ALIGNMENT CHALLENGES FOR A FUTURE LINEAR COLLIDER

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Abstract

The preservation of ultra-low emittances in the main linac and Beam Delivery System area is one of the main challenges for linear colliders. This requires alignment tolerances never achieved before at that scale, down to the micrometre level. As a matter of fact, in the LHC, the goal for the smoothing of the components was to obtain a 1σ deviation with respect to a smooth curve of 0.15 mm over a 150 m long sliding window, while for the CLIC project for example, it corresponds to 10 µm over a sliding window of 200 m in the Beam Delivery System area. Two complementary strategies are being studied to fulfil these requirements: the development and validation of long range alignment systems over a few hundreds of metres and short range alignment systems over a few metres. The studies undertaken, with associated tests setups and the latest results will be detailed, as well as their application for the alignment of both CLIC and ILC colliders.

INTRODUCTION

The alignment of an accelerator can be divided into seven steps, two of them taking place on the surface, and the five others underground. Chronologically, the first three steps lead to the determination of a geodetic network located underground: a geodetic network is first measured on the surface, nowadays by GPS means, transferred into the tunnel through pits, and then measured in the tunnel, providing a precision of ± 2 mm at the bottom of each pit in the case of the LHC where the depth of pit is about 80 m [1]. In parallel, all the components undergo the fiducialisation process, e.g. the operation during which the position of the external alignment targets (fiducials) is measured with respect to a reference axis (magnetic, electric, mechanic). This step was performed for the LHC components w.r.t the mechanical axis with an uncertainty of measurement below 0.1 mm at 1σ. The components are then transferred into the tunnel where they are aligned with respect to the underground geodetic network, in order to achieve relative accuracy of 0.25 mm. Once all is in place, the smoothing of the components is performed in order to improve the relative position of components w.r.t a trend curve. In the case of the LHC, the uncertainty of measurement was below 0.1 mm (at 1σ) over 150m, in vertical and radial directions.

In the main linacs and BDS area of CLIC and ILC linear colliders, the position of the components before the injection of a pilot beam is far tighter than what was achieved for the LHC, requiring new methods and alignment systems to be developed and implemented. In this paper, the tolerances of alignment concerning CLIC and ILC are presented. The global strategy of alignment combining long range and short range alignment systems are detailed, as well as the alignment systems themselves.

CLIC AND ILC ALIGNMENT TOLERANCES

CLIC Alignment Tolerances

Because of ultra-low emittances and nanometric beam sizes for CLIC, the CLIC components will have to be pre-aligned to a few microns over a distance of several betatron wavelengths (200 m) before a pilot beam can be injected in order to implement beam based alignment and beam based feedbacks [2]. As a matter of fact, along the main beam of the main linac, the standard deviations of the radial and vertical position of the components with respect to the straight fitting line along a sliding window of 200m, have to be maintained below 14 µm for the electrical zero of BPM, below 17 µm for the quadrupole magnetic axes, below 14 µm for the mechanical axes of the accelerating cavities. In the BDS, these standard deviations must be maintained below 10 µm for all the components (and associated reference axis).

ILC Alignment Tolerances

The ILC alignment tolerances are nearly as challenging as the CLIC ones in the BDS and final focus areas, with an error of fiducialisation of 0.02 mm and an error of misalignment on the fiducials of 0.02 mm, corresponding to a budget of error of 30 µm. In the main linac, the length of the sliding window is challenging, with a budget of error consisting of an error of fiducialisation of 0.1mm and error of misalignment on the fiducials of 0.2 mm over 600 m [3].

STRATEGY OF ALIGNMENT

General Strategy

Linear colliders like CLIC or ILC will follow the same steps of alignment as introduced before. The challenging tolerances of specific area have a direct impact on three steps:

- the fiducialisation, where methods of measurements of the magnetic axis / electrical zero / mechanical axis of the components with respect to fiducials need to be improved considerably
- the absolute alignment and smoothing: taking into account the accuracy needed and the number of components to be aligned, these steps need to be replaced by an active pre-alignment of the components of the CLIC main linac and BDS, and ILC BDS, which means that the position of the components is determined continuously by alignment systems and re-adjusted when needed by

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actuators. A strategy concerning the determination of the position of the components based on two alignment networks is proposed [4].

Primary and Secondary Networks

Two metrological networks will be associated to determine the position of the components within the required accuracy [5]:

- A primary network, named Metrologic Reference Network (MRN), consisting of overlapping straight references of a few hundreds of metres, that will propagate the precision of alignment needed over long distances, typically a few micrometres over 200 m. Sensors with a position determined at the micrometre level on the same Metrological plate, measuring their transverse position with respect to the two parallel overlapping reference, would provide a very accurate determination of the distance between the references, allowing the very precise determination of a straight reference alignment over the whole area (main linac, BDS, final focus)

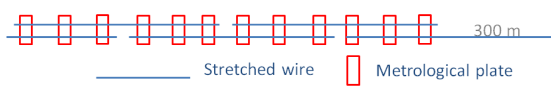

Figure 1: MRN network

- A secondary network, named Support Proximity Network (SPN) framed by the MRN, consisting of sensors associated to each component to be aligned, providing an accuracy of a few microns over 10 m.

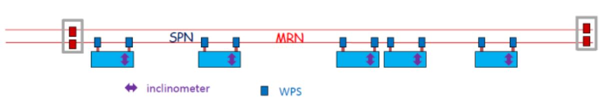

Figure 2: Primary and secondary networks.

Special Case of the ILC Main Linac

The challenge of the alignment of the ILC main linac lies in the length over which the alignment has to be performed, e.g. 600 m, a factor 4 with respect to the length considered in the LHC. As no other solution is currently available, the same solution as for CLIC main linac and ILC BDS and final focus has been proposed: a combination of MRN and SPN networks.

LONG RANGE ALIGNMENT SYSTEM FOR MRN NETWORK

Requirements

The long range alignment systems meant for the MRN have the following requirements [6]:

- A stable reference of alignment along time, with respect to the environment
- A straight and known reference at the micrometre level.

Two different references are under study to answer these requirements: a stretched wire and a laser beam under vacuum.

Stretched Wire

A stretched wire, modelized in the vertical plane by a combination of Wire Positioning Sensors (WPS) and Hydrostatic Levelling Sensors (HLS) in the vertical direction and protected from air currents can be a very accurate reference of alignment. The distance wire to wire is performed by WPS installed on the same metrological plate. An extensive R&D program has been implemented for the CLIC study in order to have a better understanding of the long term stability of a stretched wire, according to parameters such as humidity, temperature, and its modelization. Rms accuracies of 13 μm over distances of 140 m have been demonstrated [7].

Laser Beam Under Vacuum

A laser based under vacuum, to limit the effects of air turbulence and air density gradients can also be a very accurate reference of alignment. As for the stretched wire, the distance beam to beam requires also sensors performing absolute measurements, e.g. the coordinate systems of the sensors are determined at the micrometre level in the coordinate system of the component to be aligned. Different types of laser based alignment systems are under development. The lambda system, an n-point alignment system, consists of n shutters stopping the beam one after the other, the position of the beam on the shutter being observed by a CCD camera, part of the sensor/shutter [8]. A second solution is based on the Poisson method, e.g. the insertion of spherical targets in the beam the observation of the diffraction patterns generated on a CCD camera [9]. Another possibility is to insert via on/off mechanisms inside vacuum targets as position-sensitive quadrant photo-detectors.

SHORT RANGE ALIGNMENT SYSTEMS FOR SPN NETWORK

Requirements

The sensors part of the SPN network will be installed on the component to be aligned and will have to fulfil the following requirements:

- The zero of the sensor must be known at the micrometre level in the coordinate system of the component, which implies that the sensor is equipped with a kinematic support allowing the repeatability and reproducibility of its repositioning within 1 μm.
- No drift of the sensor (or the drift can be controlled and compensated)
- Sub-micrometric precision of measurements and accuracy of measurements below 5 μm over the whole range of measurements.

SPN Sensors

2 configurations of sensors can be proposed:

- Same sensors as for the long range alignment system, in case of an n-point alignment system: WPS or lambda sensors for example, installed on the components and measuring w.r.t. the alignment references of the MRN [10].
- Independent sensors from another alignment system type, linked every metrological plate to the MRN. Two 3-points alignment systems have been developed by NIKHEF institute and are under validation on a dedicated test setup at CERN: RasNik alignment system and RasDif alignment systems, their association forming the Raschain alignment system [11].

Raschain Sensors

RasNik system consists of 3 components: one coded mask illuminated by arrays of LED, transferred through a lens on CCD camera, where the radial and vertical offsets with respect to the line formed by the mask and lens are observed. In the RasDif system, the illuminated mask is replaced by a laser and the lens by a hole; the centre of the diffraction pattern created on the CCD is analysed to deduce the position of the third component with respect to the first two [12].

FIDUCIALISATION

As tolerances of fiducialisation are very tight, the most accurate means of measurement will have to be used. For short components, e.g. with a length smaller than 2 m, 3D Coordinate Measuring Machines (CMM machines) are the most efficient with uncertainties of measurements below 6 µm at 2σ, or even better [13][14]. For longer components or measurements on the field (control of the alignment of the components on a common support after transport for example), special measurements methods with associated portable instrumentation are being developed: for example, a combination of CMM measurements and Laser Tracker AT401 measurements, or a combination of CMM measurements and micro-triangulation measurements.

Inter-comparison between these means of measurements is under way on the Two Beam Test Modules (TBTM) at CERN, mixing other solutions as photogrammetry or Frequency Scanning Interferometry (FSI). As components are short, CMM measurements of the fiducials are considered as the reference and measurements performed by the other methods of alignment are compared. First inter-comparison between AT401 and micro-triangulation show standard deviations below 10 µm in the determination of the alignment of the components.

CONCLUSION

In comparison with alignment requirements of the LHC, the alignment of the linear colliders is a real challenge, with precision and accuracy of a few micrometres over several hundreds of metres, including the fiducialisation process.

Solutions are under development concerning long range alignment system. A stretched wire solution has been proposed for the TDR of ILC and CDR of CLIC. The results from test setup have shown that an uncertainty in the determination of the position of a component equipped with sensors is about 13 µm. Alternatives based on laser beam under vacuum are under development, first to validate the stretched wire solution and why not to replace it.

Short range sensors are under development as well, and the latest results show that an accuracy below 5 µm and a repeatability below 1 µm are reachable.

Fiducialisation at a micrometre level is a challenge too, with a level of difficulty depending of the size of the component. For very short components, CMM machines are a must, but will need to be replaced by portable means that are under development and validation.

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