THEORETICAL AND PRACTICAL FEASIBILITY DEMONSTRATION OF A MICROMETRIC REMOTELY CONTROLLED PRE-ALIGNMENT SYSTEM FOR THE CLIC LINEAR COLLIDER

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28 February 2012

The research leading to these results has received funding from the European Commission under the FP7 Research Infrastructures project EuCARD, grant agreement no. 227579.

This work is part of EuCARD Work Package **9: Technology for normal conducting higher energy linear accelerators**.

THEORETICAL AND PRACTICAL FEASIBILITY DEMONSTRATION OF A MICROMETRIC REMOTELY CONTROLLED PRE-ALIGNMENT SYSTEM FOR THE CLIC LINEAR COLLIDER

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Abstract

The active pre-alignment of the Compact Linear Collider (CLIC) is one of the key points of the project: the components must be pre-aligned w.r.t. a straight line within a few microns over a sliding window of 200 m, along the two linacs of 20 km each. The proposed solution consists of stretched wires of more than 200 m, overlapping over half of their length, which will be the reference of alignment. Wire Positioning Sensors (WPS), coupled to the supports to be pre-aligned, will perform precise and accurate measurements within a few microns w.r.t. these wires. A micrometric fiducialisation of the components and a micrometric alignment of the components on common supports will make the strategy of pre-alignment complete. In this paper, the global strategy of active pre-alignment is detailed and illustrated by the latest results demonstrating the feasibility of the proposed solution.

INTRODUCTION

The emittance preservation in the main linac and BDS is one of the main challenges for CLIC, with the objective to limit the emittance growth in the vertical plane below 10 nm [1]. This requires alignment tolerances never achieved before at that scale and therefore a special pre-alignment step will be needed, before the first pilot beam is sent, in order to implement beam based alignment and beam based feedbacks. Hundreds of thousands of RF components with a length up to 2 m and thousands of magnets will have to be pre-aligned within a few microns along a straight line over a sliding window of 200 m along the 20 km of linacs. Because of such tight tolerances and taking into account the number of components to be pre-aligned, an active pre-alignment will be needed: sensors from alignment systems will provide the position of the components and actuators will adjust these components at their theoretical position.

For the Conceptual Design Report, a solution has been proposed and validated through several mock-ups or test benches. In this paper, the strategy concerning the pre-alignment of the components and the corresponding error budget are recalled. Then each step of the strategy is detailed and illustrated by the latest results.

GENERAL STRATEGY OF PRE-ALIGNMENT

Metrological Reference Network (MRN)

All the components need to be pre-aligned w.r.t. a straight line over the 20 km of linacs. This straight line will have to be already determined once the components are installed in the tunnel and will consist of stretched wires with a length of at least 200 m, overlapping over half of their length. Along these parallel wires, pairs of two Wire Positioning Sensors (WPS) installed on a common metrological plate will allow the reconstruction of a straight reference line with redundancy. WPS sensors perform radial and vertical offset measurements w.r.t. a stretched wire considered as the reference of alignment, within a micrometric accuracy and precision. Their relative position on each metrological plate will be computed at a micron level thanks to measurements of their mechanical interfaces from 3D Coordinate Measuring Machines (CMM), and a biaxial inclinometer will correct all angles deviations. This combination of overlapping stretched wires and metrological plates is named "Metrological Reference Network" (MRN network).

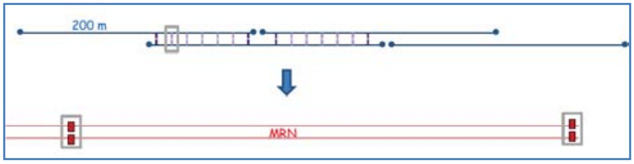

Figure 1: Metrological Reference Network.

Geodetic Network

Absolute position of this line will be provided thanks to an underground geodetic network, in which the position of each metrological plate will have been computed. At the bottom of each shaft connecting surface geodetic network to underground geodetic network (separated by a maximum length of 2.5 km), reference points sealed on the ground every 25 m will be determined within an accuracy and precision below ± 2 mm.

Fiducialisation and Articulation Point

Hundreds of thousands of RF components will have to be pre-aligned. In order to ease the problem, several steps will be followed. First, all the components will be fiducialised. The fiducialisation is an operation linking the reference axis / zero of the component to external alignment references (fiducials) which will allow the alignment of the component when its reference axis / zero is no longer accessible. Second, the components will be pre-aligned on common girders, with a maximum length of 2 m. Their external reference surfaces will be fastened on V-supports. The mean axis of these V-supports (corresponding within a few microns to the theoretical beam axis) will be included in a cylinder with a radius of 2.5 µm for each girder. Third, these girders will be interlinked by an articulation point allowing a displacement in the interlink plane within 3 Degrees Of Freedom (DOF): horizontal, vertical displacements, roll. These 3 DOF will be motorized and a possibility of manual adjustment along the beam axis.

Support Pre-Alignment Network (SPN)

Each articulation point will be equipped with one WPS sensor measuring w.r.t. the MRN network and one biaxial inclinometer in order to compute the position of the articulation point at the level of the beam. The position of the coordinate systems of these sensors will be determined w.r.t. the mean axis of the V supports at the micron level during the fiducialisation of the girder assembly. The sensors coupled to the articulation points are part of the SPN network.

Special Case of Main Beam (MB) Quadrupoles

Main Beam quadrupoles and associated BPM will be pre-aligned independently from girders, according to 6 DOF with all degrees motorized except the longitudinal one [2]; the coordinate systems of 2 WPS sensors and 1 biaxial inclinometer will be determined at a micron level w.r.t. the mean mechanical axis of BPM and MB quadrupole, allowing to determine the position of both components very accurately and precisely.

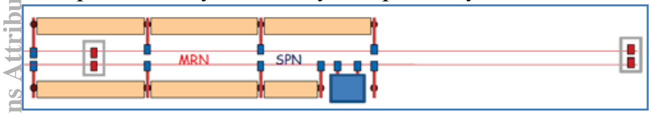

Figure 2: Configuration of alignment systems.

Budget of Alignment Errors

As a summary, the budget of errors concerning the MB components is detailed in the table below:

Table 1: Budget of Alignment Errors.

Steps	**RF structures**	**MB quad**
(a) Zero of component to fiducials	5 µm	10 µm
(b) Fiducials to sensor interface on support	5 µm	5 µm
(c) Sensor interface to sensor zero	5 µm	5 µm
(d) Sensor measurement w.r.t straight reference	5 µm	5 µm
(e) Stability, knowledge of straight reference	10 µm	10 µm
Total error budget (1σ)	**14 µm**	**17 µm**

GEODETIC NETWORK

A geodetic network will be first installed on surface, with points close to the pits and visible from the tunnel, determined through GPS measurements within ± 1 mm. The link between surface and underground tunnel will be performed through the pits using a combination of several methods: 3D triangulation and trilateration coupled with measurements on vertical plumb wires. In 2010, studies were undertaken in order to validate these methods on an LHC pit: PM32 with a depth of 65 m. The precision of each method tested appeared to be around 0.1 mm, with an accuracy of 0.5 mm.

In order to limit systematic errors associated with each method, a combination of methods will be coupled with astro zenithal measurements. This should guarantee an absolute position in the tunnel at the bottom of each shaft within ±2 mm (for a shaft depth around 120 m).

Simulations were undertaken in 2009 concerning the propagation error due to the measurement uncertainties of the alignment systems, with rather pessimistic hypotheses: a precision of points at the bottom of the pits of ± 2 mm, a calibration of metrological plates within ± 5 µm, a distance between pits of 3.5 km and wires 400 m long. A standard deviation of 3.6 µm over 200 m of sliding windows was computed [3].

MRN NETWORK

In order to study precision and accuracy of overlapping wires, a dedicated facility was installed in an old tunnel over a length of 140 m [4]. In 2009, the measurements of alignment systems were studied during a 33 days period. After final adjustment of all the readings, a precision of 2 µm rms was obtained. Then, the standard deviation of residuals was studied over one set of data: 17 µm in radial and 11 µm in vertical. The results will be improved: linearity problems in some WPS sensors were detected and are being solved.

Then, the network of alignment systems was modeled and simulated by the Monte Carlo method. It was divided into 10 steps simulated independently, the last step defining the positioning of one point every meter per wire. Along 140 m, the positions of these points had a mean value of 4.7 µm and were included in a 10 µm mean radius cylinder, in 97.5% of the cases. This corresponds to steps **(c)**, **(d)** and **(e)** in the budget of alignment errors, and demonstrates the feasibility of the solution.

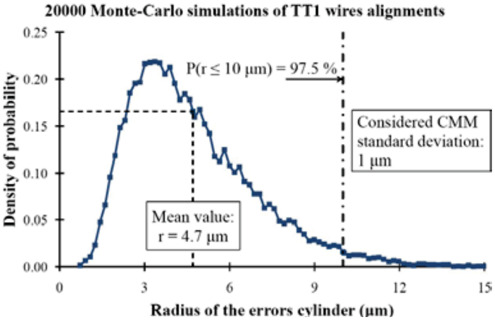

Figure 3: Radius of cylinder error of 4.7 µm.

FIDUCIALISATION AND DIMENSIONAL CONTROL

When possible, measurements for fiducialisation and dimensional control will be performed with CMM taking into account their tolerances of measurements: 0.3 µm + 1 ppm for Leitz Infinity. Unfortunately, these machines are static, and have a limited volume of measurement (maximum length of 1.2 m for Leitz Infinity for example). So, additional instrumentations and methods needed to be found. The instruments chosen will be coupled to CMM measurements when micrometric measurements will be needed in tunnel on objects with a length superior to 2 m.

In order to evaluate different portable solutions of micrometric measurements, targets located on the same metrological plate were measured with several instruments. The location of these targets were determined with the most precise CMM available at CERN, considered as the reference of measurements. The standard deviation between instruments and CMM measurements on this metrological plate were inferior to 5 µm in the case of a laser tracker AT401 and micro triangulation, and was inferior to 10 µm in the case of a Romer arm, knowing that a scale factor was applied to compensate effects due to temperature variation [5].

Using these results as input for simulations, it was computed that targets on a CLIC module would be determined within a precision and accuracy of 7 µm [6].

ARTICULATION POINT

Two concepts of articulation point are under qualification tests on a facility. This mock-up, located in a laboratory, consists of two test modules (2 x 2 m) at scale 1, with all the functionalities of a module (vacuum, cooling, pre-alignment, stabilization) except beam.

In the first solution of articulation point, the accuracy and precision needed are reached using very tight mechanical tolerances of machining for reference surfaces and components [7]. The measurements on a 3D CMM at 3σ showed an alignment of the V supports on the girder below 15 µm, an alignment of the mean axis of the Ves w.r.t the pinholes of articulation point below 20 µm, and an alignment of the V supports on the girder w.r.t sensors interface better than 20 µm. These results can be improved. First, problems were met during the manufacturing of the girders solved by add of shims between cradle and girder. Second, the inserts allowing the fixation of the cradle on the SiC girder were not positioned accurately, creating some constraints during the fixation of the cradles on the girder. Third, the volume of the CMM machine was not sufficient enough in order to measure the assembly. Some key points were measured out of the range of the CMM, with accuracy and precision degraded [6].

In the second solution of articulation point, two adjacent girders are linked through a main unit acting as an articulation point; the following side of one girder is simply laid on rollers of the articulation unit, while the master side of the adjacent girder is screwed on the main unit via a flexural blade. The adjustment of the mean axis of Ves on adjacent girders is performed using the clearance of screws linking the master part of the girder to the main unit. Measurements performed on CMM Olivetti showed that V supports were aligned at better than 12 µm on each girder. Measurements performed by a STR500 alignment telescope demonstrated a radial and vertical position of the articulation point at better than 8 µm [6].

SPN NETWORK

Repeatability below 1 µm in the installation and measurement of each WPS sensor was demonstrated on the two test modules [8]. Other tests concerning re-adjustment and algorithm of repositioning are under progress.

CONCLUSION

A global strategy consisting of overlapping stretched wires and WPS sensors is proposed for the pre-alignment of CLIC components. First results or simulations from several facilities or mock-ups show that the global budget of error concerning pre-alignment is feasible, and could even be reduced. Measurements undertaken in an LHC shaft demonstrated that an absolute position at the bottom of each shaft should be guaranteed within ± 2 mm. The MRN network has been built in a facility with 7 metrological plates and overlapping wires, over a length of 140 m. The standard deviation of the residuals of the zero of each metrological plate was computed over one set of data with the following value: 11 µm in vertical. When possible, fiducialisation will be carried out on the most precise CMM. When components are longer than 1.2 m, alternative solutions have been found. First simulations have shown that targets would be determined with a precision and accuracy below 7 µm.

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