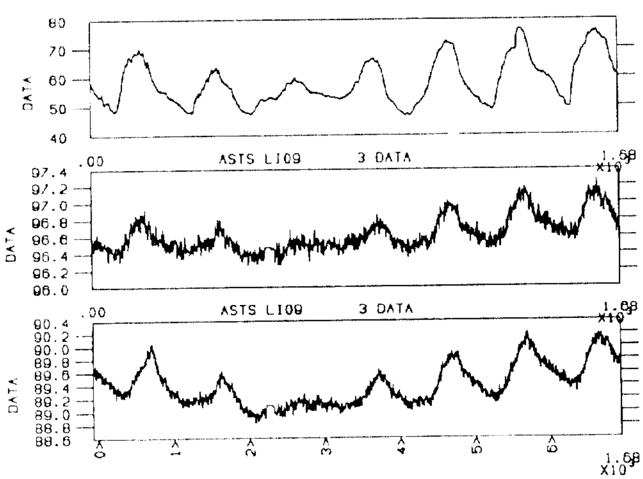

Fig. 6 Variations in temperature of the outside air (top), strongback (middle), and lightpipe (bottom) over a period of a week. The variations are correlated with a peak-to-peak variation of 25 degrees outside, 0.4 degrees for the strongback, and 1.0 degree for the lightpipe.

Fig. 7 ANSYS calculated vertical girder bowing from gradient changes. The displayed bowing over the 12 m girder is exaggerated for effect.

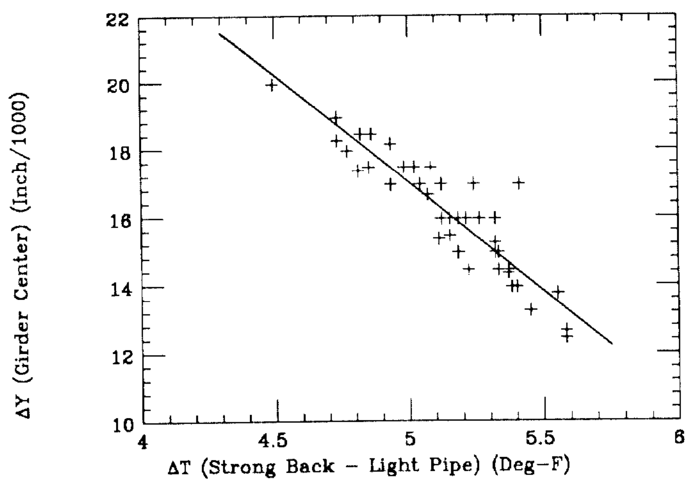

Fig. 8 Measured vertical girder bowing from gradient changes.

Acknowledgments

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References

1) W. Herrmannsfeldt, "Linac Alignment Techniques", IEEE Trans. Nucl. Sci. NS-12 No. 3, p. 9 (1965).
2) G. Fischer, "SLAC Site Geology, Ground Motion, and Some Effects of the October 17, 1989 Earthquake", SLAC-Report-358 (1990).
3) R. Sandkuhle, "Probable Error of Aligning Accelerator on the Support Girder", SLAC Engineering Note R-290501-000-007 (1966).
4) C. Adolphsen et al., 'Beam-Based Alignment Technique for the SLC Linac', IEEE 89CH2669-0 US PAC p. 977 (1989).
5) J. Seeman, 'New Compensation of Transverse Wakefield Effects in a Linac by Displacing Accelerating Structures', Proc. of 1990 Linear Accel. Conf. Albuquerque, p. 390 (1990).
6) J. Seeman et. al., "Accelerator Temperature and Girder Alignment', SLAC SLC Experimental Note 227 (1991).
7) J. Seeman et. al., "Tunnel Temperature and Alignment', SLAC SLC Experimental Note 229 (1991).
8) R. Neal, "Effects of Refraction on Optical Alignment of M Accelerator", SLAC TN-61-4 (1961).
9) L. Piemontese, "Temperatures and Heat Flow in the Linac Tunnel", SLAC SLC Experimental Note 238 (1991).