



## **Workshop Report on Metrology and Stabilization for Linear Colliders**

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### **Abstract**

A workshop was held at the Laboratoire de Physique d'Annecy le Vieux (LAPP) Institute in March 2005 on the questions related to the positioning, alignment and vibration stabilization of the components of a linear collider. It aimed at bringing together the people interested by these subjects, carrying a general reflection about the problems to be addressed and defining priorities in dealing with them. The present report gives a short summary of the content of the workshop and of the conclusions reached at the end of it.

## Introduction and summary

The note gives a short review of the topics discussed in relation with the metrology and the stabilization of the components of a linear collider. They concern the alignment and positioning of these components, ground motion measurement campaign and site surveys, stabilization and control of the vibration, modelling of the structures, finite element analysis and possible feedback systems with resonance cancelling. These topics are treated in the next three sections. The last section summarizes the conclusions reached, the future plans and the main axis of activities retained.

## Alignment and positioning stabilization

A first interesting topic concerned the automated process for positioning and aligning the components of an accelerator infrastructure, based on the laser tracker called LiCAS and the rapid transverse surveyor RTRS system developed by Oxford and DESY laboratories. It aims to the survey of future infrastructures such as the Free Electron Laser XFEL and the International Linear Collider ILC, as a basic tool for the tunnel construction, the component fiducialization (100  $\mu\text{m}$ ) and the component survey (200  $\mu\text{m}$  vertical budget over a distance of 600 m). It should also apply to the survey and alignment of curved sections, of sections with slopes or in a tunnel following a geoid. The RTRS is a train instantly measuring and memorizing the positions of the wall markers by overlapping sectors and reconstructing the relative coordinates of the tunnel shape. The LiCAS measurement unit is a laser tracker monitoring the distance between the cars, their rotation and the straightness of the train. The measurement principle based on frequency scanning interferometers has been established to 1  $\mu\text{m}$  and there is still room for improvement. During 2005, it is planned to complete the choice of the instruments and of the analysis codes, to construct three car prototypes and to equip a 60 m long service tunnel in order to install a train prototype. The latter will be operated in DESY until spring 2006 while the design of a second generation 6-car prototype will be carried out until spring 2007 in Oxford with improved calibration and smaller size system fitting the XFEL tunnel. Operation of improved 1<sup>st</sup> and 2<sup>nd</sup> generation prototypes and of a newly designed stake out instrument is foreseen in the XFEL until spring 2008. Possible use and applications were discussed, in particular in the proposed final focus test-line of ATF2 (KEK, Japan) requiring a 10  $\mu\text{m}$  accuracy over short distances. Another possibility of application for tests which is worth to be investigated concerns the CLIC Test Facility CTF3.

Active feedbacks based on laser interference method (nm scale at separations of 10 m typically) are also studied in Oxford laboratory. It requires a laser straightness monitor between two reference stake out systems, to stabilize one object with respect to the other. It was discussed to have a test set-up preferably applied to existing infrastructures for instance at KEK using their nanometer BPM or at SLAC. Questions remain to be studied, like the number of degrees of freedom needed for the actuators and the way to ensure a direct line between the two reference systems on either side of a large detector. Nevertheless, relying on beam-beam deflection only for luminosity optimization is delicate and the purpose of such a system would be to single out one parameter (center of the FF quadrupoles).

## Ground motion measurements and site surveys

Ground motion and seismic measurements represent another important subject of investigation in this field. Work was done on this topic at LAPP in order to study and compare velocity and acceleration measuring devices, monitoring power spectral density versus frequency, integrated displacements, correlation between two sensors and the measurement resolution.

Different sensors have been used:

- i) GeoSiG for coherence measurement using two neighboring devices; high frequency sensors GSV-320 providing 1 nm for  $f > 2-3$  Hz and VE-13 giving 1 nm for  $f > 30$  Hz
- ii) Guralp broadband seismometer allowing low frequency measurements,  $< 1$  Hz, with a response strongly temperature-dependent which requires temperature stabilization.
- iii) SP400 working between 0.1 and 50 Hz and based on electro-chemical motion. Smaller devices are needed. Measurements at low and high frequencies should be repeated systematically and sensitivity to magnetic field measured.

Site comparison with cultural noise is being done (DESY), based on measurements always done with the same equipment and data analysis technique. The equipment used is the GURALP seismometer (200 Hz sampling rate, 24 bits ADC) and the KEGE geophone working between 3 and 250 Hz (16 bits USB-ADC, 500 Hz sampling). The data acquisition is done for 24 hours or a week (700 MB per day per sensor). From the FFT signal treatment and integration above a cut-frequency, an rms value of the motion in nm is calculated versus frequency. General observations are the drop of the spectrum in  $1/f^4$ , the presence of a micro-seismic peak at 0.1-0.2 Hz, uncorrelated cultural noise at  $f > 1$  Hz and correlated noise for  $f < 1$  Hz. Typical results are:

- i)  $< 2$  nm in the coal mine of Asse (D), CERN-LHC, SPRING8 (J).
- ii)  $< 5$  nm at SLAC, FNAL-Numi, CERN surface.
- iii)  $< 20$  nm at APS, FNAL surface, Ellerhoop.
- iv)  $> 20$  nm at KEK-ATF, ESRF, DESY.

Measurements at LAPP give a vertical random motion of only 2 nm, which is extremely good. A permanent seismic station is installed in HERA (DESY) with live data on the web.

Future investigations considered for the ILC study concern measurements of the SC module vibration expected to be 20-30 times higher than on the floor, site comparison for the potential ILC sites, cultural noise modeling, cold quadrupole vibration and active stabilization concepts. The measurements in the quadrupole cryostats require small sensors (for instance as small as  $4 \times 4 \times 4$  cm<sup>3</sup>) calibrated within 1 nm and development of sensors smaller than the existing ones is needed.

## Structure modeling and vibration control

Modeling the behavior of supports, vibration control and vibration reduction were discussed. Modal studies about a 1m long Aluminum beam are being carried out through simulations and tests (LAPP). The dynamic behavior of the whole system is investigated by using finite element analysis (FEA) and eigen-value calculation of the structure. The software supports are Samcef for the FEA and PULSE/ME'scope for the modal design study. The models considered correspond to a beam with fixed-free ends, fixed-fixed ends and free-free ends. Tests were done by hitting the beam with a hammer equipped with a force sensor and measuring the movements with accelerometers. The beam was hit at different locations and the signals analyzed for obtaining the shape of the excited modes and the damping of each mode. The accuracy of the modeling is within 1 % in the free-free configuration, 5 % in the fixed-free case and 20% in the fixed-fixed case. These results look promising. Having a good model for a given structure would for instance offer the possibility to optimize the position of the supporting points and to avoid intrinsic modes of oscillations.

Finite element analysis combined with the harmonic analysis of the vibration (using ANSYS) make it possible to study the response of a system to a varying force or to a random excitation, like the ground motion (Cracow Univ.). For a simple system of one degree-of-freedom, numerical tests were done and ANSYS results have been found equal to the analytical results. More elaborated tests are planned for a beam randomly excited by a shaker. Such a tool should also allow to investigate possible remedies or vibration control. Among them, passive and active isolation, damping polymers, pushing the system resonances outside the excitation spectrum, damping of the resonances, minimizing the vibration propagation (by having for instance the cooling connection at the nodal points). The vibration propagation from the quadrupoles to the final focus through the structure is for instance a critical topic to be studied for a linear collider.

Another interesting approach based on feedback systems aiming at canceling single resonances was presented (ESIA, Savoie Univ.). The principle consists of measuring all together the mechanical system and the disturbances to be controlled and of applying the feedback to this overall signal. The idea is to use this principle for the reduction of mechanical vibrations and the algorithms developed has been tested on a mock-up. The assumption is that the ensemble formed by the system and the disturbances is made of independent, narrow resonances sitting on top a continuous spectrum. The amplitude and phase of each resonance are supposed to be constant and slowly varying with respect to the signal period, while the frequency of each resonance is computed through Fourier transform. On this basis, a control loop is applied to each resonance. Additional assumptions have been included for the first tests: the mechanical system is supposed to be linear and the perturbation to be a harmonic. Excitation components of the feedback are aiming to reduce to zero the values of the measured signal.

Starting from the measurements, the signal from the system and from the disturbance observer is analyzed (spectrum) and processed (frequencies), decomposed into a weighed combination of sines and cosines and finally transmitted to a state feedback. The latter generates a correction excitation, which is sent to the mechanical system while renewed measurements are done. The excitation components converge to values such that the total effect of disturbance and excitation is null at the sensor location.

The system tested is made of a small steel beam with a piezzo actuator at one end and a sensor at the other end. Results show a strong reduction of the isolated resonances without introducing other significant perturbation of the spectrum. The robustness of the control system depends on the gain, phase and rate of the feedback. The control can be improved with a faster system which then requires a better knowledge of the mechanical system. The number of resonances to be controlled is not limited, but is given by the number of parallel computers used, a feedback loop being built for each resonance. The basic idea is to have such a control feedback as a complement to the modeling of the mechanical system, which helps but cannot be sufficient.

## Conclusive remarks

Concerning ground motion study, work will continue (DESY) on the following: cross checking GURALP measurements with STSCA, measuring correlation in different direction as a function of the distance, sensor improvement, dependence on the underground depth and magnetic field influence. R&D should be done on inertial sensor small enough to take place in a cryostat and on molecular sensors should be submitted to further tests.

It is planned to pursue the development of a second generation LiCAS (Oxford), smaller and lighter, to be eventually used in the XFEL. Contacts with CTF3 should be taken to study possible applications of the system. More generally, the aims of this development should be defined in relation with possible use in existing or developed infrastructures such as XFEL, ATF and CTF3.

On the stabilization topic, major axes of activities have been raised:

- modeling, simulation and theory (LAPP, ESIA, Cracow)
- development of small and well performing sensors in collaboration with industrial companies
- launch work on actuators where development is needed, define where tests could be done, e.g. ATF
- establish contacts with the designers and builders of the final focus quadrupoles and link the actuator work to possible tests.

The idea was raised to make cross-check possible between the LAPP inertial system and the system developed in Oxford, by having a common set-up for tests, for instance with a quadrupole mock-up.

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