# THE CLIC ALIGNMENT STUDIES: PAST, PRESENT AND FUTURE

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## 1. ABSTRACT

CERN is studying the feasibility of building a high energy e+ e- linear collider: the CLIC (Compact LInear Collider). One of the challenges of such a collider is the prealignment tolerance on the transverse positions of the linacs components which is typically ten micrometers over distances of 200m. This paper reviews all studies carried out in order to find one possible solution for active prealignment. It describes the overall solution for the alignment proposed in 2003. It then introduces the prospects for CLIC alignment future studies.

## 2. INTRODUCTION

CERN is studying the feasibility of building a high energy (0.5-5 TeV centre of mass), high luminosity ($10^{34}$ – $10^{36}$ $cm^{-2}s^{-1}$), e+ e- linear collider named CLIC (Compact LInear Collider). CLIC is based on the Two Beam Acceleration method in which the RF power for sections of the main linac is extracted form a secondary, low energy, high intensity electron beam running parallel to the main linac. Beam acceleration uses high frequency (30GHz) normal conducting structures operating at high accelerating fields (150 MV/m). For a centre-of-mass of 3 TeV and an accelerating gradient of 150 MV/m, CLIC would cover a total length of approximately 38 km. The higher CLIC RF frequency makes the scheme more sensitive to alignment errors and ground stability. The basic parameters of the machine assume levels of performance that are at the limit of what is currently possible to be feasible. For example, the prealignment tolerance on the transverse positions of the components of the CLIC linacs is typically 10μm over distances of 200m. Since normal seismic ground movement and cultural noise associated with human and industrial activity quickly creates significant errors, it is foreseen to maintain the prealignment of the components in place using an active-alignment system which will be linked to a permanent metrology and geodetic network. This paper reviews all the studies carried out in order to find one possible solution for active prealignment and describes the overall alignment solution proposed two years ago. It then introduces the future studies to be carried out.

## 3. REVIEW OF THE CLIC PAST ALIGNMENT STUDIES

### 3.1. Philosophy of these studies

Studies regarding the alignment of CLIC started 16 years ago after the physicists asked if it would be feasible to have transverse alignment tolerance regarding the accelerating sections of 10μm over the total length of one linac (at that time 15 km). The study of the CLIC active prealignment was then initiated by I. Wilson, W. Coosemans and W. Schnell. G. Fischer helped to get the work started and considerably influenced the basic design philosophy of the system. [5]

Such an active prealignment system guarantees that the first beams injected will not be too far from the design trajectory and that they will be detected by the BPM[1] in order to implement the beam based alignment system. It is foreseen that four accelerating structures and one BPM are fixed and aligned on the same girder before their installation in the tunnel. To align the components in the tunnel means aligning the girders with respect to some pre-determined accelerator axis. The quadrupoles that are independent from these girders must also be aligned with respect to this axis.

It has been decided to link the girders between themselves by means of an articulation system designed in such a way that the two girders only move angularly around their common theoretical articulation point, without relative linear displacement except longitudinally where a micrometric stop allows such a displacement. Thus, the extremities of the two adjacent girders rest in the same cradle: the extremity of the first girder being held down rigidly to the cradle, the other part being connected to the cradle by means of small link rods. The cradle is supported by three micrometric jacks (two vertical and one horizontal) by means of link rods and the micrometric stop mentioned earlier. [2]

As for the quadrupoles, these are independent from the girders; they are supported by five actuators, three of which are quasi vertical so as always be free of backlash, compressing the two horizontal actuators and push the cradle against the micrometric stop.

Two tests benches and one test facility named CTF2 have given promising results allowing conclusions to be drawn and leading to an overall proposal for the CLIC alignment two years ago.

### 3.2. First micro-movement test bench

The first test bench had been implemented in 1990 in order to study the problems associated with support and the precise positioning in space of the accelerating structures. It was composed of two girders with stuck V blocks on which cylinders representing accelerating cavities were resting. The girders were supported by nine actuators on a 2t granite table taken as a spatial reference. In order to control the performance of such a mechanical support, the displacements were controlled by two types of instruments: linear length gauges (accuracy of a micron for a measuring range of 10 mm) and two inclinometers. Micrometric actuators were incorporated in an active feedback loop to maintain the position of the girders in space when subject to external disturbances. [1]

This test facility demonstrated the feasibility of controlling submicron movement using commercially available components and confirmed the mechanical design regarding the support of the accelerating structures.

[1] BPM: Beam Position Monitor

### 3.3. Second micro-movement test bench

The second test bench was implemented to test the mechanics, the supports of the accelerating cavities and the feasibility of active alignment. This bench was composed of 6 girders, e.g. 7 cradles supported by 21 stepping motors fixed on a concrete block. It represented a model of the CLIC on a 1/1 scale. On each cradle, sensors - precursors from the WPS[2] sensor-simulated BPM. These sensors were made up of a right angle fitted with two capacitive measuring sensors, one vertical, another horizontal, and able to measure resolutions of 0.1mm. A stretched wire, simulating the beam, was taken as reference for the measurements.

There were two important improvements concerning the mechanical supports:

- The positioning of the accelerating cavities on the girders by aligning and sticking V blocks on the girders with a maximum error margin of 3 micrometers.
- In order to avoid any backlash, link rods never move into a vertical position.

The active alignment was carried out as follows: by assimilating the stretched wire to beam, and the WPS sensors to BPM, the girder was considered aligned when the stretched wire was centered inside each sensor, e.g. the value read by each sensor should be nominally equal to 0 on both axes. The stepping motors associated with each cradle were supposed to bring and keep the cradle to these reference values.

After deliberate displacements of 1mm, the system programmed for active alignment settled back to nominal positions within 1 micrometer in 3 seconds. This test bench enabled confirmation of the mechanical support of the cavities. It was also the start of the development of the WPS sensor and opened the way for the proposal of the double stretched wire method of alignment. [3] [6]

### 3.4. CLIC Test Facility 2 (CTF2)

CTF2 was built to demonstrate the feasibility of the two beams acceleration scheme. This facility was a 30 GHz two beams section composed by four identical modules. Each module consisted of two girders, supporting accelerating cavities or power generating transfer structures and BPM. The alignment system had two functions:

- To prealign the elements to produce signals in the BPM
- To maintain the elements in the reference position.

The reference for each linac was a stretched wire whose spatial position was fixed by two reference systems located at each end of the two modules. The reference systems were composed of one HLS[3] sensor surrounded by a WPS sensor put in the theoretical position by geometrical measurements from the local geodetic network. Each point of articulation of the girders and each quadrupole were equipped with a WPS sensor whose position was known with respect to the axes of the accelerator components. Like the previous facility, each girder cradle was supported by three micrometric actuators, while the quadrupoles, independent from the girders, were supported by five actuators. [8]

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[2] WPS : Wire Positioning System
[3] HLS: Hydrostatic Leveling System

The proposed alignment control command system enabled a simple and fast way of reading the sensors and consequently of moving the actuators. In closed loop, the elements on the girders and the quadrupoles were continuously maintained with respect to the wire within a ± 5μm window and operated reliably in a high radiation environment without any evidence of deterioration. [4]

The results of the measurements carried out on these different test facilities have led to the proposal of a global alignment solution.

## 4. AN OVERALL SOLUTION FOR THE ALIGNMENT OF CLIC

### 4.1. Introduction

For optimal machine stability, the linacs will be set up in a tunnel located in the most appropriate underground structure. The tunnel will be linked to the surface by shafts. The CLIC alignment can be set out according to the following steps [9]:

- The setting up and the determination of the surface geodetic network
- The transfer of reference into the tunnel
- The setting up and determination of the tunnel geodetic network.
- The absolute alignment of the elements
- The relative alignment of the elements
- The active prealignment of the elements
- The control and maintenance of the alignment

The overall solution described below will review all these stages.

### 4.2. Description of alignment stages

#### 4.2.1. The setting up and determination of a surface geodetic network

This will consist, at first, in establishing a geodetic surface network made up of pillars located close to the shafts and reinforced by pillars which guarantee good network homogeneity. The position of the pillars would then be determined by means of GPS.

#### 4.2.2. The transfer of reference into the tunnel

The transfer of reference into the tunnel through the shafts will be performed using the methods used in the previous CERN particle accelerators.

#### 4.2.3. The setting up and determination of the tunnel geodetic network

The absolute alignment of the elements calls for the installation and the determination of an underground geodetic network. This network would be composed of reference pillars installed along the whole length of the tunnel, determined with respect to the geodetic surface network, by vertical drops via the shafts, and additional measurements including wire offset measurements and pillar to pillar distance measurements.

#### 4.2.4. The absolute alignment of the elements

The concrete blocks which support the machine would be positioned starting from these pillars, as well as the metrology plates which are the framework of the metrological network. When these plates have been installed and aligned, e.g. when the metrological network has been set up, the reference pillars of the tunnel can be destroyed. The installation of the machine elements and the sensors is carried out using these metrological plates.

#### 4.2.5. The relative alignment of the elements

The relative alignment enables the installation of the sensors which will compose the primary and secondary network.

#### 4.2.6. The active prealignment of the elements

The active prealignment relies on the readings of the sensors of the primary and secondary networks. Then actuators are displaced consequently. All the cradles are then kept in an optimal position allowing the BPM to pick up the beams and enter into the beam based alignment system.

#### 4.2.7. The Control and maintenance of the alignment

At regular intervals, the positions of all the components can be read thanks to the sensors and computed. This allows the monitoring and recording of changes in the alignment of the accelerator and enables to take preventive measures if the alignment reaches a critical configuration. [5]

### 4.3. A solution for an active prealignment

#### 4.3.1. Description of the solution

The solution proposed for the active prealignment is based on the conclusions and results of the different test facilities. The mechanical supports, for example, are identical to those already tested, e.g. the girders linked to each other by articulation points. The primary metrology network is made up of two parallel lines of stretched wire over a 100m distance and overlapping in the middle of their length. The secondary metrology network is made up of redundant optical systems associated to each cradle so as to determine the articulation points of the girders. They are linked at regular intervals to the primary metrology network.

Each articulation point is equipped with optical RASNIK CCD[4] sensors supplying redundant information. They are linked to the stretched wires by means of WPS sensors which allow the prolongation of the geometry. Plates are positioned in such a way that they support four WPS sensors. Two WPS sensors are located on the ends of two adjacent wires while the other two are located at the sag of the parallel overlapping wire. These plates act also as support

[4] RASNIK CCD Sensor : Red Alignment Sensor from NIKEF. The part of the image of a coded mask, illuminated by a network of infrared diodes through a diffusor, is projected into a digital camera by means of a lens.

for the HLS sensors, associated with a two axes inclinometer, used to modelize the sag of each wire.

This optimal configuration has been proposed not only taking into account the results of the previous test facilities, but also the studies dealing with the gravity perturbations and their consequences, as well as simulations. [5]

4.3.2. The studies of gravity perturbations and their consequences

Bearing in mind the accuracy needed to be obtained, a complete study has been carried out concerning gravity disturbances and their consequences, bringing to light the following conclusions:

- The deformations of an accelerator of 38 km due to ground movements engendered by the attraction of the moon and the sun are about 6 μm, which is negligible in our case.
- Regarding the use of the WPS sensors: the non uniformity of the gravitational field and the deviation of the vertical may deform the wires significantly, but these two effects can be easily corrected.
- Regarding the use of the HLS sensors, it is known how to precisely correct the tidal effects of the moon and the sun. However, exact knowledge of the geoid is indispensable and we do not know today if it is indeed possible to determine this with accuracy. [7]
- The RASNIK CCD system is not subject to these phenomena as it is optical.
- The inclino accelerometers are subject to the same perturbations as the HLS sensors.

4.3.3. Simulations

Simulations have determined the optimal configuration of the metrology network based on the following hypotheses:

- Length of each wire : 100m
- A priori accuracy of the RASNIK CCD observations : $\sigma_{RASNIK}$=2μm
- A priori accuracy of the measurements of an horizontal offset from a wire: $\sigma_{WPS}$=5μm
- A priori accuracy of the measurements of a vertical offset from a wire $\sigma_{WPS}$=8μm
- A priori accuracy of leveling observations $\sigma_{HLS}$ =7μm

The principle of the simulations is to assign simulated values to a network of observations. The network is then determined as if it had really been measured, which allows estimation of the perturbation effects which can affect the geometry. For these simulations, the software LGC++ developed by the CERN Survey Group has been used.

The results obtained are the following:

- The configuration of the primary metrology network enables to achieve a relative alignment accuracy of ± 10 μm over 200m, both in planimetry and altimetry.

- The R.M.S. value of the misalignment of the girders articulations points is ±5µm in case of the following and best configuration: overlapping RASNIK-CCD systems combined with connections to WPS every 4 or 5 modules.

## 5. PROSPECTS FOR CLIC ALIGNMENT STUDIES

For 16 years, feasibility studies have been carried out on the CLIC alignment. Now a technical solution must be found and cost estimation made concerning the future CLIC alignment for the end of 2007. So as to reach these objectives, a complementary program has been finalized.

As indicated in paragraph 4.1., the future CLIC alignment can be divided into seven stages. The first three stages are “standard”, e.g. they are common to all particle accelerators, apart from the degree of accuracy, dependant on the machine to be built. They are however new as far as a linear accelerator of this length is concerned, but the problems and solutions are common to all future linear particle accelerators. This has led to the following proposal of study:

- Develop feedback concerning all stages of the preceding accelerators of the CERN
- Participate in different working groups existing on these subjects.

The four last stages are directly associated to sensors and actuators. The search of [**for??]** sensors is a subject common to the different projects, thereby the need to exchange on this topic with different existing working groups. However, the search of micrometric actuators, the use of the sensors and actuators, taking account of the size of the objects to be aligned and the tight alignment tolerance needed, is a care specific to CERN. The Survey Group has to manage its own studies at CERN, following two directions:

- To strengthen the solution already proposed, knowing that the simulations carried out on various sensors configurations show accuracy of 10µm. At the same time, some questions need to be answered: the use of the HLS sensors to modelize the sag of each stretched wire requires a very precise knowledge of the geoïd, which is perhaps not achievable. In the same way, only few tests have been performed on RASNIK CCD system, especially regarding the performance of the acquisition system on long distances.

- To define an alternative solution:

    - Regarding alignment systems. For example, optical sensors would not be sensitive to gravity perturbations.

    - Regarding the mechanical supports, where each girder would be independent from the others.

    - Regarding the control command system, taking into account all technological progress in that field.

These two directions explored, a choice will have to be made in order to describe and calculate the solution which suits the best to the CLIC alignment.

## 6. CONCLUSION

This solution proposed and described above is the fruit of work initiated and coordinated by Williame Coosemans for more than 16 years. The different test facilities and studies carried out have shown that it was not illusory to conceive a linac with tolerances on the transversal positions of ± 10μm over 200m. Some questions however still subsist: the solutions concerning the wire and the hydrostatic leveling system depend on the knowledge we have of the geoid and the associated pertubating phenomena, contrary to purely optical solutions. Also, few tests have been carried out concerning the RASNIK system, especially as far as the acquisition system on long distances is concerned. We hope that the studies dealing with the Survey and alignment of CLIC will soon start again in order to be able to give a valuable technical solution at the end of 2007.

## Acknowledgments

All the developments, tests, improvements, studies have been initiated and carried out by Williame Coosemans, who retired in 2003.

### References

[1] W. Coosemans, I. Wilson, P. Poirier, *Experimental approach of micropositioning problems on future linear colliders*, Proceedings of the second International Workshop on Accelerator Alignment, DESY, 1990.

[2] W. Coosemans, *Recent developments on CLIC alignment tests and concepts*, Proceedings of the third International Workshop on Accelerator Alignment, CERN, 1993.

[3] W. Coosemans, H. Mainaud, *Pre-alignment of CLIC using the double wire method*, Proceedings of the 5th International Workshop on Accelerator Alignment, Argonne National Laboratory, 1997.

[4] J-M Bouché, W. Coosemans, R. Pittin, I. Wilson, *Active alignment system for CLIC 30 GHz modules in CTF2*, CLIC Note 350, 1997

[5] F. Becker, W. Coosemans, R. Pittin, I. Wilson, *An active pre-alignment system and metrology network for CLIC*, CLIC Note 553, 2003

[6] H. Mainaud, *Une nouvelle approche métrologique: l'écartométrie biaxiale. Application à l'alignement des accélérateurs linéaires.* Ph.D. Thesis, Université Louis Pasteur.

[7] F. Becker, W. Coosemans, M. Jones, *Consequences of perturbations of the gravity field on HLS measurements*, Proceedings of the 7th International Workshop on Accelerator Alignment, Spring-8, 2002.

[8] I. Wilson, W. Wuensch, W. Coosemans, C. Achard, *The CLIC 30 GHz Two Beam Test Accelerator*, XIX International Linear Accelerator Conference, Argonne National Laboratory, 1998.

[9] R. Ruland, *Alignment Considerations for the Next Linear Collider*, Proceedings of the 4th International Workshop on Accelerator Alignment, KEK, 1995.