FIRST DATA FROM THE LINEAR COLLIDER ALIGNMENT AND SURVEY PROJECT (LiCAS) *

Armin Reichold, Patrick Brockill, Sigal Cohen, John Dale, Mike Dawson, Tony Handford
Mark Jones, Gregory Moss, Lee Anthony Rainbow, Michael Tacon, Cecilia Uribe Estrada
David Urner, Roy Wastie, Stephanie Yang:
John Adams Institute for Accelerator Physics, University of Oxford, UK
Johannes Prenting, Markus Schlösser: DESY, Hamburg, Germany
Grzegorz Grzelak: University of Warsaw, Warsaw, Poland

Abstract

The LiCAS project has developed a prototype robotic survey system for rapid and highly accurate surveying of long linear accelerator tunnel networks. It is aimed at the International Linear Collider (ILC). This Rapid Tunnel Reference Surveyor (RTRS) is an R&D instrument for evaluating the performance of the RTRS concept and its survey technology. The prototype has been commissioned in a test tunnel at DESY with initial calibrations and measurements ongoing. We will report recent results where they improve over previously reported work.

INTRODUCTION

The International Linear Collider (ILC) is an e^+e^--collider aiming to achieve a luminosity of $2 \times 10^{34} cm^{-2}s^{-1}$. The necessary ultra low emittance of 30 $nmrad$ can only be maintained throughout its 100km of beam line if all elements are accurately aligned. In the main linacs the required reference network survey accuracy stands at 200 (500) μm in the vertical (horizontal) direction over distances of 600m. The dependence of the emittance on the details of the alignment process is very complex and still subject of current research [1].

The high sensitivity to misalignments demands frequent realignment. This mandates a rapid and preferentially robotic survey system [3] to keep the costs of machine down-time and manpower at an acceptable level [2]. The LiCAS project addresses the most challenging problem of the long distance reference survey. The functional principles, measurement technology and co-ordinate system convention of the LiCAS RTRS have been described earlier in [6]. Figure 1 shows a photograph of the prototype RTRS in the test tunnel at DESY.

MEASUREMENT PERFORMANCE

Laser Straightness Monitors (LSM)

A detailed description of the LSM system can be found in [4]. The LSM beams are detected by analogue CCD cameras with pixel size of 8.6 (hor.) $\times$ 8.3 (vert.) μm^2 and

Figure 1: The prototype RTRS after commissioning in the DESY test tunnel (Jan. 2008). The electronics crates in the service cars have temporarily been supported by metal bricks during an analysis of vibration sources.

760(hor.) $\times$ 572 (vert.) pixels, running asynchronously at 25 frames per second (fps). The frames are digitised by a four channel pci-x frame grabber card.

For image analysis we apply a low-pass Butterworth filter to the Fourier-transformed image to remove effects from dust. This takes 1 second per image. We have evaluated two beam fitting procedures. The simple fit fits a 1-D Gaussian to the vertical and horizontal image projections and takes 0.2 seconds. Because the CCD cameras weakly reflect, some cameras detect reflections from their opposite camera (ghosts). Therefore we fit multiple 2-D Gaussians to these image, identifying the primary via its smaller width. This takes approximately three minutes.

Analysis of 9000 images taken at 25 fps revealed broad and slowly moving vertical bands of 0.1% of normal beam intensities. These are caused by interference between frame grabber channels. The interference patterns slowly move due to the asynchronicity of the cameras. This leads

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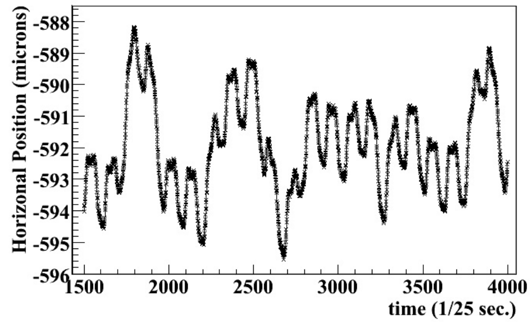

Figure 2: Horizontal beam position versus time before averaging (simple fits).

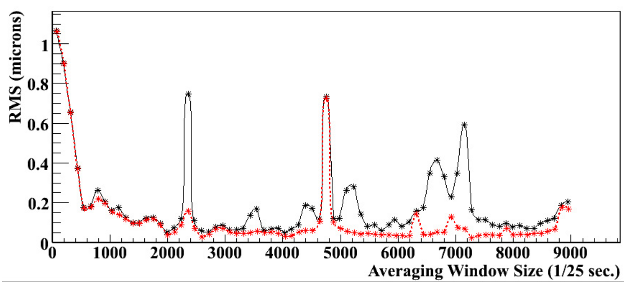

Figure 3: RMS of horizontal beam position vs. averaging window size. Averages of 40 (20) simple fits shown in dotted red (solid black).

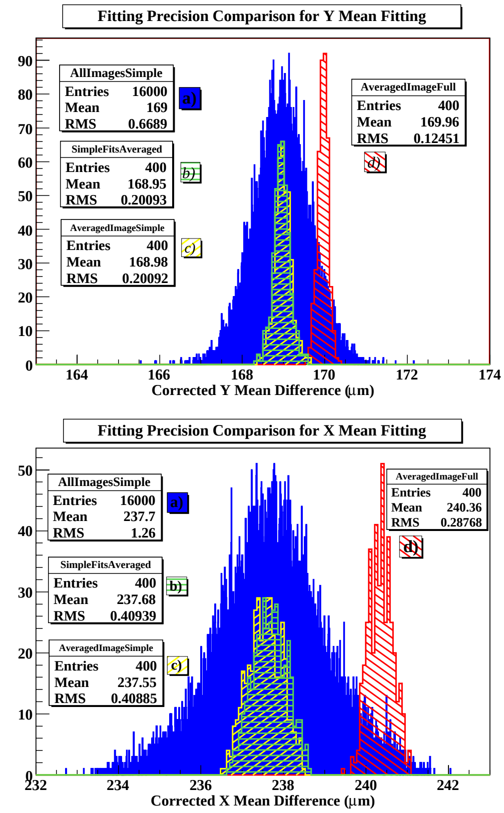

Figure 4: Histograms of vertical (bottom) and horizontal (top) image position for: (a) simple fits, (b) averaged simple fits, (c) simple fitted averaged images and (d) 2D fitted averaged images

to oscillatory shifts of the fitted horizontal beam positions of up to 10 μm as shown in figure 2.

Two techniques for removing these were evaluated. Firstly the averaging of multiple fits and secondly fitting an averaged image. Figure 3 shows how the former technique, using simple fits, reduces the RMS noise for averages of 20 (40) fits as a function of the period over which images were taken. Averaging 20 simple fits taken over 20 seconds reduced the RMS below 200 nm.

Figure 4 shows how the vertical (horizontal) RMS varies for different analyses. Here we average 40 images over a period of 117 s. The data spans 13 hours.

Frequency Scanning Interferometry (FSI)

A detailed description of the FSI system can be found in [5]. FSI measures the length ratio of an unknown interferometer to a reference interferometer. Therefore accurate calibration of the reference interferometers length L_{ref} is essential. To do this, a computer controlled linear stage moves a pair of back-to-back retro reflectors over a distance of two meters. An FSI interferometer measures the distance from one end of the stage to the nearest reflectors. A laser tracker anti-co-linearly measures the distance from the other end to the other reflector. Figure 5 shows a linear fit to the length change measured by the laser tracker versus the FSI length ratio. The slope of this fit determines L_{ref} to an accuracy of 0.6 μm (0.19 ppm). The perpendicular residuals have an RMS of 0.4 μm.

Figure 6 shows histograms of the the changes of lengths measured by the evacuated internal FSI system over a period of 14 hours. Resolutions of 45nm have been achieved.

CALIBRATION

To calibrate an RTRS car approximately 150 internal parameters, such as positions and orientations of CCDs or interferometer components must be determined. To this end we have developed a Gauss Markov model of the calibration process in which a laser tracker witnesses a set of 50 moves (small translations and rotations) of the car under calibration while the RTRS measures all its sensors. We use an iterative least squares procedure to find those internal parameters that best reproduce the laser tracker observations [7] [8]. Neighbouring cars and the LSM beam are assumed to be stationary during calibration.

The design matrix A for this model has 2320 rows and 447 columns. Each row represents a measured value, each column an unknown internal parameter. The latter not only include the original 150 internal parameters, but also the translations and rotations for the 50 moves, as well as some constraint equations.

This problem is well-determined and the solution con-

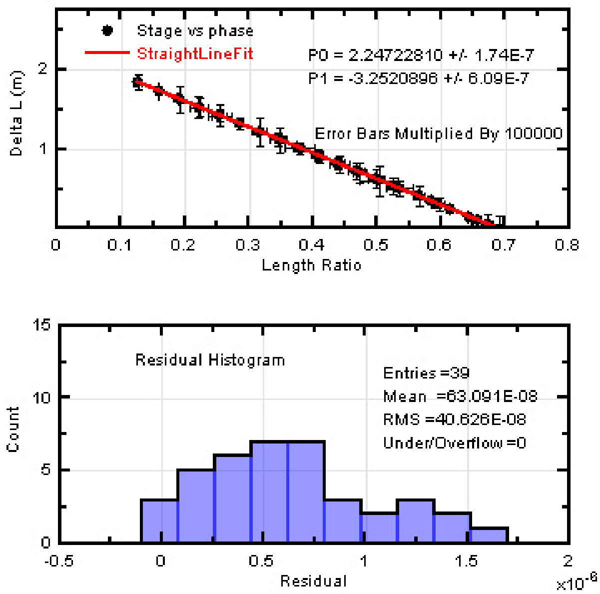

Figure 5: Linear fit to laser tracker lengths vs. FSI length-ratio (top) and histogram of the perpendicular residuals

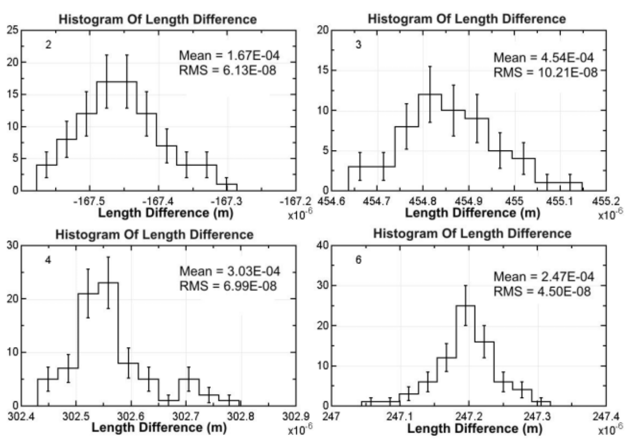

Figure 6: Histograms of the length changes of the 4.5m long internal FSI lines over a 14h period

verges. A simulated calibration is shown in figure 7. The true component positions are depicted in orange, and assumed initial positions in gray. After several iterations, the components converge to their true values, as shown in the lower half of figure 7. Two sets of experimental calibration data are currently being processed. We expect to be able to publish these results shortly.

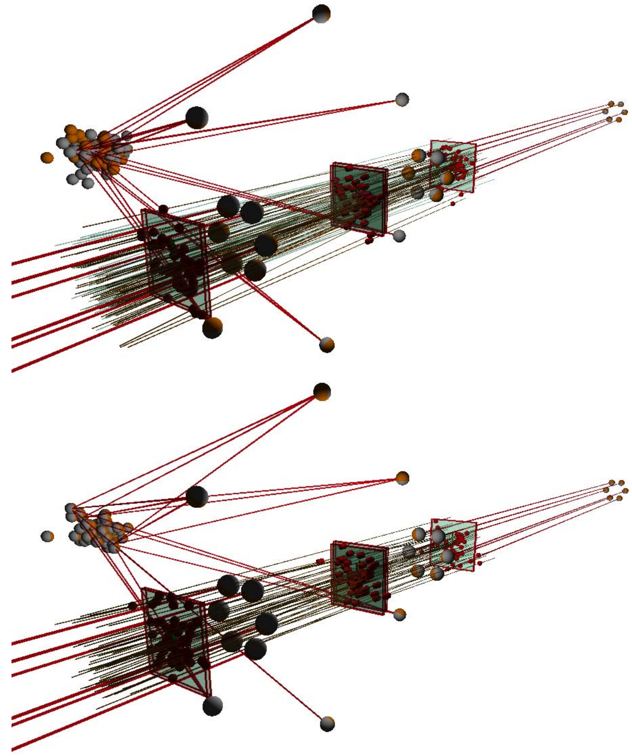

Figure 7: True (grey), initial (orange top) final (orange bottom) positions of components during calibration

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