9th International Particle Accelerator Conference IPAC2018, Vancouver, BC, Canada JACoW Publishing
ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAF066

THE NEW CLIC MAIN LINAC INSTALLATION AND ALIGNMENT STRATEGY

H. Mainaud Durand, J-C. Gayde, J. Jaros, V. Rude, M. Sosin, A. Zemanek, CERN, Switzerland

Abstract

A complete solution was proposed for the pre-alignment of the CLIC main linac in 2012 for the Conceptual Design Report. Two recent studies provide new perspectives for such a pre-alignment. First, in a study on Particle Accelerator Components Metrology and Alignment to the Nanometre scale (PACMAN), new solutions to fiducialise and align different types of components within a micrometric accuracy on the same support were proposed and validated, using a stretched wire. Second, 5 degrees of freedom adjustment platform with plug-in motors showed a very accurate and efficient way of remotely adjusting components. By combining both, we propose a new strategy for the installation and alignment of the CLIC main linac, object of this paper.

INTRODUCTION

In 2012, we proposed in the Conceptual Design Report of the CLIC collider [1] a general strategy for the pre-alignment based on two assumptions. Considering the high number of components to be aligned, e.g. more than 4000 Main Beam Quadrupoles (MB Quad), 160 000 Accelerating structures (AS) and 40 000 Drive Beam Quadrupoles (DBQ), we proposed to pre-align several components on the same support. This allows simplifying the process of alignment later in the tunnel: we will just align the support itself and no longer the components on it, the support being equipped with alignment sensors and being supported by actuators to perform active pre-alignment [2]. The second assumption relies on high tolerance of manufacturing of the support and of the outer surface of the components to align the components on their supports [3]. It appeared that mechanical tolerances were difficult to be fulfilled (in particular the ones concerning the AS assemblies) and were very costly. Then, some question marks were raised concerning the stability of such a micrometric pre-alignment after transport on surface and underground.

Two recent developments, combined together, can solve the issues raised and provide new perspectives. First, we developed methods to determine the reference axes of accelerator components using a stretched wire, and to measure the position of the wire w.r.t. external targets by portable methods of measurements with micrometric uncertainty of measurement. Secondly, we designed a compact platform to perform micrometric adjustments according to 5 Degrees of Freedom (DoF). The first part of the paper will resume the results achieved on both developments and we will then present the new strategy for the main linac installation and alignment.

PACMAN PROJECT AND ASSOCIATED RESULTS

Introduction to the PACMAN Project

PACMAN is an acronym for a study on Particle Accelerator Components' Metrology and Alignment to the Nanometre scale [4]. The project took place from September 2013 to August 2017. It was an EU-funded Initial Training Network where 10 students were working towards a PhD thesis on new solutions for the alignment of CLIC components, in microwaves, magnetic measurements, metrology, large-scale metrology, high precision manufacturing, nanopositioning. The main objective of the project was to validate all the new methods developed on a common test bench (namely the PACMAN bench, Fig. 1) consisting of a real MB Quad, a BPM and AS in the environment of a 3D Coordinate Measuring Machine (CMM), with an uncertainty of measurement (MPEE, ISO 10360-2) of 0.3 µm + 1 ppm [5].

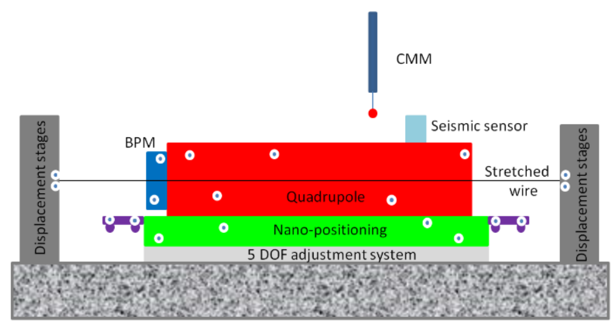

Figure 1: PACMAN bench.

Main Results Achieved

Introduction: among the significant results achieved [6], we demonstrated that the reference axis of the main CLIC components could be determined within a micrometric repeatability and an accuracy below 10 µm, using a common CuBe stretched wire (98% Copper, 2% Beryllium 0.1 mm diameter wire).

Measurement of the reference axis of AS: a new non-destructive technique has been proposed to determine the electro-magnetic center of AS cells, based on a wire stretched inside the AS. The wire disturbs the originally excited Electro-Magnetic (EM) field in one cell and the perturbation is minimum when the wire is at the center. The EM center was measured with a resolution of 1 µm and a repeatability below 5 µm (after change of wire) in a CLIC TD24 AS [7]. We can extend such a method to all cells, by increasing the number of Vector Network Analyzer ports to measure the centres of cells simultaneously.

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAF066

In that case, the wire would materialize the average EM centre of the structure [7].

Measurement of the reference axis of a 15 GHz BPM: in that case we use the same perturbation method as for the AS. The interference on the dipole eigen-mode excited by the wire is at its minimum when the wire is at the electrical centre of BPM. We demonstrated a resolution below 12 nm and a sub-micrometric repeatability [5][8].

Measurement of the reference axis of a MB Quad: the wire, stretched through the quadrupole, is fed with a sinusoidal current signal and starts to oscillate inside the magnet. The amplitude of displacement of the wire is at its minimum when the wire is located at the magnetic axis. Different corrections then have to be applied (sag of the wire, background fields, etc.) and for a given intensity of the magnet, the position of the magnetic axis is known within a sub-micrometric repeatability [5].

Determination of the position of the wire w.r.t. external targets, once the wire is located at the reference axis of the components. We demonstrated that portable means: Frequency Scanning Interferometry (FSI) (absolute distance measurements) [9] or micro-triangulation (angle measurements) could perform such a fiducialisation process. First tests carried out on the PACMAN bench showed that for targets located on the MB Quad measured by both CMM and FSI from 10 stations, the coordinates of points agreed within 2 µm [5]. The position of the wire was measured using the alignment targets located on the stretching device. We stretch the wire by a pre-tensioning system using a stepper motor. Each wire extremity lays in between two ceramic spheres with a known diameter. The determination of the wire w.r.t. the alignment targets was measured within 4 µm.

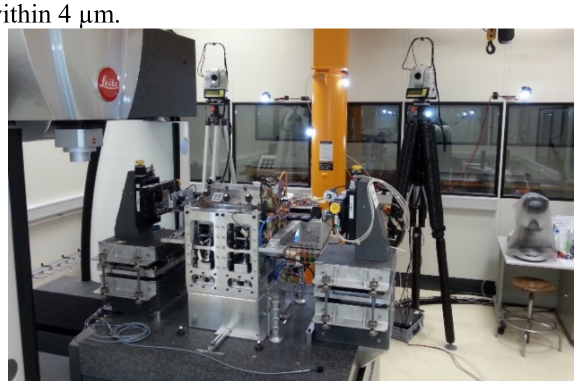

Figure 2: PACMAN bench and micro-triangulation.

The same targets on the MB Quad were also measured by four stations of micro-triangulation and crosschecked by CMM measurements. Preliminary results showed an accuracy always inferior to 20 µm, and an orientation of the wire within 40 µm/m. The stations configuration was not favourable at all (Fig. 2): as all the targets were located on top of the quadrupole, the tripods needed to be at a height of 2.3 m. For a delta of temperature of 0.4 K, this had an impact of 21 µm over cycles of 1.5 h [5].

FIVE DEGREE OF FREEDOM PLATFORM

The Initial Requirements and Results

We decided to develop such an adjustment tool, after having spent more than 1 day aligning 2 DB quadrupoles on the same girder, within 20 µm, using shims [10]. The main constraint for the design of the platform was that we had hardly any space to integrate it: less than 2 cm between the girder and the component [11]. We laid the emphasis on the access to the platform (all the adjustment knobs are located on the same accessible side), on an intuitive kinematics (the displacement on one axis has nearly no impact on the other axes), allowing micrometric adjustments over a range of at least ±1 mm.

The new platform integrates a fixed part linked to the girder and a movable part attached to the quadrupole. Two differential threads allow radial displacement of the quadrupole, while a combination of wedges and regulation screws allow three vertical displacements. In each case, flexural guides provide the backlash free and rigid regulation along the DoF concerned and flexibility for the other ones.

Towards a Plug-In Solution

Tests carried out demonstrated that the initial requirements were fulfilled: we achieved a resolution lower than 2 µm over ± 1 mm of stroke [12], and that the position of the platform is stable along time. First displacements were carried out by acting manually on the knobs. Considering the number of DB quadrupoles that will have to be aligned for a 3 TeV configuration of the CLIC accelerator, a specific plug-in solution has been developed. Using this solution, it takes less than 1 minute for an operator to plug temporarily motors on the adjustment knobs and perform the requested adjustment. The dismounting of the whole assembly is as easy as its installation.

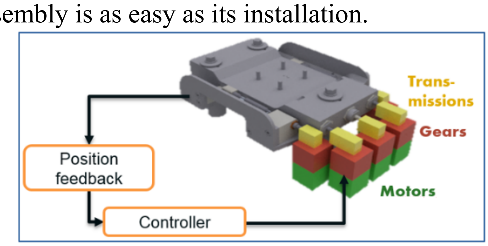

Figure 3: plug-in motors.

The position feedback (Fig. 3) can be given by different means: punctual measurements using a laser tracker to follow the difference of position of different targets during the process of readjustment, permanent measurements using alignment sensors coupled to the quadrupole or plugged just before the adjustment process to monitor the displacements carried out.

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAF066

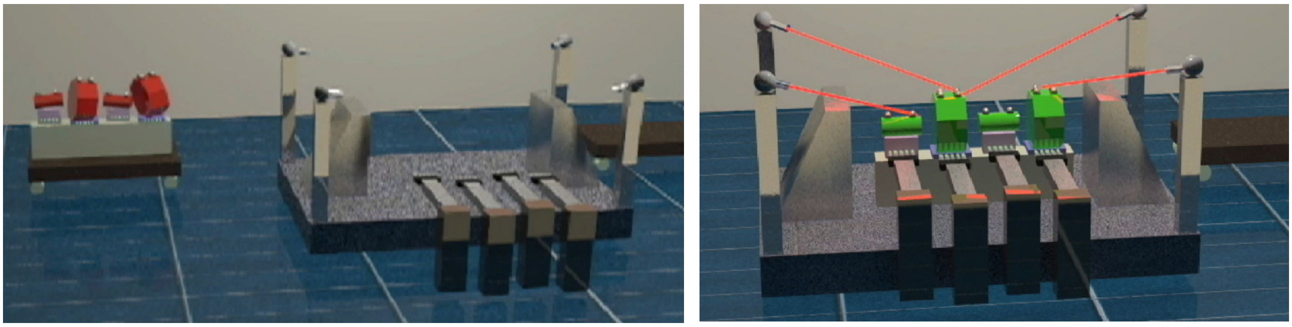

Figure 4: First alignment scenario. a) The support assembly with its misaligned components and the equipped marble with FSI. b) Adjustment of the components using plug-in motors and FSI measurements.

ALIGNMENT SCENARIOS PROPOSED

To relax manufacturing tolerances on CLIC components and gain time and accuracy, we propose two scenarios of fiducialisation and alignment of components. In the first one, we fiducialise the components and then we adjust them at a micrometric accuracy, either in lab or in the tunnel, within a few minutes, in an automatized process, while for the second one, we perform at the same time the fiducialisation and adjustment of the components on their support.

In both cases, we insert a 5 DoF adjustment platform below each component and its girder assembly.

First scenario

The first scenario consists of the following steps (Fig. 4):

- Each component is fiducialised individually using methods and techniques developed in the PACMAN project, i.e. inserting a stretched wire inside the components and measuring its position w.r.t. external targets, by either CMM or FSI measurements. In parallel, each girder assembly is fiducialised as well.
- Each component is installed roughly (within a submillimetre accuracy) on the common girder assembly.
- We transfer the girder assembly to an equipped marble with FSI and /or micro-triangulation systems.
- We determine the position of the fiducials of the components and girder assembly by FSI and/or micro-triangulation systems.
- We connect plug-in motors to all adjustable platforms.
- We adjust the components at their nominal position on their girder assembly. The new position of their targets is measured in the girder referential frame.
- The girder assembly is ready to be transferred and installed in the tunnel.

Individual fiducialisation and alignment of components on girders are steps that can be fully automatized and performed within a small duration of a few minutes. FSI and micro-triangulation are portable measurement systems: such an adjustment can be performed in either the assembly premises or underground, after transport of the support assemblies. In that case, the alignment systems will have to be integrated in rigid and easily movable structures while plug-in motors will be directly installed on the platforms between two sets of measurements.

Second Scenario

In the second scenario, the fiducialisation and adjustment of the components on their girder assembly take place at the same time and location. We roughly pre-align the components on their girder assembly, and we equip them with alignment targets. We stretch a wire through the components. We put the wire at its nominal position using displacement stages. Then, for each component, we install plug-in motors on the platform adjustment knobs, and we displace the platform until the wire is located at the reference axis of the component. Once all the components are adjusted at their nominal w.r.t. the girder, the fiducialisation can take place. The girder assembly plus its components are ready to be transferred in the tunnel.

Such a method cannot be used directly in the tunnel as it is impossible to install a wire through the components at that stage, but the first scenario can be applied using the alignment targets on the components and on the girder.

CONCLUSION

With such an association of adjustment systems and very accurate and portable measurements, the manufacturing tolerances of the assembly supports and of the outer surface of the components can be considerably reduced. This corresponds to a gain of time and cost during the manufacturing process. Such a combination allows also a very interesting flexibility as the fiducialisation and pre-alignment of the components on their assembly support can take place in the industry premises, at CERN on surface, or underground, once the components are in place, keeping the same accuracy.

We propose the first scenario in the updated baseline of CLIC, e.g. fiducialisation of the components using techniques developed in the PACMAN project, and alignment and adjustment of the components on their assembly using portable means and adjustment systems, either in the manufacturer premises or underground in the tunnel after transport.

REFERENCES

[1] A multi-TeV linear collider based on CLIC technology: CLIC Conceptual Design Report, edited by M. Aicheler, M. Draper,

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAF066

T. Garvey, P. Lebrun, K. Peach, N. Phinney, H. Schmickler, D. Schulte, CERN, 2012-007.

[2] H. Mainaud Durand, T. Touzé, "The active pre-alignment of the CLIC components", in *Proc. IWAA 2006*, Stanford, CA, USA, 26-29 Sep 2006, pp. WE006.

[3] H. Mainaud Durand *et al.*, « Alignment methods developed for the validation of the thermal and mechanical behaviour of the two beam test module for the CLIC project », in *Proc. IWAA 2014*, 13-17 October 2014, IHEP, Beijing, P.R. China, CERN-ACC-2015-0088

[4] PACMAN project website: ***http://pacman.web.cern.ch/***

[5] D. Caiazza *et al.*, "New solution for the high accuracy alignment of accelerator components", in *Phys. Rev. Accel. Beams*, vol. 20 (2017), 083501, ***DOI: 10.1103/PhysRevAccelBeams.20.083501***

[6] H. Mainaud Durand *et al.*, "Main achievements of the PACMAN project for the alignment at micrometric scale of accelerator components", in *Proc. IPAC17*, Copenhagen, Denmark, 14-19 May 2017, pp. TUPIK077, ***DOI: 10.18429/JACoW-IPAC2017-TUPIK077***

[7] N. Galindo Munoz, "Development of direct measurement techniques for the in-situ internal alignment of accelerating structures", PhD thesis, February 2018, CERN/IFIC

[8] S. Zorzetti *et al.*, "Stretched wire techniques and measurements for the alignment of a 15 GHz RF BPM for CLIC", in *Proc. IBIC15*, Melbourne, Australia, 13-17 Sep 2015, pp. TUB063, ***DOI: 10.18429/JACoW-IBIC2015-TUPB063***

[9] J-C. Gayde, S. Kamugasa, "Evaluation of Frequency Scanning Interferometry performances for survey, alignment and monitoring of physics instrumentation", presented at IPAC'18, Vancouver, Canada, Apr.-May 2018, paper WEPAF069, this conference.

[10] H. Mainaud Durand *et al.*, « Validation of the CLIC alignment strategy on short range », in *Proc. IWAA 2012*, Fermilab, Batavia, IL, USA, 10-14 Sep 2012, pp.30, CERN-ATS-2012-272.

[11]H. Mainaud Durand *et al.*, "Drive beam quadrupoles for the CLIC project: a novel method of fiducialisation and a new micrometric adjustment system", in *Proc. IWAA 2014*, 13-17 Oct 2014, IHEP, Beijing, P.R. China, CERN-ACC-2015-0083.

[12] M. Sosin *et al.*, "Design and study on a 5 degree-and-freedom adjustment platform for CLIC drive beam quadrupoles", in *Proc. IPAC'14*, Dresden, Germany, 15-20 Jun 2014, pp. TUPRI095.

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.