THE LICAS-RTRS - A SURVEY SYSTEM FOR THE ILC*

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Armin Reichold, Mike Dawson, John Green, Yanmei Han, Mark Jones, Gregory Moss, Brian Ottewell, Colin Perry, Roy Wastie, John Adams Institute and Physics Department University of Oxford, UK
Daniel Kaemtner, Johannes Prenting, Ernst-Otto Saemann, Markus Schloesser, DESY, Hamburg, Germany
Grzegorz Grzelak, University of Warsaw, Poland

Abstract

The ILC requires an unprecedented accuracy and speed for the survey and alignment of its components. The Rapid Tunnel Reference Surveyor **(**RTRS**)** is a self-propelled survey train, intended to automatically survey a reference network in the ILC tunnels with a design accuracy of 200 (500) microns vertical (horizontal) over each 600 m segment [1]. A prototype RTRS has been built by the LiCAS collaboration. It will shortly commence operation at DESY. The operation principle and expected performance of the RTRS will be explained. The status of the project as well as the principles and performance of the underlying measurement technique will be described.

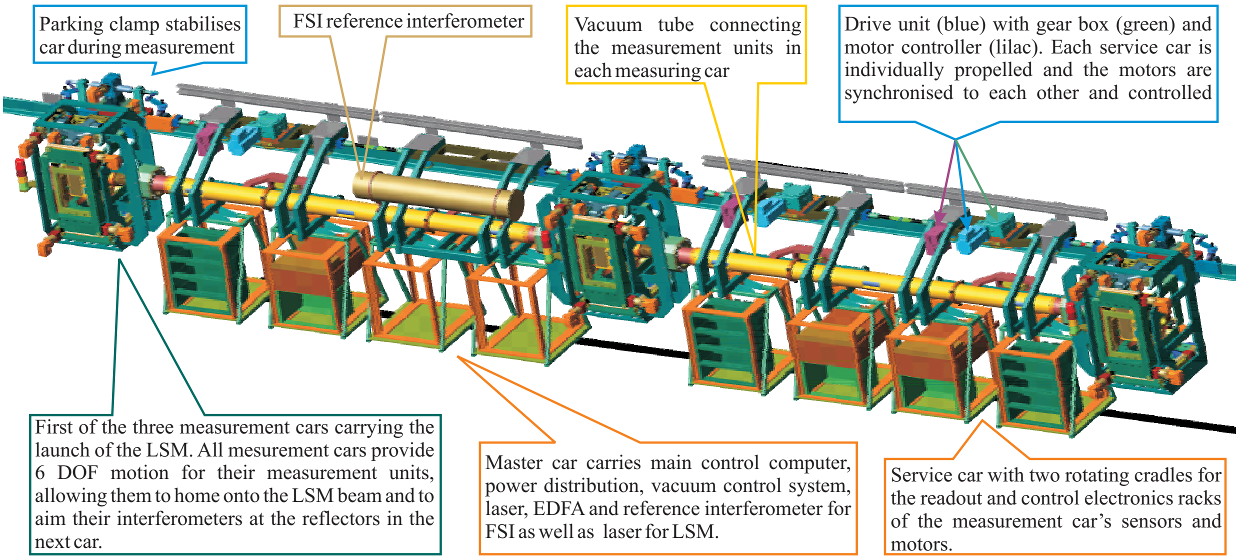
THE ILC SURVEY PROBLEM

In order to maintain the very small ILC emittance of 0.04 mm mrad it is necessary to position all accelerator components accurately to their nominal positions. Refraction in the tunnel air prevents classical optical survey methods from achieving adequate accuracy. To minimise machine down time the survey has to be performed as fast as possible. The latter is particularly important as the ILC will have in excess of 50km of beam line. These requirements led to the development of the RTRS which automatically and autonomously surveys a regular reference network in the tunnel wall opposite the accelerator. Accelerator components can then be surveyed manually or automatically with respect to the reference network, depending on their accessibility and regularity.

THE RTRS MEASUREMENT PRINCIPLE

The prototype RTRS shown in Figure 1 consists of 3 measurement cars spaced at 4.5 m centre to centre, travelling on a rail along the accelerator tunnel wall. Each measurement car carries one measurement unit in its centre. Readout for each measurement unit is carried in its service car and a master car carries the common infra structure.

The RTRS utilises a straightness reference - realised by a laser beam in vacuum (Laser Straightness Monitor, LSM) - against which transverse distances to the wall markers in front of each measurement unit can be measured. A tilt sensor on each unit ensures that all co-ordinates can be related to the vertical. It is important to notice that only rotation around the LSM laser direction is taken from the tilt sensors to not conflict with the geometric definition of straightness from the LSM. Distances along the tunnel are measured by Frequency Scanning Interferometers (FSI) in the vacuum between the measurement units. The sensor configuration is shown in Figure 2. The RTRS moves forward by one wall marker separation at a time and therefore measures each marker three times; once with each unit. In the analysis the overlapping measurements are assumed to be measurements of one identical marker positions which can then be obtained from a fit to all measurements. The



Parking clamp stabilises car during measurement

FSI reference interferometer

Vacuum tube connecting the measurement units in each measuring car

Drive unit (blue) with gear box (green) and motor controller (lilac). Each service car is individually propelled and the motors are synchronised to each other and controlled

First of the three measurement cars carrying the launch of the LSM. All mesurement cars provide 6 DOF motion for their measurement units, allowing them to home onto the LSM beam and to aim their interferometers at the reflectors in the next car.

Master car carries main control computer, power distribution, vacuum control system, laser, EDFA and reference interferometer for FSI as well as laser for LSM.

Service car with two rotating cradles for the readout and control electronics racks of the measurement car's sensors and motors.

Figure 1 The prototype RTRS with its 3 measurement, 3 service and one master car

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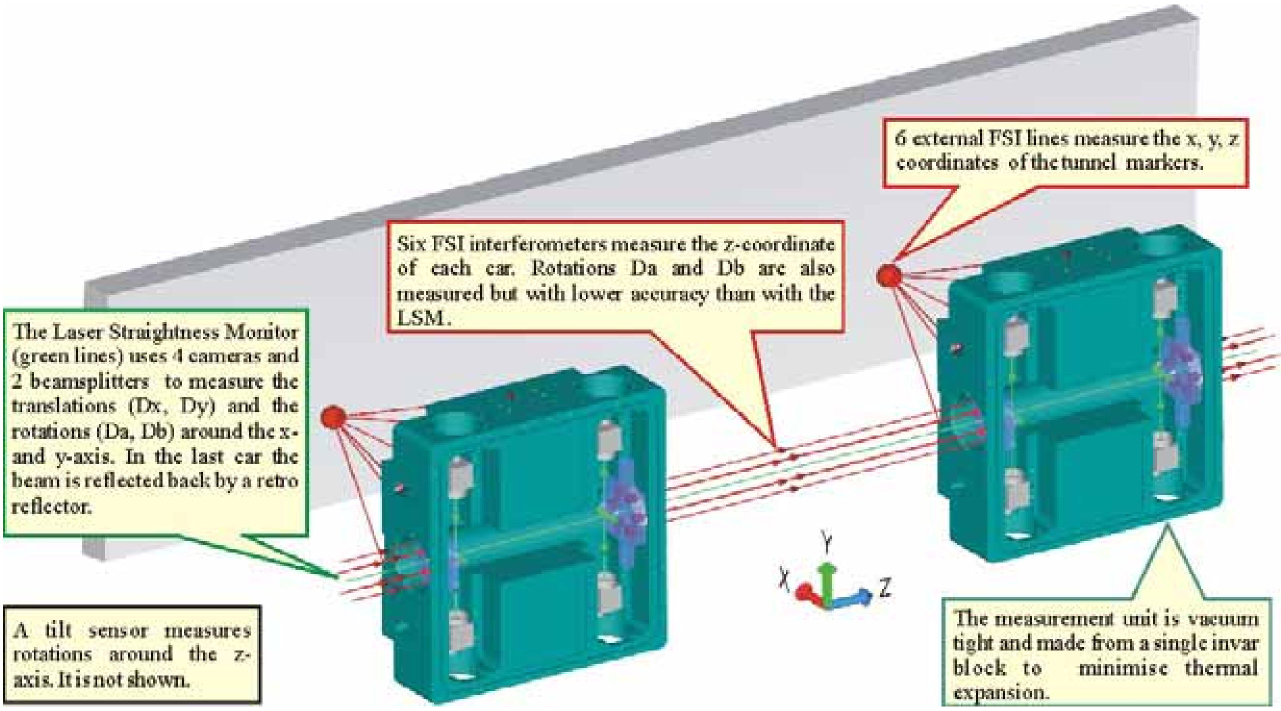

The Laser Straightness Monitor (green lines) uses 4 cameras and 2 beamsplitters to measure the translations (Dx, Dy) and the rotations (Da, Db) around the x- and y-axis. In the last car the beam is reflected back by a retro reflector.

Six FSI interferometers measure the z-coordinate of each car. Rotations Da and Db are also measured but with lower accuracy than with the LSM.

6 external FSI lines measure the x, y, z coordinates of the tunnel markers.

A tilt sensor measures rotations around the z-axis. It is not shown.

The measurement unit is vacuum tight and made from a single invar block to minimise thermal expansion.

Figure 3 Sensor configuration between two measurement units of the RTRS. The vacuum tube and surrounding support structures of the measurement and service cars are not shown.

ILC-RTRS will have six cars to improve the accuracy of the overlap measurements.

SIMULATIONS

This section is broken into simulations of the survey process and of the consequences that the survey will have on the performance of the ILC.

Survey Simulations

The expected performance of the ILC-RTRS (6 cars) was simulated using a two step process. At first a full opto-geometric model of the entire measurement process for 20 overlapping train stops was described in SIMULGEO[2] (left inset Figure 3). This procedure is extremely computation intensive. In the second step the predicted accuracy was fitted to a random walk model with angular correlations between steps. The random walk model can then be used to rapidly predict the performance over long distances. Details of these simulations can be found in [5]. The right inlay of Figure 3 shows one random walk seed and the expected residuals to a straight line over 600m. Figure 3 assumes a resolution of 1 micron for the FSI and LSM and 1 micro radian for the tilt sensor.

Impact Simulations

To evaluate the impact of the survey process on the ILC emittance an interface between the performance simulations and PLACET [3] was written. This takes as input the nominal positions of accelerator elements and changes them according to the output of an RTRS survey simulation. In Figure 4 the emittance along one ILC linac is plotted against the quadrupole number (effectively the length along the linac) taking into account only the

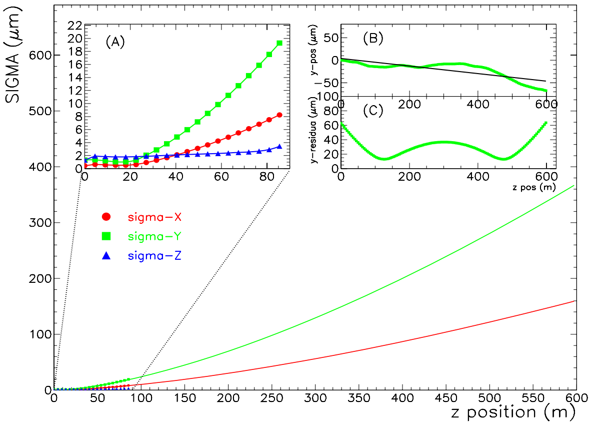

Figure 2 Simulations of the survey performance. The sigmas are the width of the corresponding Gaussian residual distributions

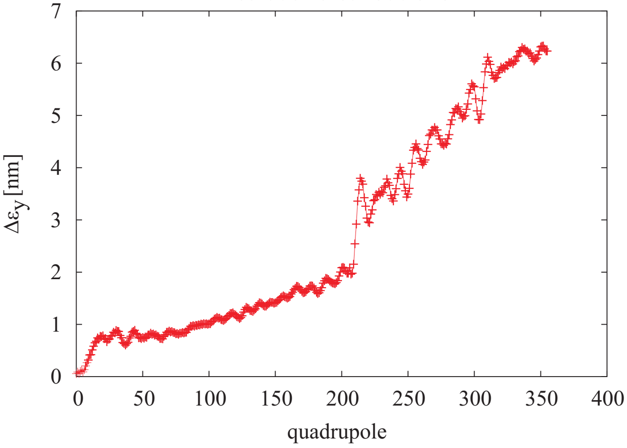

Figure 4 Preliminary emittance in one ILC linac versus quadrupole number after survey. (Daniel Schulte, CERN)

misalignments after the survey. This study is still preliminary but will be very useful to better specify the required survey accuracies in all areas of the ILC.

MEASUREMENT SUB-SYSTEMS

The three major sensing sub-systems are the FSI distance meters, the LSM and the tilt sensors. The first two are novel devices developed at Oxford and their preliminary performance is discussed here.

FSI

The principles of Frequency scanning interferometry used in the RTRS are described in [4]. While the FSI techniques used for the ATLAS inner detector alignment [6] rely on two scanning lasers with opposite tuning directions to compensate length drift in the interferometer, the LiCAS group has chosen to use only one laser of much faster tuning speed and wider tuning range. The resultant much simpler laser and DAQ system has a low enough drift sensitivity to achieve sub micron accuracy with only one laser. An example of these are shown in Figure 4.

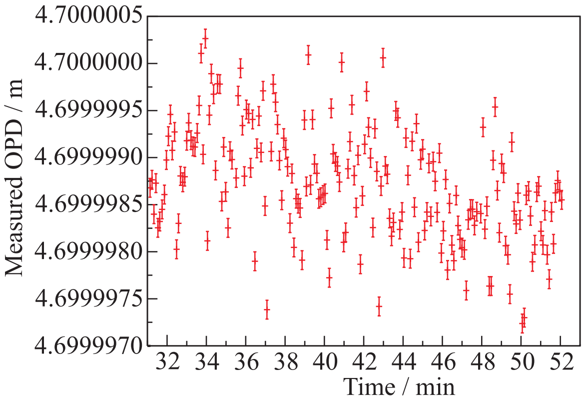

Figure 4 FSI measurement of the length of an open air interferometer of approximately 5m OPD

Here a collimated open air interferometer of about 5m optical paths length difference (OPD) was measured 200 times, over a period of 20 minutes using as length standard, a Michelson style reference interferometer mounted on a steel table under a thermally insulating foam shield. The RMS variation of the measured length is 590 nm. With the introduction of evacuated, Fizzau-style reference interferometers which are ultra stable and compensated for thermal expansion we expect these results to further improve. It should be noted that similar results have been obtained with uncollimated short distance FSI interferometers (1m OPD) used for wall marker measurements, at return light levels of a few pW, using a high gain, low noise version of the custom photo-amplifiers system. The data from all interferometers are digitised by a custom amplifier and ADC chain and links to the DAQ computers via a high speed USB-II link.

LSM

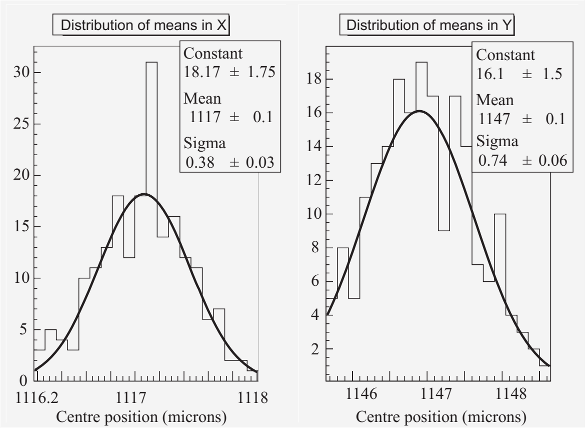

Figure 5 Distribution of the x and y centroids from fits to 200 images in an open air LSM unit.

The LiCAS laser straightness monitors principle has been described in [4]. Large improvements to the fitting of spots on the CCD cameras and the noise suppression such as fixed pattern noise subtraction, no-beam background subtraction, 2D-Fourier filtering have been made. Figure 5 shows the distribution of centroids of 200 fits made in an open air LSM with 4m beam paths from launch to CCD. The resolution is limited by refraction effects and will improve once the unit operates in vacuum as originally designed. It should be noted that a new reflection system has been developed for the return of the beam in the last car. It utilises a semi transparent mirror and a retro reflector, both on motion stages and with a shutter between them. When the beams from both reflection elements appear in the same location on all CCDs along the train, the retro walk is zero and the mirror is hit perpendicularly by the beam.

REFERENCES

[1] The TESLA Collaboration, “TESLA, The Superconducting Electron-Positron Linear Collider with an Integrated X-Ray Laser Laboratory”, Technical Design Report, DESY 2001-011

[2] Simulation and reconstruction software for optogeometrical systems, L.Brunel, CERN,CMS note 1998/079.

[3] http://dschulte.web.cern.ch/dschulte/ placet.html

[4] Measurements of the LiCAS systems, A. Mitra et al., Proceedings of the Eighth International Workshop on Accelerator Alignment, CERN, Switzerland/France, October 2004

[5] Simulation of the performance of the LiCAS train**,** G. Grzelak et al., Proceedings of the Eighth International Workshop on Accelerator Alignment, CERN, Switzerland/France, October 2004

[6] P.S. Coe, D.F. Howell and R.B. Nicherson, “Frequency scanning interferometry in ATLAS: remote, multiple, simultaneous and precise distance measurements in a hostile environment”, Meas. Sci. Technol. 15 (2004) 2175-2178