An Alignment and Stabilisation System for Future Linear Colliders

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Simulations of the performance of a stabilisation and alignment system for linear collider components based on a geodetic grid of length measurements using frequency scanning interferometry (FSI) are presented here.

1. Motivation

The next generation of linear electron positron colliders have to transport nano metre (nm) sized beams of extremely small emittance over distances of nearly 30 km and collide them at the interaction point. In order to maintain the low emittance and resulting high luminosities it is necessary to accurately steer the beams and tune the collider components throughout its entire length. In order to obtain the information about the collider state necessary to operate it, beam instrumentation has to be developed that can unambiguously and robustly determine the state of the collider. This note presents one possible type of beam instrumentation designed to measure the absolute positions and slow, sub Hz, relative motion of collider components. These motions are driven by ground motion and can reach root mean square (RMS) amplitudes in the μm regime over a correlation length of several tens of metres in a matter of days. Although the currently existing linear collider proposals NLC and TESLA already some have very different strategies for correcting these motions, redundant means of measuring them with reliable and simple methods will improve collider performance.

2. Grid Layout

The grids discussed here are based on frequency scanning interferometry distance measurements (FSI) only. FSI has been developed for ATLAS and has shown resolutions of O(200nm) RMS over distances of O(1m) [1, 2]. It is believed that this resolution can be maintained over distances of O(10m) by the use of beam collimation optics. This study conservatively assumes that a resolution of 1 μm will be obtainable. General issues about the application of FSI in linear colliders have been discussed in [3]. Although an optimised alignment system will include measurements of straightness, in particular when dealing with long and thin structures like a linear collider, these have not been used here in order to obtain a baseline performance against which future improvements can be compared. Figures 1 and 2 show the grid geometry. The square inner grid is rigidly fixed to the beam line components and the square outer grid is fixed to the tunnel walls. Each section of the grid is labeled with I(n) or O(n) for the n'th inner and outer section respectively, as can be seen in figure 2. The sections are separated by 10m each and the outer grid dimension is assumed to be 2m. There are no diagonal lines through the tunnel center. Each inner grid node is viewed by 9 outer grid nodes. The linked grid has 18 degrees of freedom and 56 measurements per section and is thus more than 3 fold redundant.

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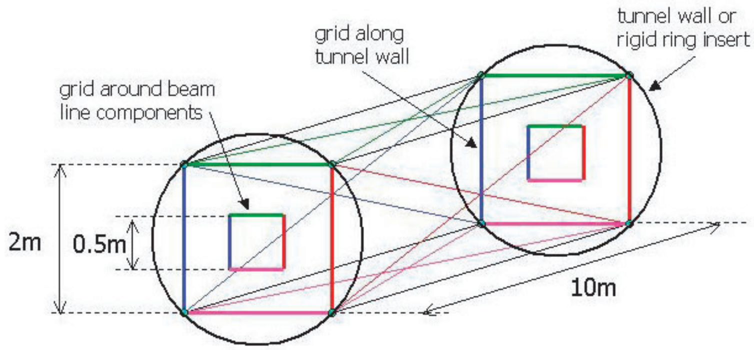

Figure 1: The outer grid without the linking grid (inner grid analogous).

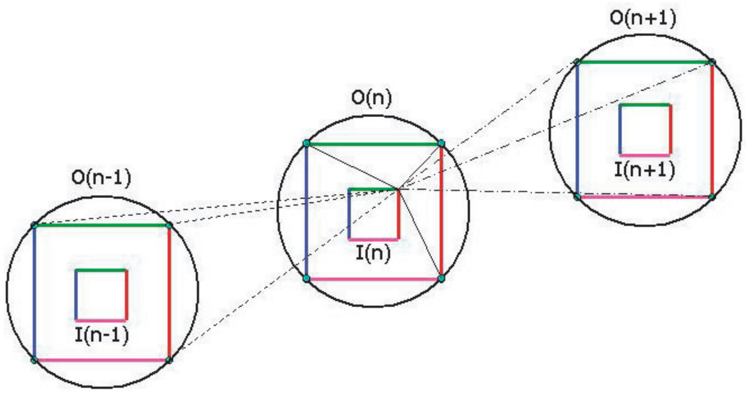

Figure 2: The linking grid for one node of one inner grid section.

3. Grid Simulations

The performance of a grid with 5 of the above sections was simulated with a program called Simulgeo [4] which evaluates the errors in the determination of node co-ordinates in the grid given a set of measurements and constraints in the grid. The Z co-ordinate runs along the tunnel, X is horizontal and Y vertical. The following assumptions are made:

- Nodes of one inner grid section can not move relative to each other. This implies that beam line components do not distort on scales relevant to their relative motion.
- Nodes on the outer grid are point like, implying that they only have 3 degrees of freedom. This demands that rotations of real, extended nodes will not move node contours on scales relevant to the relative node motion.
- Each line of sight is a distance measurement with fixed RMS error. This error is 1 μm for all lines, except when studying the scaling with single line error. Systematic errors are neglected.
- The zeroth section of the inner grid defines the co-ordinate system. The zeroth outer grid section was assumed to either be locked to the co-ordinate system (*lock-linked*) or to be free (*free-linked*).

The grid performance is shown in table I. Due to the symmetry of the grids, Y co-ordinates have the same errors as the X co-ordinates and are not shown. The unlinked grids can not achieve transverse position errors better then 30 μm. Both inner and outer measurements reach a transverse resolution of about 12 μm for *lock-linked* measurements. The Z resolution is always much better then the transverse resolution. In figure 3 the dependence of the transverse resolution of a stand alone grid on the transverse size of a grid section can be seen. The larger the grid the

Table I RMS errors [μm] of X and Z node co-ordinates for Z from 10 to 40 metres. Subscripts O and I refer to outer and inner grid co-ordinates respectively.

	unlinked				*lock-linked*				*free-linked*			
Z	dX_O	dZ_O	dX_I	dZ_I	dX_O	dZ_O	dX_I	dZ_I	dX_O	dZ_O	dX_I	dZ_I
10	4.77	0.77	12.26	0.28	2.73	0.43	2.01	0.17	8.66	1.20	8.43	0.23
20	11.00	1.09	26.47	0.41	5.27	0.58	4.68	0.23	16.88	1.26	16.68	0.27
30	19.28	1.34	45.30	0.50	8.63	0.70	8.11	0.27	25.37	1.32	25.18	0.31
40	29.66	1.67	67.86	0.57	12.74	0.83	12.22	0.33	34.15	1.39	33.95	0.36

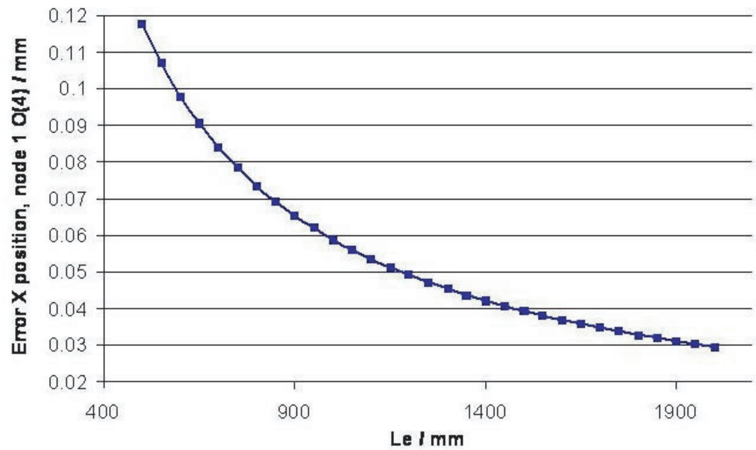

Figure 3: The scaling of transverse position errors after 40 metres with the transverse size of the grid.

better the measurements. The size scale extends from that of the inner grid (40cm) to that of the outer grid (2m). In figure 4 the transverse errors on an inner and outer grid node of the linked grid after 40 metres is plotted against the RMS error of a single distance measurement. The slope of both curves is about 10 and the inner points are measured slightly better then the outer ones.

4. Conclusion

It has been shown in simulations that a simple geodetic grid of dimensions suitable for installation into a linear collider tunnel and based on length measurements alone can achieve absolute

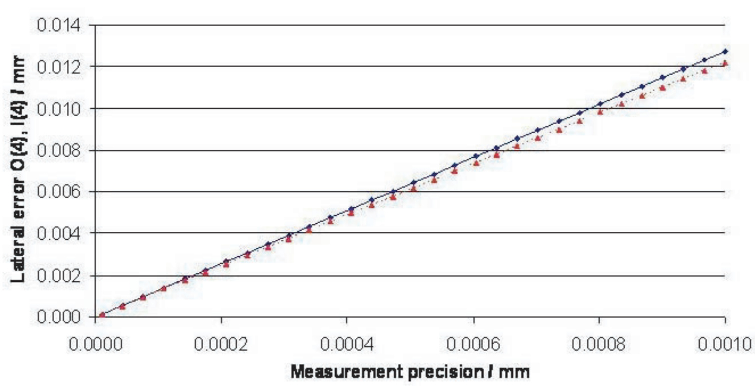

Figure 4: Scaling of transverse position errors (mm) after 40 metres with the resolution of a single length measurement. The red triangles and blue square are for inner and outer grids respectively.

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transverse position measurements of 12 μm over distances of 40 metres when a single line RMS error of 1 μm is assumed. Provided a technical solution for *lock-linking* can be found This behavior is expected to scale with single line resolution. Such scaling could be utilised when operating the grid in Michelson mode (M-FSI) during which only length changes would be detected by standard Michelson interferometry. The sensitivity of Michelson interferometers can be O(nm) and thus the grid sensitivity over 40 metres may be expected to reach the sub μm level. Experiments to evaluate FSI, straightness monitors and M-FSI for use as LC beam instrumentation are being performed at Oxford.

References

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[3] A. Reichold, in *The 22nd Advanced ICFA Beam Dynamics Workshop on Ground Motion in Future Accelerators*, http://www.slac.stanford.edu/pubs/slacwps/slac-wp-018.html (November 2000), no. SLAC-WP-18, "A Novel Dual-Laser Frequency Scanning Interferometry Distance Measurement System".

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