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STUDY AND APPLICATION OF MICROMETRIC ALIGNMENT ON THE PROTOTYPE GIRDERS OF THE CLIC TWO-BEAM MODULE

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Abstract

The Compact Linear Collider (CLIC), currently under study at CERN, aims at the development of a Multi-TeV $e^+ e^-$ collider. The micro-precision CLIC RF-structures will have an accelerating gradient of 100 MV/m and will be mounted and aligned on specially developed supporting girders. The girder fabrication constraints are dictated by stringent physics requirements. The micrometric pre-alignment over several kilometers of girders, allow for the CLIC structures to fulfill their acceleration and collision functionality. Study of such girders and their sophisticated alignment method, is a challenging case involving dedicated mechanical design as well as prototype production and experimental testing.

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Study and application of micrometric alignment on the prototype girders of the CLIC Two-Beam Module

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Abstract. The Compact LLinear Collider (CLIC), currently under study at CERN, aims at the development of a Multi-TeV $e^+ e^-$ collider. The micro-precision CLIC RF-structures will have an accelerating gradient of 100 MV/m and will be mounted and aligned on specially developed supporting girders. The girder fabrication constraints are dictated by stringent physics requirements. The micrometric pre-alignment over several kilometers of girders, allow for the CLIC structures to fulfill their acceleration and collision functionality. Study of such girders and their sophisticated alignment method, is a challenging case involving dedicated mechanical design as well as prototype production and experimental testing.

Introduction

The CLIC study [1] is dedicated to the design of an $e^- e^+$ linear accelerator, colliding particle beams at the energy of 3 TeV with a luminosity of $2 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$. In parallel, an equally interesting design is developed at a deduced lower energy, set to 500 GeV and in the same luminosity with alternative technology (International Linear Collider) for comparison reasons. The CLIC required luminosity can be reached with powerful particle beams (14 MW each) colliding with extremely small dimensions and high beam stability. At the interaction point, the accelerated particle beams must have dimensions of 45 nm in the horizontal plane and 1 nm in the vertical plane.

CLIC relies upon a novel two-beam acceleration concept in which the Radio Frequency (RF) power is extracted from a low energy but high-intensity particle beam, called Drive Beam (DB), and transferred to a parallel high energy accelerating particle beam, called Main Beam (MB). The particle beam acceleration is achieved with high precision RF-accelerating structures, operating at 11.9942 GHz with an accelerating gradient of 100 MV/m, which are mounted and pre-aligned on specially developed supports, so-called girders. The decelerating structures of the DB are linked to the Accelerating Structures (AS) of the MB via waveguides, connecting several RF components such as choke mode flange, hybrid, high-power loads and splitters.

The two linacs are formed by Two-Beam Modules, the smallest repetitive unit of the collider, housing all the main RF components and focusing magnets (*Figure 1*). The overall length of each linac is about 21 km. A few Two-Beam Module types were defined according to the optics requirements for the MB. To fulfill them, quadrupole focusing magnets are integrated, which have high stability requirements (1 nm at above 1 Hz) and their own support.

The MB girder length depends on the module type. The focusing magnets might replace one or few pairs of AS. For example, the type 1 module is equipped with the shortest MB magnet; therefore the required girder length is roughly 1.5 m. The type 4 module does not require any MB girder, since the magnet covers the whole length of the MB module. The length of the DB girder is fixed to 1946 mm.

For the active pre-alignment of CLIC, the RF-structures must be pre-aligned within a few microns over a distance of 200 m, with respect to a straight line, so as to make the first collision happen. Such values are significantly lower compared to the tolerances achieved in other accelerators.

Figure 1: CLIC Two-Beam Module (Type 0)

Figure 2: Girder space reservation

Inter-comparison between different alignment systems for a period of more than 20 years of R&D, led to the solution which is currently under validation at CERN through real-life mock-ups. This consists of stretched wires of more than 200 m length and overlapping over half of their length, providing thus a stable and defined alignment reference for the determination of the position of components. Wire Positioning Sensors (WPS) coupled to the components to be pre-aligned, are performing measurements within few microns, with respect to these wires [2]. These measurements will then serve as the input for linear actuators, which will carry out the necessary re-adjustment of the supporting system.

Two different types of sensors are used for this pre-alignment. As the mechanical link between components to be pre-aligned has been limited to 3 degrees of freedom, capacitive Wire Positioning System sensors (cWPS) will provide the information on radial and vertical displacement, and inclinometers the tilt information with respect to the particle beam axis passing through the RF-structures. The necessary re-adjustment will be carried out by linear actuators, containing high resolution absolute encoders.

CLIC Supporting System – Girders

Girders Technical Specification. The girders form a mechanically articulated chain all along the linac, supporting and allowing for alignment of the RF-structures. Damping and isolation of the dynamic behavior of the CLIC Two-Beam Modules are additional requirements for the girders so as to maintain the micrometric alignment of the particle beam. The main requirements for the girders are summarized in *Table 1*.

Table 1: Girder Technical Requirements

Modulus of elasticity	≥ 400 GPa
Mass per girder (universal)	≤ 240 kg
Max vertical deformation in loaded condition	10 μ m

Max lateral deformation in loaded condition	10 μm
Max weight on top of the girder (distributed)	400 kg/m
Allocated Girder Space: Height (H), Width (W), Length (L), Wall Thickness (wt) *	H = 320 $\pm$ 1 mm, W = 150 $\pm$ 1 mm, L = 1946 $\pm$ 1 mm, wt = 50 $\pm$ 1 mm
Extremity cross-section interface	8 standard threaded holes $\varnothing 10$
Reference surfaces	Coloured surfaces of 2 μm flatness (<i>Figure 2</i>)
Baseline cross section shape	Rectangular, hollow

Girders Study and Fabrication. The basic guidelines of the study for the girder were the technical requirements and the preliminary weight estimation for the Two-Beam Module.

Girder material choice was decisive, along with feasibility control at this step of the study. Industrial materials (e.g. aluminum, stainless steel and others) were excluded due to the stringent girder technical specification. Alternative investigated materials (e.g. carbon fibers, metal foams) could not meet the length application for the girder. Therefore, baseline material for the Two-Beam Module girders is chosen to be silicon carbide (SiC) and alternative material, newly developed, the Epument mineral cast. Both selected baseline and alternative materials meet the technical requirements and in parallel compile optimized solutions with adequate damping behavior to possible accelerator dynamic loads (girder eigenfrequencies ≥ 50 [Hz]).

From the space reservation of the supporting system components, only the external envelope of the girder was determined in the technical specifications. Therefore, according to the fabrication methods and the available precise machining applications (for the reference surfaces), different cross-sections were investigated. Internal girder reinforcements were analyzed and simulations for different I-shaped and H-shaped girder cross-sections performed. Baseline configurations of the prototype Two-Beam Module girders were selected to be one solid and one hollow reinforced I-shaped girder. These two different configurations were determined for different reasons:

- I. Solid I-shaped girder provides stability and stiffness for the Two-Beam Module. The reference surfaces are simply obtained by high-precision machining.
- II. Hollow I-shaped girder is formed by glued standardized SiC beams. The reference surfaces machining, in this case, is achieved by pre-stressing the overall girder on its longitudinal axis.

Recently, prototype girders of the Two-Beam Module were procured and delivered at CERN in December 2010 [3]. From the prototypes, extensive alignment tests are being conducted in parallel with precision assembly methodology investigation. At the same time, the materials used for the girder fabrication are under mechanical and radiation testing for final evaluation. The series production of such a component requires experimental validation to reassure the optimized performance for the Two-Beam Module supporting system.

Sensors and Actuators

The cWPS. The WPS sensors, adopted at CERN, use the capacitive measurement technique along two perpendicular axes, to measure the distance between its mechanical axis and a stretched wire which serves as a reference. On each measurement axis, the wire goes between two electrodes. The wire is made of carbon fibres and its geometry is maintained by a sheath of woven peek (polyether-ether-cetone) filaments. It is held in tension by a frictionless pulley system and a counterweight, deployed by the survey team.

While the cWPS remains an accurate and precise type of sensor which fulfils the pre-alignment requirements, its relatively high cost and dependency on conductive wire performance, led to research and evaluation of alternative types of sensors, such as the optical ones.

Figure 3: Capacitive WPS sensors in series

Figure 4: AILSO Inclinometer working principle

The Inclinometer. The type of inclinometer mainly used in pre-alignment is the AILSO series inclinometer from ALTHEN. The working principle of this inclinometer is explained hereafter. As the inclinometer is tilted along its sensitive axis, a pendulum mass located in the inside tries to move also in the direction of tilt. This displacement is detected by position sensors in the two ends of the mass travelling path, which then produce an error signal output. This error signal is then fed to a servo amplifier coupled to the armature of a torque motor which moves the mass back to its original position. The output voltage that is created after the current passes through an ohm resistance is proportional to the sine of the tilt angle [4].

Linear Actuators. The actuators which will be used for re-adjustment of the RF-structures are manufactured from ZTS firm. They are linear actuators with a required displacement of $0.5 \mu\text{m}$ over the whole range and they use high resolution stepper motor for acquiring the necessary torque, while all movements are controlled by RENISHAW RELA absolute position sensors of 50 nm resolution along 60mm moving range [5].

After the first tests of these actuators at CERN, some minor errors appeared concerning backlash behavior and oscillations of connecting blocks, but development is still ongoing. In addition, another type of actuators is due to be installed and evaluated by mid of 2011 providing an alternative solution for re-adjustment.

Summary/conclusions

The aim of this study is the definition and fabrication of the prototype CLIC supporting system with integrated alignment equipment. Technical specifications were issued and extensive experimental program is ongoing. Such study for advanced supporting and alignment systems is very challenging and the test results will be of prime importance for further development and optimization of CLIC Two-Beam Modules.

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