Modeling of the CLIC propagation network

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Analysis of the TT1 results

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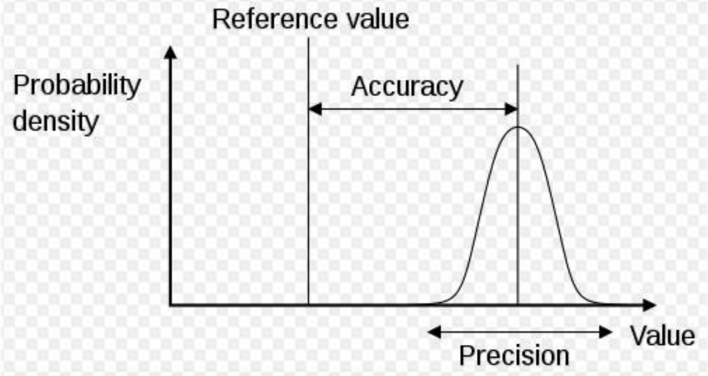
Introduction

The CLIC project requires very tight alignment tolerances on the transversal and vertical positions of the components :
10 µm along a 200 m sliding window !

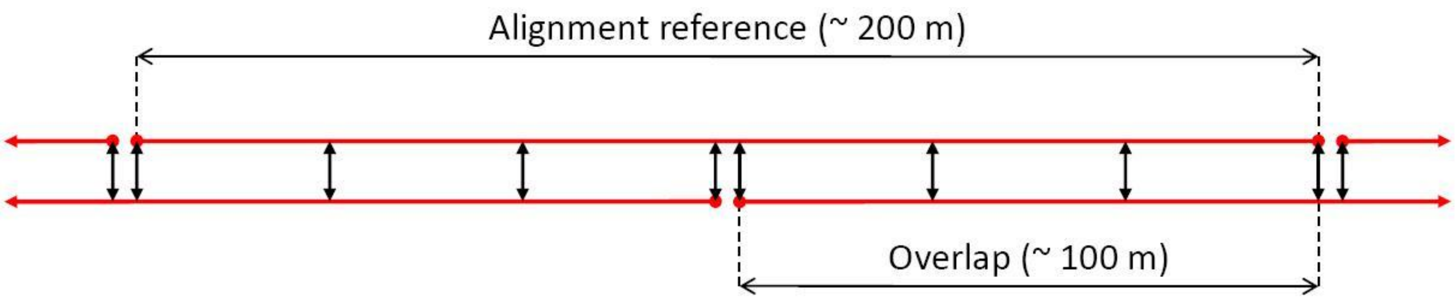
In the CLIC note 553, a propagation network, based on overlapping alignment references, has been proposed. The actual research is focussed on this concept which requires high precision and accuracy alignment systems.

This presentation will introduce the strategy to reach the specifications. The last results, concerning the precision, will be presented.



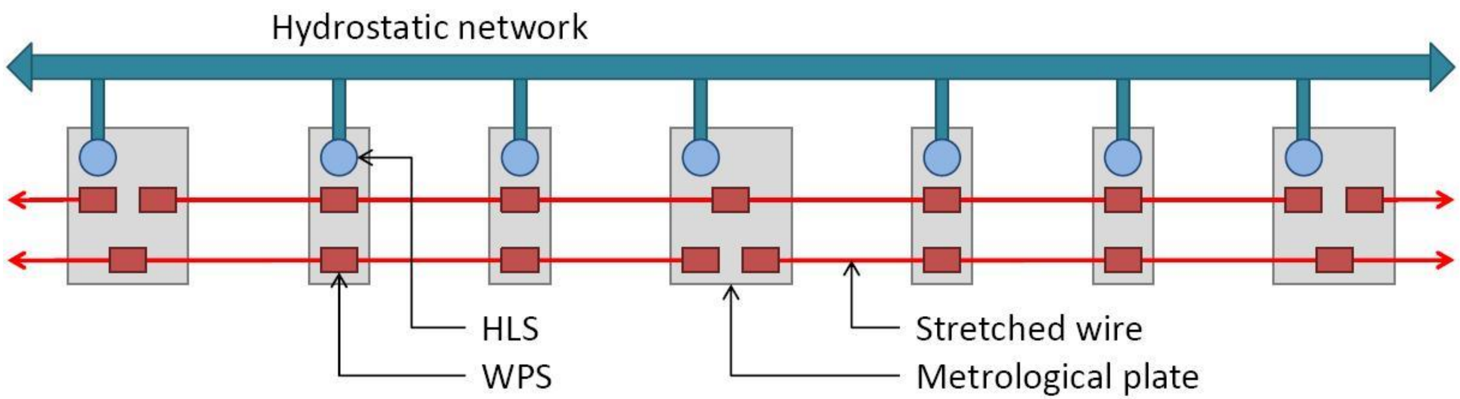
The CLIC propagation network

In order to align the 10000 modules and 2000 Main Beam quadrupoles of each CLIC linac, a straight reference, according to which the positions of these components are defined, is required. Such a reference, along 20 km does not exist.



The CLIC propagation network consists in building this straight line by overlapping alignment references with redundancy.

Components of the network



Requirements for an alignment system in the propagation network :
- Long distance (~ 200 m),
- Micrometric uncertainties (precision & accuracy),
- "N-points" alignment system

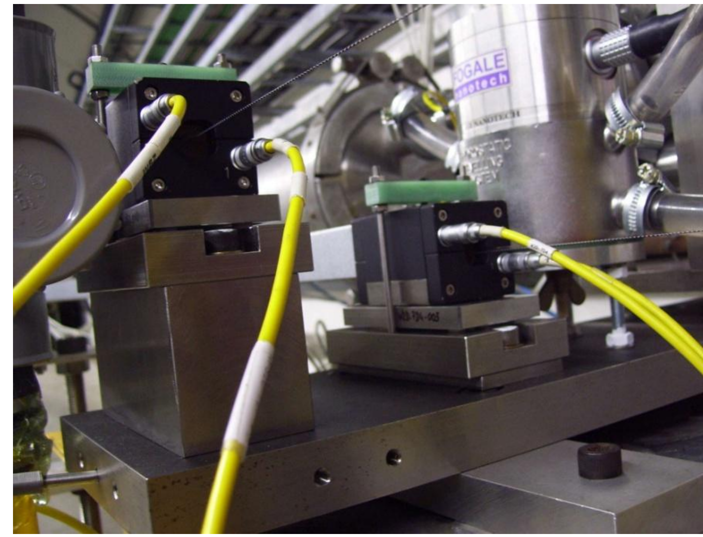
The stretched wires, measured by WPS sensors, is actually one of the most advanced system. It is coupled with HLS to model the wire in vertical and add redundancy in this dimension.

WPS = Wire Positioning System – HLS = Hydrostatic Levelling System

Components of the network

In order to ensure the wire overlap, sensors are installed on a calibrated metrological plate.

WPS on such a plate >>



The relative positions of the sensors on one plate is known with a 3 µm uncertainty.

<< HLS and WPS on a plate

The coordinates systems

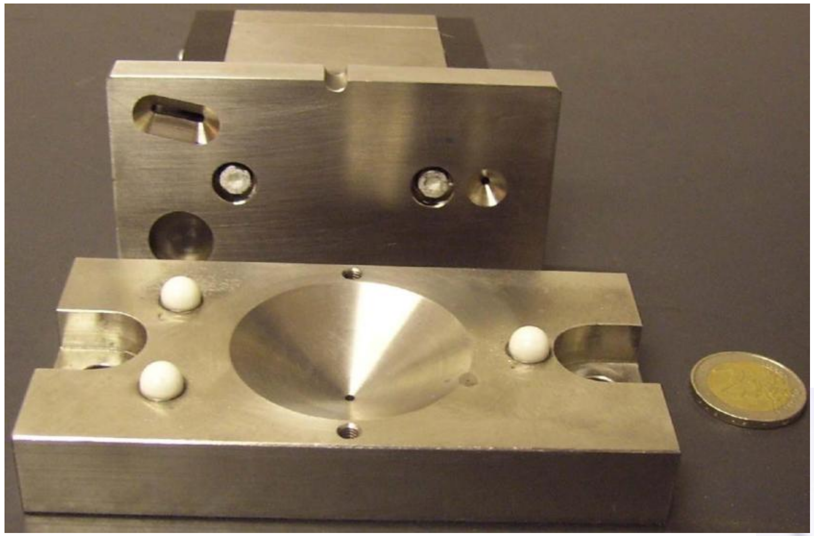
The sensors readings are the coordinates of the reference's measured points in its system. To align, this system has to be defined in a general Euclidian coordinates system by a set of translations and rotations matrixes.

$$(X)_{\substack{\text{Sensor}\\\text{System}}} \xrightarrow[\tau,\rho]{\textit{Calibration}} (X)_{\substack{\text{Centering}\\\text{System}}} \xrightarrow[t,r]{\textit{Metrology}} (X)_{\substack{\text{Plate}\\\text{System}}} \xrightarrow[T,R]{\textit{Topo \& Sensors}} (X)_{\substack{\text{General}\\\text{System}}}$$

Challenges :

- Calibration : Definition of the sensors zeros and axis with a 5 µm uncertainty,
- Transformation from the plate to the general system : it requires a high accurate and reliable model of the wires and the water surface.

The coordinates systems

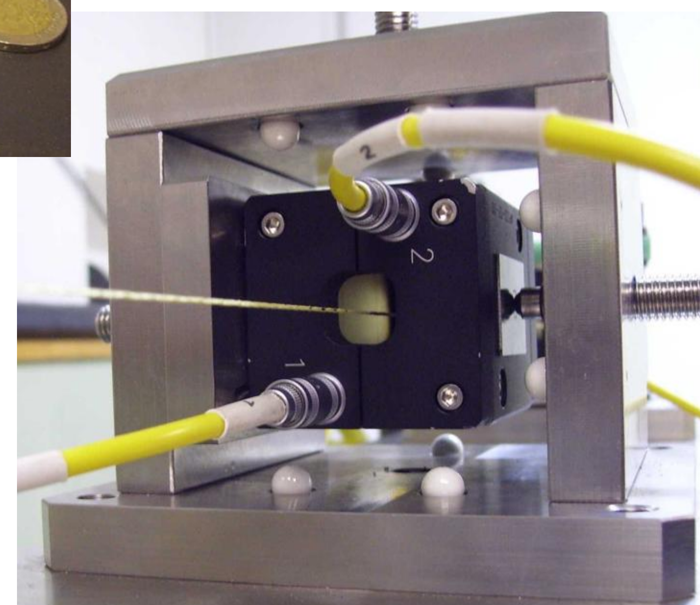


A new WPS centering system has been defined with respect to 3 precision balls.

<< New WPS centering system

A calibration bench has also been designed. A 5 µm accuracy is expected after the calibration.

Calibration of a WPS >>



Micrometric uncertainties

Sensors readings

↓ *Plates and sensors calibrations*

Wires positions in plate system

↓ *Standard survey measurements*

Wires positions in general system @ 200 µm

↓ *Wires modeling*

Model's residuals

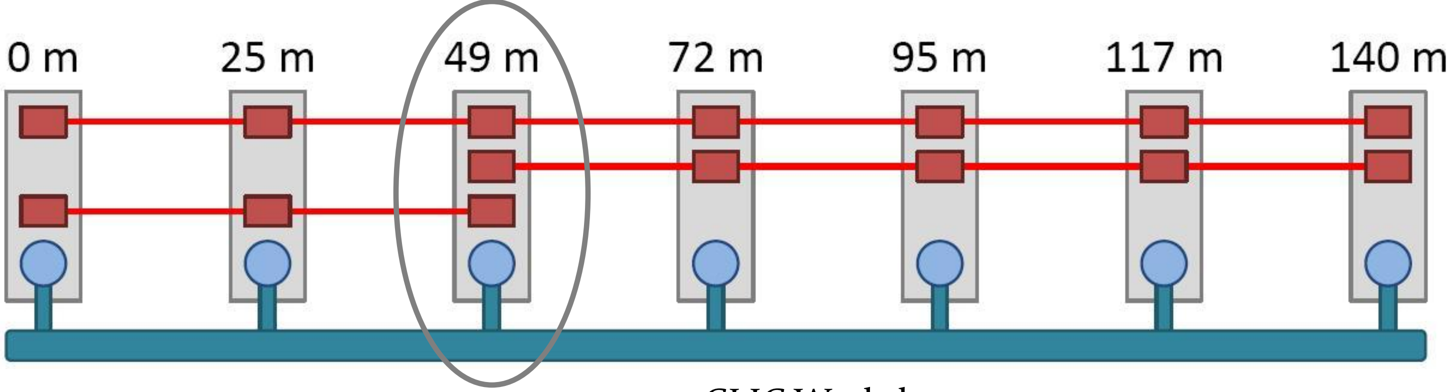
↓ *Plates transformations parameters recomputed from the residuals*

Wires positions in general system @ 10 µm

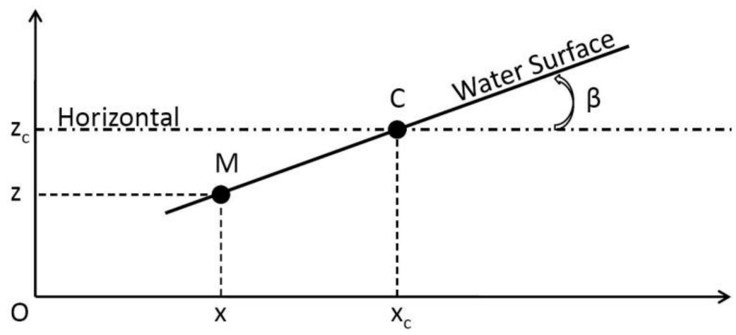
Results of the TT1 facility

The TT1 facility is designed for the validation of the wires overlap in the propagation network.

- 140 m long,
- 7 invar plates,
- 1 hydrostatic network,
- 3 wires (49, 91 and 140 m),
- 15 WPS and 7 HLS sensors.



HLS model

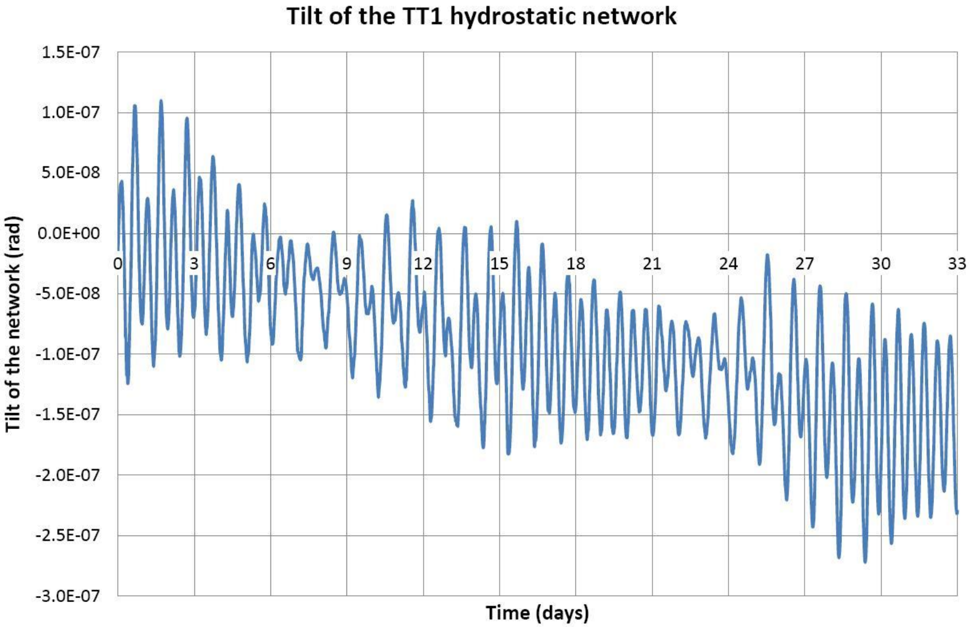


The water surface follows an equi-potential of gravity. Because of the tides effects, it oscillates around C, the central point of the network.

$$z = z_c + \beta.(x - x_c) + \varepsilon$$

The model residual ε includes the absolute error of position and the sensor random error.

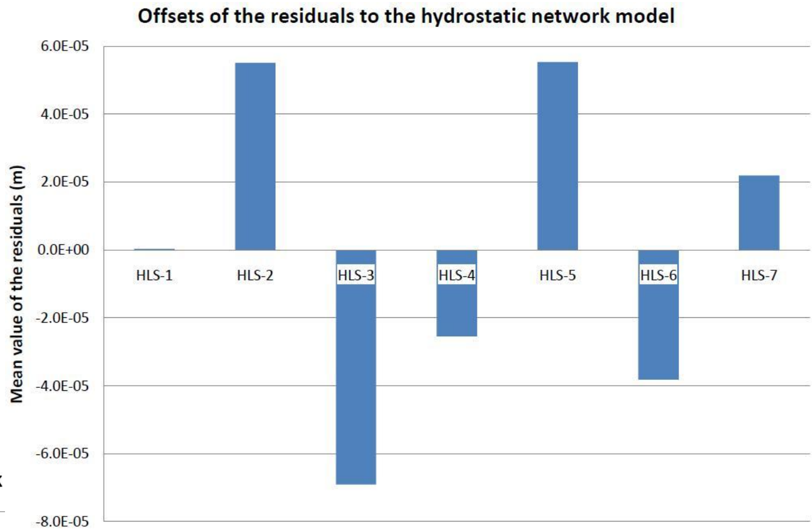
Adjustment of the surface tilt β >>

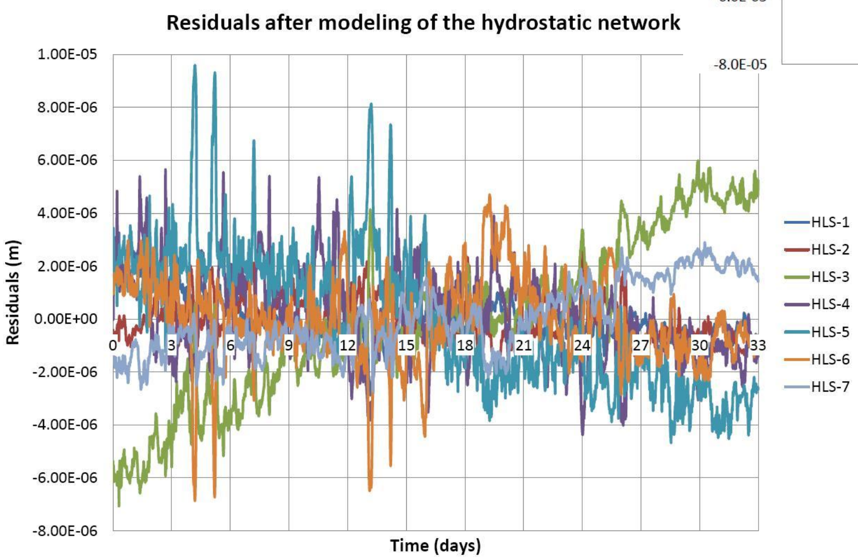


HLS model

The residuals of the HLS are between ± 60 µm. It is the accuracy of the mechanical prealignment.

Mean values of the residuals >>

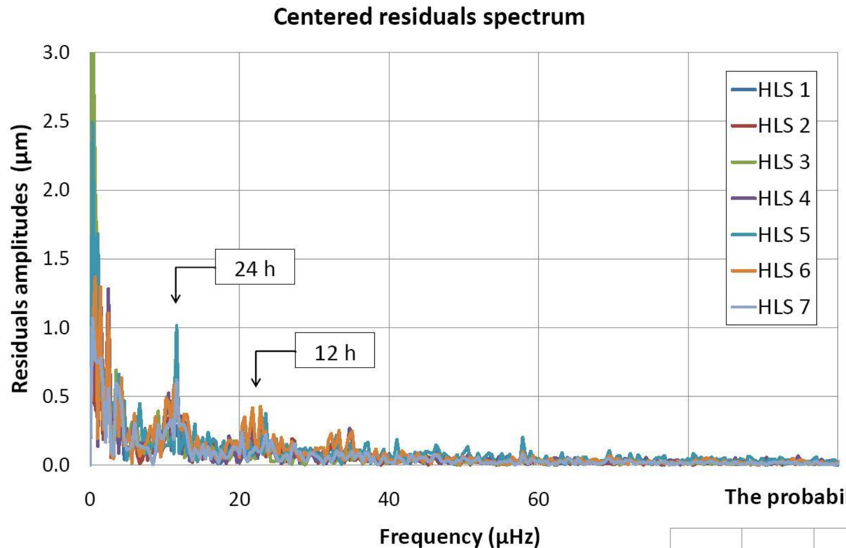




But the residuals have a high precision. The global standard deviation for the 7 HLS is 1.9µm !

<< Centered residuals

HLS model

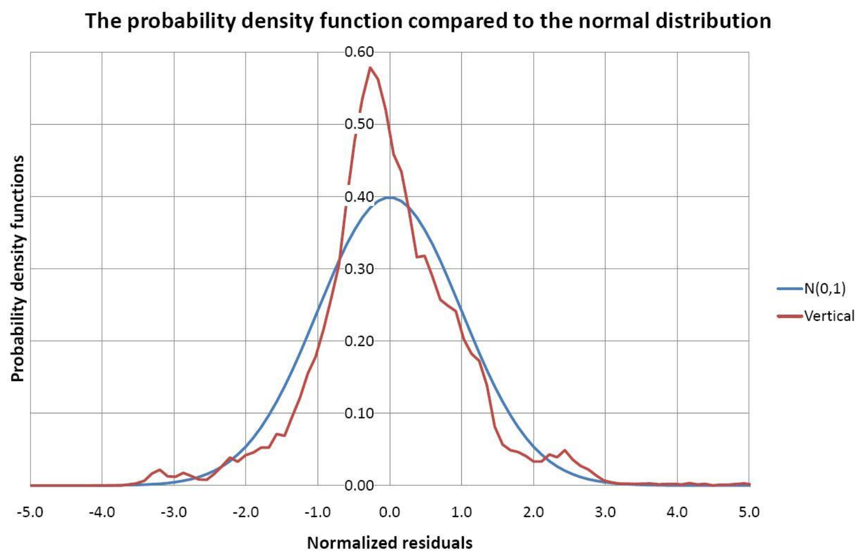


This way to model the tides seems to be efficient enough along 140 m.

<< FFT on the residuals

The distribution of the normalized residuals is close to the Gaussian law (successful Chi-Square test).

Residuals distribution >>

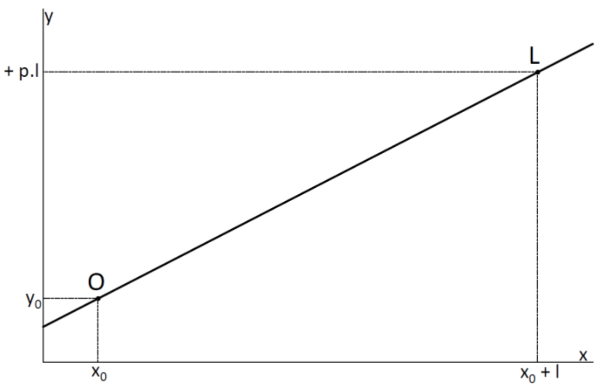


HLS model

Conclusions on the TT1 hydrostatic network, 7 HLS, along 140 m, during 33 days :

- Precision = 1.9 µm,
- Accuracy = 60 µm,
- No systematic effects detected.

WPS horizontal model



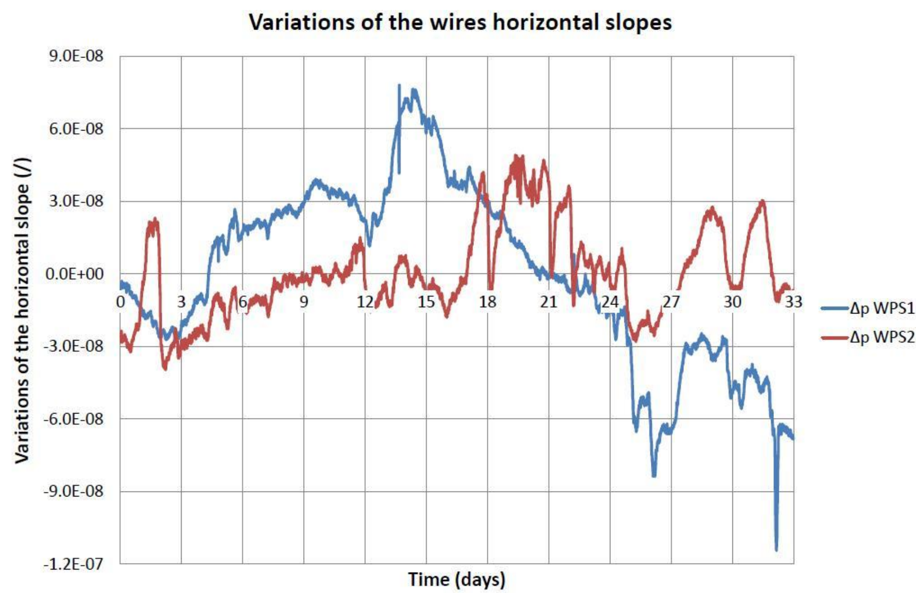
The wires, projected on an horizontal plan, are considered as straight lines.

$$y = y_o + p.(x - x_o) + \varepsilon$$

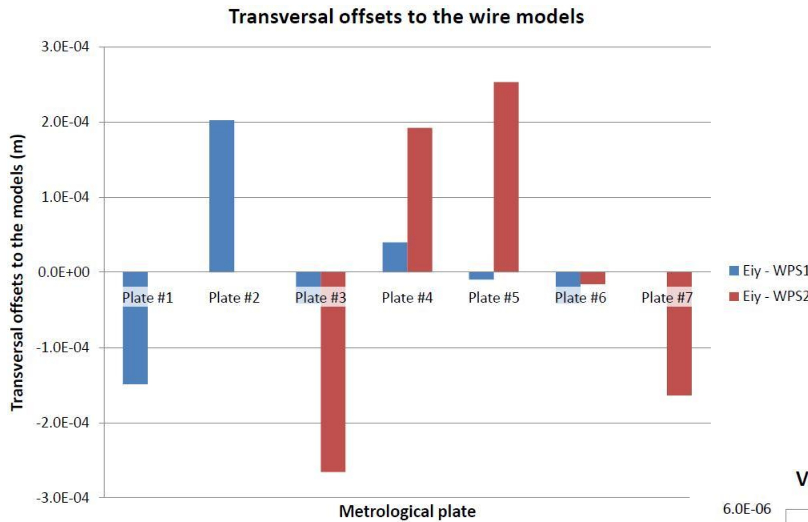
The residual ε also include the absolute and random errors.

The adjusted horizontal slopes are varying between ± 6 x 10^{-8}, i.-e. for the 140 m wire ± 8.4 µm.

Horizontal slope >>



WPS horizontal model

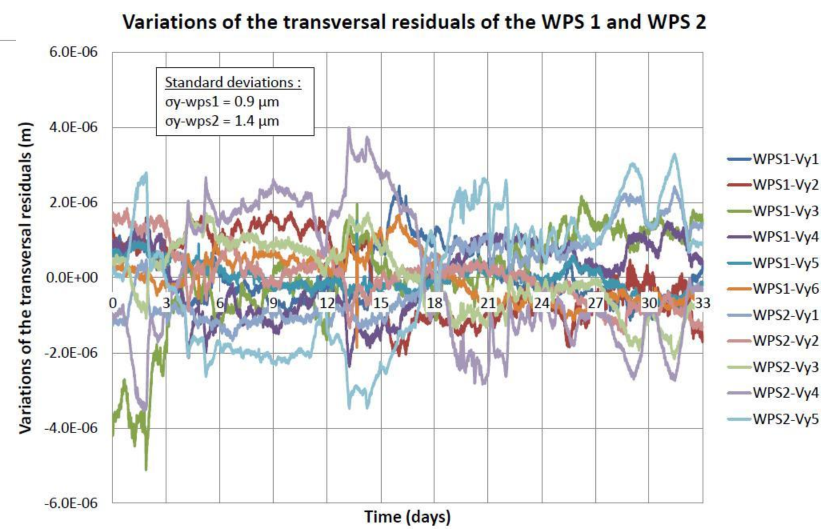


The precision of the mechanical prealignment is 0.2 mm in the transversal direction. The value of the residuals are due to this fact.

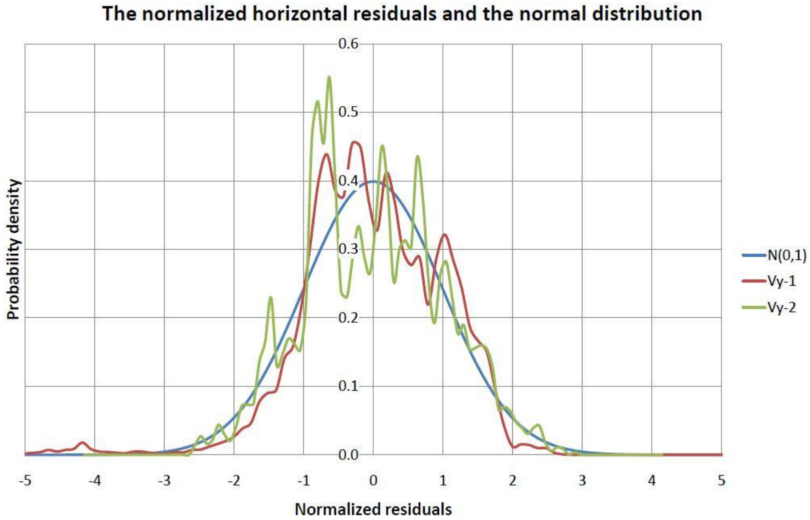
<< Residuals mean values

Like the HLS, the transversal residuals of the 91m and 140m wires have excellent standard deviations : 0.9 and 1.4 µm !

Centered residuals >>



WPS horizontal model



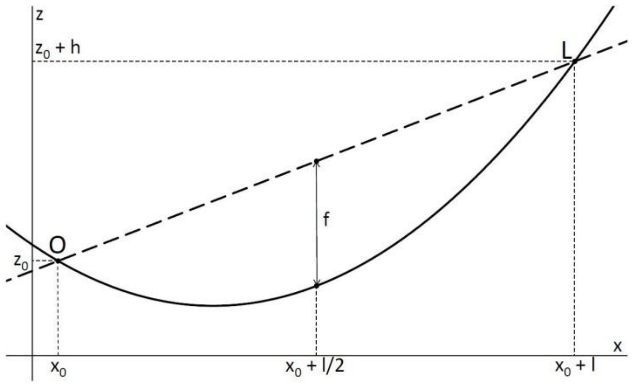
The distribution of the normalized residuals is close to the Gaussian law (successful Chi-Square test).

<< Residuals distribution

Conclusions on the TT1 stretched wires in horizontal, 15 WPS, along 140 m, during 33 days :

- Precision = 1.4 µm,
- Accuracy = 0.2 mm,
- No systematic effects detected.

WPS vertical model



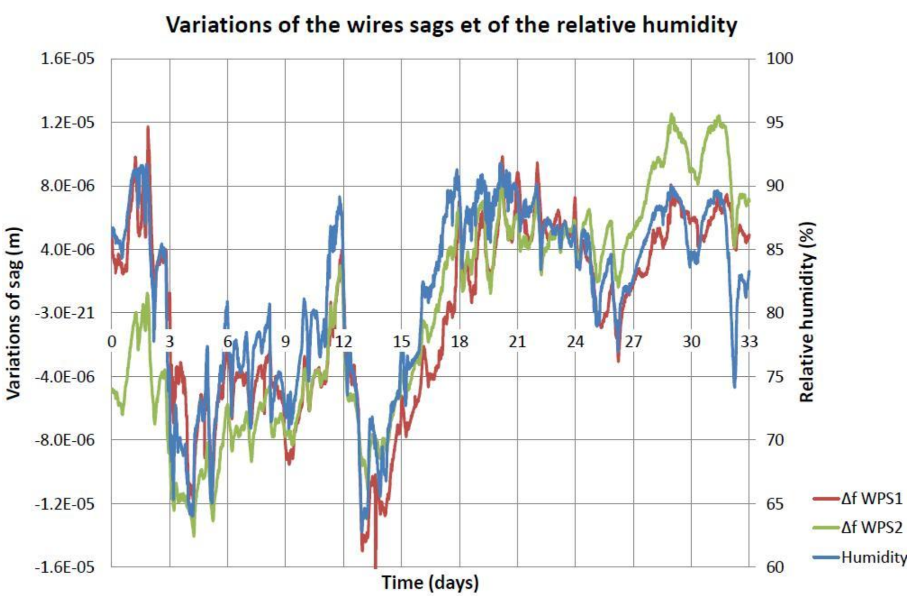
A straight wire is modeled by a catenary and approximated by a 2nd order polynomial.

$$z = z_o + \frac{4f}{l^2}.(x - x_o)^2 + \frac{h - 4f}{l}.(x - x_o) + \varepsilon$$

The residual ε also include the absolute and the random errors.

The adjusted sag f is mainly varying because of humidity variations (90% of correlation for both of the 140m and 91m).

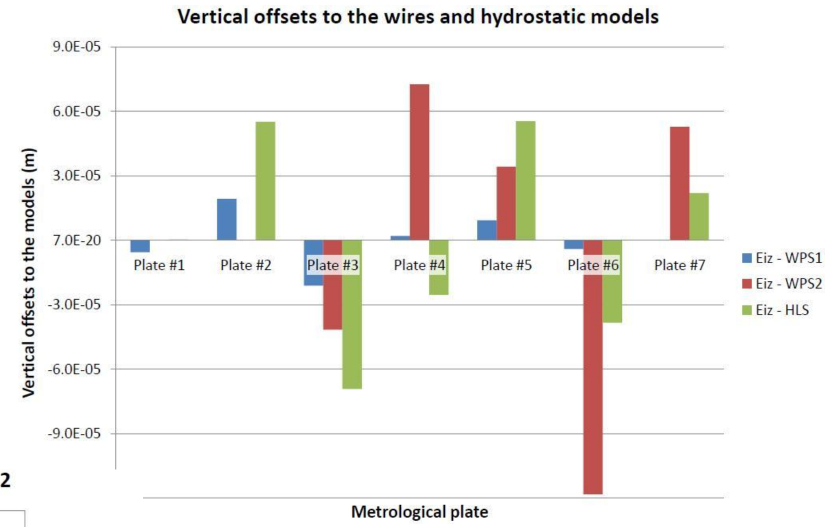
Sags and humidity >>

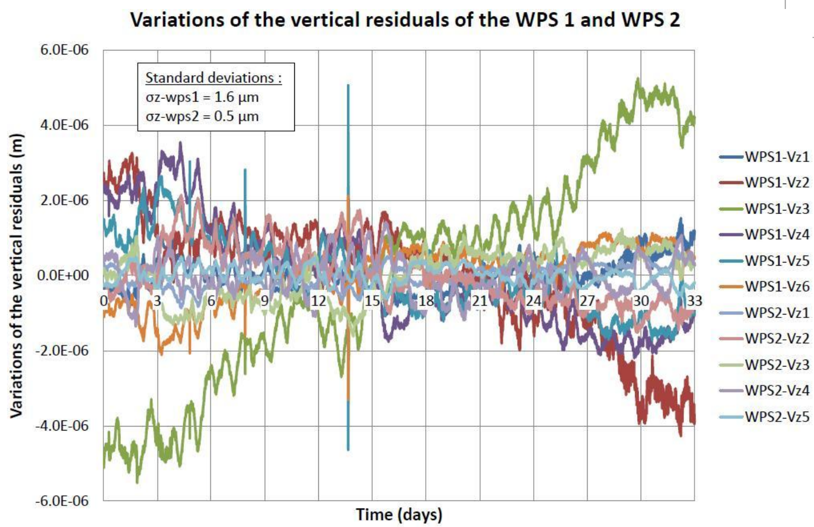


WPS vertical model

The vertical offsets of the WPS (~ ± 90 µm) can be compared with the vertical precision of the survey network (0.1 mm).

Residuals mean values >>

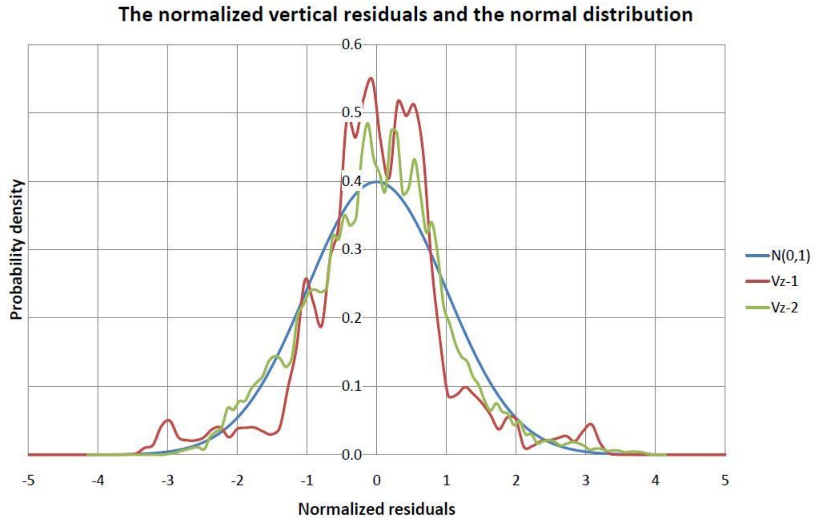




The vertical residuals of the 91m and 140m wires have excellent standard deviations : 1.6 and 0.5 µm !

<< Centered residuals

WPS vertical model



The distribution of the normalized residuals is close to the Gaussian law (successful Chi-Square test).

<< Residuals distribution

Conclusions on the TT1 stretched wires in vertical, 15 WPS, along 140 m, during 33 days :

- Precision = 1.6 µm,
- Accuracy = 0.1 mm,
- No systematic effects detected.

Conclusion

The propagation network seems to enable a micrometric precision. 2 µm of precision along 140 m has been reached in the TT1 facility during 33 days of measurements, even with huge meteorological variations.

It is a significant step in the CLIC prealignment feasibility. The next one is the accuracy. When the WPS are calibrated, it will be possible to check the reliability of the wires and hydrostatic networks. This will be particularly delicate for the HLS which require a geoide and tides models. It will be linked to the PhDs of Julien Boerez & Sébastien Guillaume.

When this new model is validated, it will possible to simulate the whole CLIC propagation network in order to study the error propagation and its effects on the beam physics.

Thanks for your attention !