

STRATEGY AND VALIDATION OF FIDUCIALISATION FOR THE PRE-ALIGNMENT OF CLIC COMPONENTS

S. Griffet, A. Cherif, J. Kemppinen, H. Mainaud Durand, V. Rude, G. Sterbini, CERN, Geneva, Switzerland

Abstract

The feasibility of the high energy e^+e^- linear collider CLIC (Compact Linear Collider) is very dependent on the ability to accurately pre-align its components. There are two 20 km long Main Linacs which meet in an interaction point (IP). The Main Linacs are composed of thousands of 2 m long modules. One of the challenges is to meet very tight alignment tolerances at the level of CLIC module: for example, the magnetic centre of a Drive Beam Quad needs to be aligned within 20 μm rms with respect to a straight line. Such accuracies cannot be achieved using usual measurement devices. Thus it is necessary to work in close collaboration with the metrology lab. To test and improve many critical points, including alignment, a CLIC mock-up is being assembled at CERN.

This paper describes the application of the strategy of fiducialisation for the pre-alignment of CLIC mock-up components. It also deals with the first results obtained by performing measurements using a CMM (Coordinate Measuring Machine) to ensure the fiducialisation, using a Laser Tracker to adjust or check components' positions on a girder and finally using a Measuring Arm to perform dimensional control after assembling steps.

INTRODUCTION

One of the main challenges of CLIC is to preserve the beam emittance in the main linac and BDS (Beam Delivery System): the objective is to limit the emittance growth in the vertical plane to below 10 nm [1]. To be able to achieve this value, the zero of the hundreds of thousands of components must be pre-aligned within a few microns along a straight line over sliding windows of 200 m along the 20 km of linacs. The fiducialisation is a critical part of the pre-alignment strategy deployed to meet the requirements [2]. Fiducialisation means the measurements that link a component's reference axis to external benchmarks, called fiducials, which will allow the component's alignment. The reference axis (magnetic or mechanical) of a component or a supporting device is not always accessible or easily measured accurately after assembly.

One of the targets of the CLIC mock-up, being assembled at CERN, is to validate the strategy of fiducialisation. It is currently composed of 2 modules of 2 supporting systems where 2 m long girders are fixed to cradles and linked by articulation points. The girders support, among other components, quadrupoles (DBQ) as well as Power Extraction and Transfer Structures

(PETS) [3]. Unlike CLIC, there is no particle beam in this mock-up.

This paper presents first the strategy concerning the fiducialisation for the pre-alignment of CLIC components. Then, the requirements are revised. Finally, the first results obtained with the mock-up are presented and potential improvements are discussed.

STRATEGY OF FIDUCIALISATION FOR THE PRE-ALIGNMENT

Taking into account the size and number of the components to be aligned, it was decided to ease the problem by aligning various objects on a common supporting girder. Each girder is equipped with several V-supports to clamp the RF components (PETS) rigidly and with plane reference surfaces to pre-align DBQ. The mean axis of the V-supports is included in a cylinder with the diameter of 10 μm . The girders are equipped with position sensors and supported by actuators to enable the active pre-alignment which is needed to align the zero of each component. The role of fiducialisation is to geometrically link the zero of a component to fiducials and to sensor supporting devices materialized by 3 ceramic balls.

The objective is to use the most accurate means of measurement, the Coordinate Measuring Machine (CMM), as far as possible. However, measurements by CMM become impossible when dimensional controls on site are necessary and they lose accuracy when the object to be measured exceeds the usual measurement volume. It is for these reasons that it is necessary to find a portable and accurate means of control and to develop adapted fiducials.

The emphasis was laid on employing universal fiducials which are measurable by the largest possible number of instruments, to minimise centering errors and to measure to the nearest what is required to be determined. The girder axis, for example, is defined by measurements of a reference cylinder put on the V-supports instead of direct measurements of the V-support surfaces.

REQUIREMENTS

The requirements for the fiducialisation, presented in Table 1, are very tight; each error is applicable to vertical and transversal (both perpendicular to beam axis) axes. The 2 last errors listed in Table 1 don't differentiate fiducialisation and pre-alignment. Only values which concern the current CLIC mock-up are presented here.

The girder axis is defined by the mean axis of V-supports which are integrated to girder.

Table 1: Requirements for Fiducialisation [4]

Error of misalignment	1 σ
Error of girder axis with respect to articulation points	5 μm
Error of DBQ centre with respect to straight lines defined by wires	20 μm
Error of the PETS axis with respect to straight lines defined by wires	80-100 μm

THE CHOICE OF THE MEANS OF MEASUREMENTS

Tests to Select Means of Measurements

A bench was developed to test several instruments by measuring the same accurate object under comparable conditions. The bench is equipped with 15 fiducials of 3 different types and it was measured in the metrology lab by the most accurate CMM available at CERN. Measurement sessions of this bench have resulted in the purchase of an AT401 -the laser tracker of the last Leica generation- and a 60 cm long measuring arm Romer Multi Gage [5]. The bench offered also an opportunity to test the Micro-Triangulation, a measurement device developed in collaboration with ETHZ [6].

Improvement of the Means of Measurements

Keeping in memory the CLIC constraints and so to limit the use of magnets to hold spheres on their supports, alternative ways of measurements had to be found. A 0.5" diameter probe was manufactured to equip the measuring arm. This probe allows a measurement at one point in a holder initially provided for a ball or a reflector with a 0.5" diameter. On the same principle, the new CMM available at CERN can now be equipped with an auto-centering probe. Concerning the laser tracker AT401, studies have identified optimal parameters to obtain the best possible accuracy: warm-up time up to 2 h, measurement times up to 2 s, stationing time less than 30 min, several checking during measurements, etc.

THE FIDUCIALS

Fiducials measurable by the metrology lab, by optical devices and by measuring arm have been chosen or designed. The more a fiducial is universal, the more there is redundancy and ability to detect any faults. The location and the number of fiducials were defined in such a way that there are always enough points available to geometrically link the components using all available means of measurement, even if some targets are damaged. Thanks to all these fiducials, it is possible to check the ability of portable measurement devices to measure the misalignment between girders or adjust components on a common support.

"Traditional" Fiducials

According to the space available and the size of the objects, 1.5" or 0.5" sphere holders are glued on supporting devices and on components. Unlike the 0.5" in-house fiducials, the 1.5" sphere holders are equipped with removable magnets. Measurements can then be performed by a CMM by probing accurate balls held by the magnets whereas the 0.5" fiducials can only be measured in one point in the metrology lab. All fiducials are also measurable by a laser tracker (on spherical cone cube reflectors) and by a measuring arm.

Fiducials Dedicated to Micro-Triangulation

Due to problems of reflection on ceramic balls and disappointing results on photogrammetric targets, a fiducial dedicated to Micro-Triangulation measurements was designed and machined at CERN. It consists of two parts: the aluminium main part is equipped with an 8-mm-diameter ceramic ball and the removable drawer contains a power LED which illuminates the accurate ball.

FIDUCIALISATION IN THE CERN METROLOGY LAB

Different measuring machines by contact are available at CERN; they are presented in the Table 2.

Table 2: Characteristics of CMMs

CMM	Measurement uncertainty	Major axis stroke	Probe head
Ferranti	$\pm 3 \mu\text{m}$ (3σ)	750 mm	Renishaw PH10
Olivetti	$\pm 5 \mu\text{m}$ (3σ)	1600 mm	Idem
Leitz	$0.3 \mu\text{m} + 1\text{ppm}$ (MPEE, ISO 10360-2)	1200 mm	Leitz LSP-S4

The two first machines are located in a conditioned environment at $20^\circ\text{C} \pm 1^\circ\text{C}$. For the newest Leitz machine, a specific environment has been studied, not only with regard to air conditioning, but also in terms of location and mechanical vibration stability. To be within the uncertainties specification, the Leitz machine must be in a room where both the temperature and the humidity level are controlled. The acceptable variations are: 0.3 K/hour and 0.4 K/day as temporal gradients and 0.1 K/m as spatial gradient with a relative non-condensing humidity between 30 % RH and 80 % RH. This room has been designed and installed at CERN in an insulated metrology laboratory which is itself controlled at $20^\circ\text{C} \pm 1^\circ\text{C}$.

Fiducialisation of Supporting Systems

The cradles were measured on the Ferranti machine. Girders and in a second time cradles/girder assemblies were measured on the Olivetti machine. Due to girder length, final coordinates of points were calculated by combining the measurements in the same reference system. According to the configuration of the machine and the accessibility to the measurement places, the probe

length was increased. The associated uncertainty was then affected and estimated to be between 15 μm and 20 μm at the extremities of the girders. The machine used for these measurements is not adapted in terms of measurement volume. Market survey is underway to identify machines which are adapted to the required measurements with a large measurement volume and an uncertainty as low as possible.

Fiducialisation of Components

The two available PETS units were fiducialised by one-point measurements in the Leitz CMM (firstly part by part and secondly by unit). Controls on PETS units were also performed by Romer arm measurements during assembling steps: at the end, the offsets between CMM and arm results were within 10 μm [7]. The DBQs and its associated BPM were fiducialised by probing in the same CMM. As these 2 items are mock-ups, the fiducialised reference is only the beam tube axis. However, studies of fiducialisation of DBQ magnetic axis and electric BPM axis performed directly in a CMM are underway.

ALIGNMENT PERFORMED WITH OPTICAL DEVICES

According to realistic simulation calculations [8], the expected accuracy of AT401 measurements on a girder and its components is about 5 μm rms along each axis.

Adjustment of Articulations Points

The AT401 laser tracker allowed the adjustment of the articulation point between 2 consecutive girders on one side of the mock-up within 20 μm along each axis already before absolute data was provided by positioning sensors and tilt meters [9]. The adjustment precision is limited by the adjustment device and not by the laser tracker. On the other side of the CLIC mock-up, the laser tracker permitted to detect a machining problem of the mechanical articulation (approximately 0.12 mm vertical error) and to solve a part of it. Now the adjustment reaches 20 μm precision along the vertical axis and below 10 μm precision along the transversal axis.

Alignment of Components

The AT401 was used to align DBQs with respect to girder axes [10]. Again, the alignment accuracy is limited by mechanical devices (adjusting plates) and not by the laser tracker itself. The obtained alignment is accurate to about 20 μm along each axis. These results will be certainly improved when the new DBQ supporting plates will be available.

Micro-Triangulation Measurements

This method has clearly demonstrated its high precision capability on the 2 m long mock-up where a precision below 10 μm along each axis was obtained in the determination of the illuminated fiducials locations [11]. The nominal accuracy of the angular encoders of the theodolite could be fully exploited over a few meters with

an a posteriori standard deviation of the angular observations of 0.12 mgon concerning the angles.

CONCLUSION

Fiducialisation, included in the pre-alignment strategy, is under test on the CLIC mock-up. As far as possible, the fiducialisation is performed in the metrology lab of CERN. The most accurate CMMs available at CERN are used, but the length of the girder, 2 m, still causes problems. As a first result, the sensors fiducials could be determined at better than 15 μm in the girder coordinate system.

When the use of portable means of measurements is needed, measuring arm Multi Gage, Micro-Triangulation and laser tracker AT401 are able to control or align components within 10 μm rms along each axis.

The future emphasis on development is to fiducialise a complete module, including all components and their supporting devices, in an adapted CMM. Following this idea, a test to fiducialise the magnetic zero of a quadrupole in the Leitz CMM will be performed.

REFERENCES

- [1] D. Schulte, "Beam based alignment in the new CLIC main linac", PAC 09, Vancouver, Canada, 2009
- [2] H. Mainaud Durand and al., "Theoretical and practical feasibility demonstration of a micrometric remotely controlled pre-alignment system for the CLIC linear collider", IPAC 2011, San Sebastian, Spain, 2011
- [3] N. Gazis and al., "Fabrication and validation of the prototype supporting system for the CLIC two beam modules", IPAC 2011, San Sebastian, Spain, 2011
- [4] D. Schulte, "CLIC Two-beam Module review meetings on 15-16 September 2009. Main requirements. Beam Dynamic and the CLIC Module", CERN, edms n°1032793
- [5] S. Griffet, "Inter-comparison of measurements performed on the Micro-Triangulation bench", CERN, 2010, edms n°1155733
- [6] B. Burki and Al., "DAEDALUS: a versatile usable digital clip-on measuring system for total station", IPIN 2010, Zürich, Switzerland, 2010
- [7] S. Griffet, "Contrôle des PETS à l'aide du bras de mesure Romer Multi Gage; confrontation aux mesures CMM", CERN, 2011, edms n° 1175924
- [8] S. Griffet, "Simulations de mesures avec le laser tracker AT401 sur les poutres CLIC TM0", CERN, 2011, edms n°1157095
- [9] V. Rude, "Tests performed on two test modules in lab", CERN, 2011, edms n°1158386
- [10] S. Griffet, "Alignement des DBQ et BPM associés à l'aide du laser tracker AT401", CERN, 2011, edms n° 1171946
- [11] S. Griffet, "Inter-comparaison par des mesures sur la maquette CLIC TM0 : Micro-Triangulation et Laser Tracker AT401", CERN, 2011, edms n°1177171