PROPAGATION ERROR SIMULATIONS CONCERNING THE CLIC ACTIVE PREALIGNMENT

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Abstract

The CLIC[1] components will have to be prealigned within a thirty times more demanding tolerance than the existing CERN machines. It is a technical challenge and a key issue for the CLIC feasibility. Simulations have been undertaken concerning the propagation error due to the measurement uncertainties of the prealignment systems. The uncertainties of measurement, taken as hypothesis for the simulations, are based on the data obtained on several dedicated facilities. This paper introduces the simulations and the latest results obtained, as well as the facilities.

INTRODUCTION

Before the final beam-based alignment, the CLIC components must be aligned within a transversal and vertical tolerance of $10\ \mu\text{m}$ along a $200\ \text{m}$ sliding window [1]. Such a tolerance is thirty time more demanding than the SPS and the LHC, the existing machines at CERN. It represents a technical challenge as well as a key issue for the CLIC feasibility.

In order to define the CLIC alignment strategy from both of the survey and beam dynamics points of view, simulations of the CLIC prealignment have been made. The uncertainties of the different kind of measurement systems have been chosen in order for the results to fulfill the requirements. Then developments and facilities have been made to prove if these uncertainties could be reached.

THE PROPAGATION NETWORK

The prealignment requirement, based on the $200\ \text{m}$ sliding window, comes from the beam dynamics simulations. It is a simplified concept used before prealignment simulations were available. The results presented here are used in beam dynamics simulations to study the prealignment effects on the the beam emittance [2].

The main concept of the prealignment consists of a straight reference line according to which the CLIC components are aligned. Overlapping stretched wires are used in order to build such a reference line along the whole CLIC linacs. This concept is defined as the propagation network [1].

The principle of the stretched wire measurement system is the double-axis ecartometry [3]. Sensors are providing the transversal and vertical distances to the wire. The system currently used at CERN is the WPS[2] produced by Fogale Nanotech [1].

[1] Compact LInear Collider
[2] Wire Positioning System

Uncertainties Considered in the Simulations

In order to know if the deviation due to the propagation network errors fits within the requirements of $10\ \mu\text{m}$ along a $200\ \text{m}$ sliding window, simulations, based on the Monte-Carlo method [4], have been done. Hypothesis have been made concerning the uncertainties of the different measurement systems involved in the propagation network.

The propagation network has to go through reference points which take place at the feet of each pit in the tunnel. The precision of these points is $2\ \text{mm}$.

In order to overlap, the sensors corresponding to parallel wires are installed on a metrological plate which is calibrated in a laboratory. The precision of this calibration is $5\ \mu\text{m}$. The link between the propagation network and the reference points is also made by a metrological calibration.

The stretched wire system uncertainties depend on the precision and the accuracy of the WPS, and on the stability of the wire. The value of $5\ \mu\text{m}$ for all of them has been considered in the simulations.

Simulations of the Prealignment

The stretched wire measurements in both of the horizontal and vertical plans are simulated by distances to a straight line [4]. All the other measurements, i.-e. the metrological calibrations and the definitions of the reference points, have been considered as differences of coordinates.

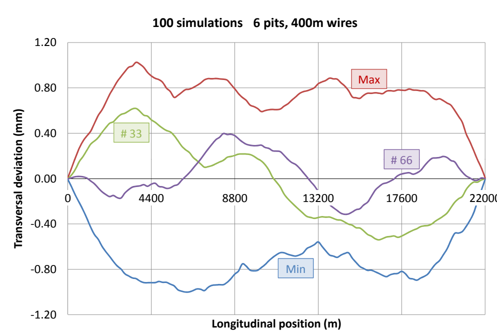

Figure 1: Propagation network simulations.

The simulations have been made along a whole linac, which represents $21\ \text{km}$ without the beam delivery system. The figure 1 shows the global transversal deviation after one hundred simulations using six pits and $400\ \text{m}$ wires. The maximum deviation along the linac fits between $\pm\ 1\ \text{mm}$.

The most important is not such a small global deviation but a deviation as smooth as possible, below $10\ \mu\text{m}$ along $200\ \text{m}$. The simulations give the coordinates of the propagation network points. In the figure 2, one can see how the deviation along 200 m, ξ_i, has been defined from those coordinates.

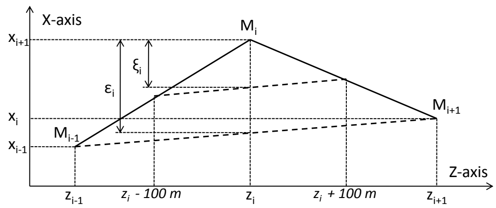

Figure 2: The deviation along 200 m.

This deviation has been studied in order to see the effect of the wire length between 300 m and 500 m. The figure 3 is presenting the maximum, mean and minimum values of the standard deviations of this error along 200 m as a function of the length of the wire.

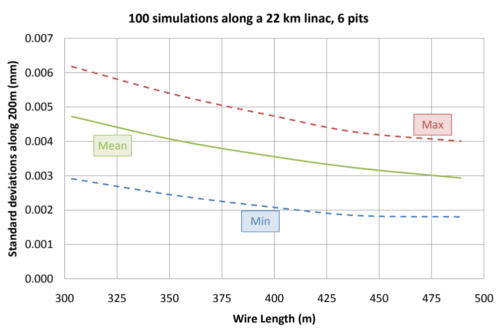

Figure 3: Simulations of the effects of the wire length.

The requirement, which, as mentionned before, is 10 µm, is a 3σ tolerance. Therefore the precision that has to be reached is 3.3 µm. According to the mean value of the standard deviation in the figure 3, such a precision can be reach by using wires longer than 425 m.

Improvements of the Simulations

The simulations, in any case, should be as close as possible to the reality. The ones that have just been presented have to be improved. The required modification concerns the way to simulate the ecartometry measurements, the overlapping system and the systematic effects.

A WPS sensor provides the vertical and horizontal distances to the wire. Both of those measurements are simulated as distances to a straight line [4]. The catenary modelization of the wire in vertical [3] has to be implemented in the simulation software.

The propagation network does not yet take into account any redundancy of the overlapping wires. The propagation error along 200 m should be reduced.

The main modification is the implementation of systematic errors in the wire overlap. Such an effect, even tiny, could decrease dramatically and very fastly the precision. Systematic errors could be due, for instance, by micrometric variations of the geoid along short wave-lengths or unexpected fields of force [5].

VALIDATION OF THE UNCERTAINTIES

The simulations are not yet fully validated. When it is the case, one will be able to consider the feasibility of the CLIC prealignment as proven, if the uncertainties taken into account are demonstrated.

Some of the uncertainties previously listed are already proven. The 2 mm precision of the reference points in the tunnel is standard in the accelerators survey community [4]. The 5 µm precision chosen for the metrological calibrations is the uncertainty of the CMM[3] currently used at CERN by the metrology group (CERN EN/MME).

The uncertainties that still need to be validated concern the wire itself, the WPS sensors and the overlapping principle.

The Knowledge of the Wires

The simulations confirm that the longer the wires are, the smaller the error propagation is. According to the last results, the specifications could be reached by using wires longer than 425 m. In 2008, a 500 m long wire has been stretched at CERN. The stability of the wire was below 5 µm per day when the wire was protected from the tunnel ventilation (see figure 4).

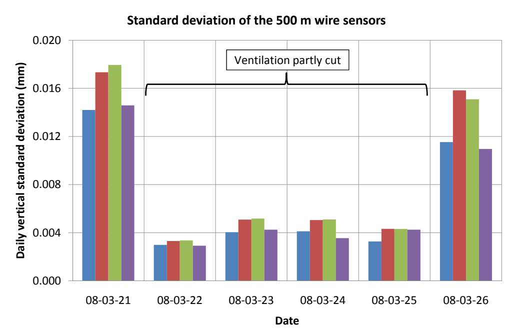

Figure 4: Standard deviations of the 500 m wire sensors.

Further developements will be done to increase the knowledge of the wire behaviour. Tensile tests have already been done [6]. Facilities are under development to study the long term creeping effects.

Accuracy of the WPS Sensors

The propagation network, based on the overlapping wires, requires high precision and high accurate sensors. The stretched wire system, composed by the WPS sensors and the wire, has a 1 µm precision [4].

A new interface has been designed in order to define the translations and the rotations of the center and the axis of the sensor according to a three balls reference system [7] (see figure 5). The tolerance on the sphericity of these balls is 1 µm.

A calibration bench has been developped in order to measure these translations and rotations (see figure 6). It

[3] Coordinate Measuring Machine

Figure 5: A WPS sensor with its new centering system.

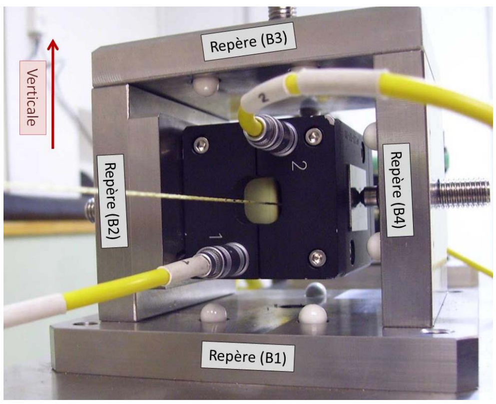

Figure 6: A sensor being calibrated.

is not yet achieved [8]. The accuracy that is looked for is $5\ \mu\text{m}$.

The Overlapping Wires Validation

A main facility has been made in an old transfer tunnel at CERN, the TT1. The figure 7 shows the general layout of this facility. The overall length is $140\ \text{m}$.

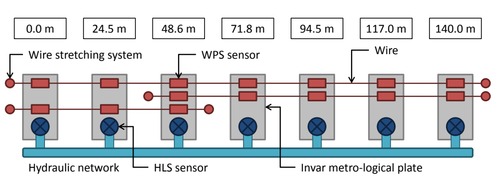

Figure 7: Layout of the TT1 facility.

There are seven invar metrological plates on which take place HLS[4] and WPS sensors. It consists of three overlapping wires, whom lengths are $49\ \text{m}$, $91\ \text{m}$ and $140\ \text{m}$.

As one can see on the figure 8, the three balls supporting system has recently been installed. As soon as the sensors are calibrated, the overlapping of the wires will be studied. The redundancy of the measurements should underline the Earth inertial effects, if it exists on a stretched wire [5].

[4]Hydrostatic Levelling System

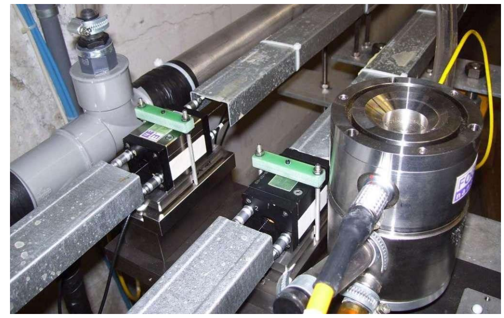

Figure 8: View on one TT1 metrological plate.

CONCLUSION

The required uncertainties of the measurement systems have been defined from the simulations. All of them are not yet demonstrated, but dedicated facilities are, or are going to be, set up.

The stability of a long stretched wire system at $5\ \mu\text{m}$ has been demontrated in the $500\ \text{m}$ wire facility. The precision and accuracy of the WPS are currently studied with the calibration bench and the TT1 facility.

Finally, the improvement of the simulations should provide a better knowledge of the different uncertainties, if they have to be tighted or can be relaxed. This aspect will be studied in collaboration with the CLIC beam dynamics team.

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