# An active alignment test facility for the CERN Linear Collider

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*Abstract*

The accelerating and focusing structure of the CERN high energy linear collider must be aligned and maintained in the transverse plane to very tight tolerances (5µm for the accelerating sections and 1µm for the quadrupoles) to avoid excessive beam blow-up due to beam-induced transverse wake fields. Since normal ground motion produces displacements which exceed these tolerances, a dynamic alignment system is foreseen using beam-derived signals from beam position monitors to drive precision micro-movers under closed-loop control to maintain the components in position . A remote computer-controlled micro-movement test facility has been constructed at CERN to study the various problems associated with such systems.

## INTRODUCTION

An active alignment system is required for the CERN Linear Collider (CLIC) to maintain the many thousands of accelerator components of each linac within the very tight transverse tolerances of a few µms. This alignment system assumes

(i) that the accelerator can be pre-aligned with respect to an external reference with sufficient precision that the beam can be made to pass through the available aperture and produce a signal in a beam position monitor

(ii) that beam position monitors of µm resolution can be built and referenced accurately to the electrical and magnetic axes of the accelerator components

(iii) that using the signals from these beam position monitors, the accelerator components can be positioned and maintained in space with micron precision using remote controlled micromovers

In order to simplify assembly and reduce costs in a real-life situation it is envisaged that several accelerator components would be mounted and pre-aligned on a support girder before installation in the underground tunnel.

This paper describes development work being done at CERN to demonstrate the feasibility of these assumptions.

## MICRO-MOVEMENT TEST BENCH

A remote computer-controlled micro-movement test bench [see Fig.1] - permitting controlled submicron displacements - has been built in an unused underground accelerator tunnel to study the problems associated with the support and precise positioning in space of CLIC main linac components [1].

The test module is shown schematically in Fig.2 It consists of two 1m long silicon carbide support girders each holding four dummy accelerating sections. The ends of two adjacent girders sit on a common support platform. One of the ends is fixed rigidly to the platform, the other is connected to it via swivel-joint link rods which allow four degrees of motion (rotation in the XY, XS, YS planes and S displacements).

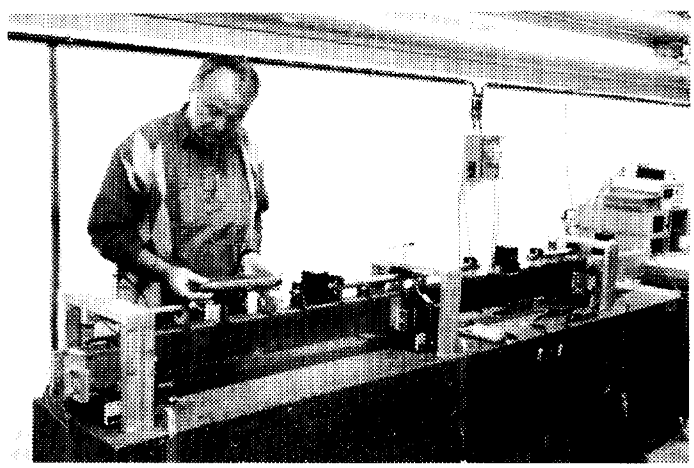

Fig. 1 CLIC micro-movement test bench

Each platform is activated by three MF 08 PP precision jacks made by the firm Micro-control. Two in the vertical plane produce vertical displacements and transverse rotations; the third is situated, and acts, in the horizontal plane. These stepping-motor-driven micro-movers with a resolution of 0.1µm and an absolute accuracy of 1µm over ±4mm provide both large displacements for initial alignment and micron movements for correction of slowly varying perturbations (< 1 Hz) during CLIC operation. Piezo-electric movers with a stroke of ± 3µm will be mounted in series with the existing jacks at a later stage to investigate higher speed response (up to kHz) for experimental purposes.

The complete unit is mounted on a granite block which serves as a stable outside reference. Relative movements of the

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sections with respect to the reference block are measured with linear and angular displacement transducers.

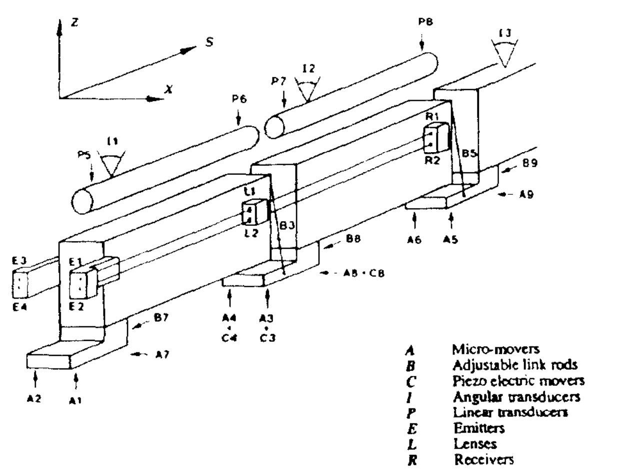



Fig. 2 Support, movement and measurement system of present experimental test module

The test facility is piloted remotely from an Olivetti PC. The software is written in C and runs under the XENIX operating system.

Two computer test programs (CINEMA and OPERA) are operational. CINEMA monitors the open-loop behaviour of the system during displacements - it calculates the theoretical displacements that should occur at the various transducers and compares them with the values obtained. OPERA drives the micromovers under closed-loop control to obtain and maintain a specified set of transducer readings.

The present performance of this micro-movement test device can be summarised as follows.

Smallest step in one direction (resolution) = 0.2μm
Max. measured stick/slip over ±4mm = 3μm (open loop)
Precision over ±4mm in closed loop = 0.2μm

## BEAM POSITION MONITORS

It has been demonstrated, at least on paper [2], that the beam position can be measured with sub-micron resolution by microwave $E_{110}$ resonant cavities. Such cavities would be built as an integral part of the main linac accelerating sections and focusing quadrupoles and would provide signals for the feedback system. By choosing a cavity frequency 3 GHz above the main linac frequency, interference from the RF power pulse is avoided. Some contribution to the overall resolution is expected from symmetry rejection via two diametrically opposed cavity outputs but most of the accuracy is achieved by narrow band filtering. Details of the prototype hardware being developed for this signal processing system is given elsewhere [3].

## PRE-ALIGNMENT OF THE MAIN LINAC

A new approach to pre-alignment is being studied [4]. The idea is to use the micro-movers in an active system to maintain the relative positions of the ends of two adjacent support girders to within a few microns in both transverse planes but to allow greater overall excursions from a straight line (say 0.2mm) over longer distances of say 100m between reference pillars. The pillars could be aligned themselves with present day technology to a relative precision of 0.2mm and an overall precision of about 5mm over the entire length of the linac.

Since the linac components are aligned accurately with respect to the support girders, and the fixation of the girders is such that they only articulate about a common moveable point, it is only necessary to align the string of common points to align the linac between reference pillars.

This section describes a technique and the instrumentation to do this.

### *Instrumentation*

The RASNIK optical displacement measuring system shown in Fig.3 has been developed by NIKHEF in Amsterdam and has been used to align physics detectors in LEP [5]. The image of a square object illuminated by a red light source is focused on a light detecting four quadrant cell by a thin lens. Displacements of the object, the lens or the four quadrant cell out of the optical axis of the instrument produce an imbalance at the detector.

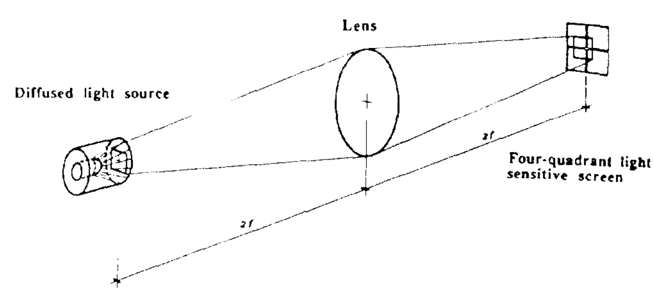



Fig.3 RASNIK optical displacement system

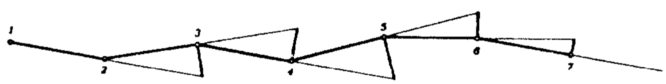
Two of these systems have been mounted as shown in Fig.2 on the two girders of the test module and initial tests indicate that the relative positions of the ends of the two girders can be measured with respect to a reference line defined by the first girder to better than 2μm.

### *Technique*

Each articulated point of the support girders will be equipped as above, the reference line having an emitter and a lens, and the displacement being measured at the receiver. The distances between the optical elements are assumed to be fixed.

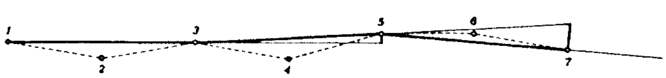
The following sequence of measurements is then necessary.

| Reference line | Measurement point |
|---|---|
| 1 2 | 3 |
| 2 3 | 4 |
| . | . |
| . | . |
| n-2 n-1 | n |

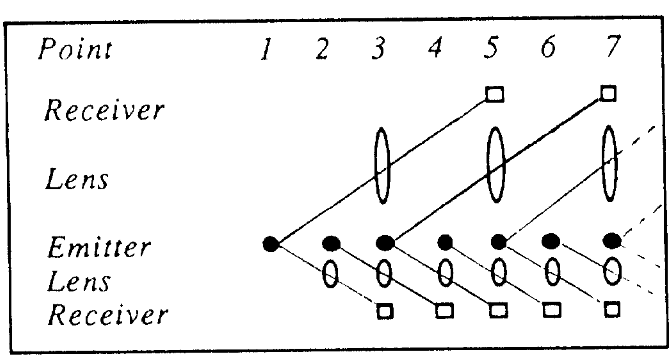


These measurements however are not sufficient to enable the inevitable errors in the string to be identified and minimised. To be able to do this some redundancy is required, this is provided by a second set of overlapping measurements as given below from additional detectors.

| Reference line | Measurement point |
|---|---|
| 1 3 | 5 |
| 3 5 | 7 |
| . | . |
| . | . |
| n-4 n-2 | n |



The overall system would therefore require the two types of optical component combinations indicated below and.shown incorporated into CLIC support girders in Fig.4.




A statistical analysis of this redundant set of measurements using a least squares technique enables the absolute displacements of the articulated points in space with respect to the ideal straight line to be determined and the necessary movements of the jacks to be calculated to minimise the excursions. Such a system would necessarily be connected to a computer so that the "measurement-calculation-correction" operation could be automated and if necessary reiterated.

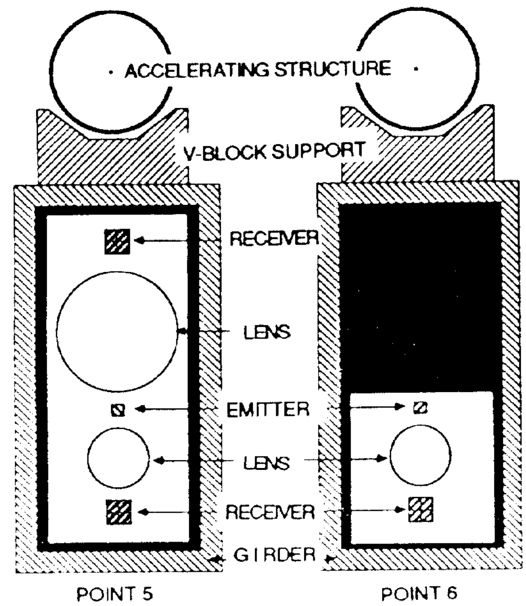



Fig.4 Possible configuration of RASNIK optical components in CLIC support girders

## *Simulation*

The behaviour of a string of 40 2.5m long girders using this pre-alignment system has been simulated using an existing CERN geodesic compensation program called LGC. The string has 41 articulated points and for displacements in one plane there are 59 measurements. Assuming two fixed points there are therefore 59 equations for 39 unknowns. The LGC program in fact simply generates a gaussian distribution of simulated RASNIK measurements with a given standard deviation $\sigma_m$ and predicts the corresponding deviations of each articulated point from the desired straight line. A statistical analysis of the results of 100 simulations indicates that over the 100m length maximum typical excursions of 0.05mm are obtained for $\sigma_m = 2\mu m$ (within the measured precision of the device) and that the resulting relative positions of adjacent girders have a typical standard deviation of 6μm.

## REFERENCES

[1] W. Coosemans, I. Wilson and P. Poirier, "A micro-movement test facility for CERN linear collider studies", EPAC, Nice, June 1990.

[2] W. Schnell, CLIC Note 70, 1988.

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[4] W. Coosemans, CLIC Note 139, 1991.

[5] Duinker. P et al., "Some methods and tools for testing and optimizing proportional wire chambers", NIKHEF-H, Kruislaan 409, 1098 SJ Amsterdam, Netherlands, 1988.