

ELECTROMAGNETIC FIELD PRE-ALIGNMENT OF THE COMPACT LINEAR COLLIDER (CLIC) ACCELERATING STRUCTURE WITH HELP OF WAKEFIELD MONITOR SIGNALS

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Abstract

The CLIC project, currently under study at CERN is an electron-positron collider at 3 TeV centre-of-mass energy and luminosity of $2 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$. Achieving such luminosity requires a beam dimension of 1 nm in the vertical plane and high beam stability. The TD24 is a traveling wave structure operating at 12 GHz designed to reach 100 MV/m at constant gradient. It consists of two coupling cells and 24 disks. The RF is coupled from cell to cell through an iris of 5.5 mm. To minimize the occurrence of wake-fields and minimize the emittance growth $\Delta\epsilon_y$ below 5%, the pre-alignment precision of the electrical centre of the accelerating structure (AS) on its support has to be better than 7 μm . Following, the AS is actively aligned with beam using the wakefield monitor (WFM) signals, with a resolution of 3.5 μm . A test bench for laboratory measurements has been designed and exploits the asymmetry created by RF scattering parameters by an off-centre conductive wire, stretched to locate the electromagnetic centre of the AS. Simulations and preliminary measurement results are presented.

INTRODUCTION

The study that concerns this paper is part of a project founded by the European Commission under the name of PACMAN* [1] (Particle Accelerator Component's Metrology and Alignment in the Nanometre scale). The status of this project is presented in these proceedings [2].

The CLIC (Compact Linear Collider) [3] [4] accelerator currently under study at CERN, aims to collide electrons and positrons with vertical beam sizes of 1 nm and an emittance growth budget $\Delta\epsilon_y$ of less than 5%. To preserve the emittance at the main linac at CLIC, very tight micrometric tolerances are required concerning the position of the components focusing (Quadrupole), accelerating (Accelerating Structure, AS) and detecting (Beam Position Monitor, BPM) the beam over a distance of several hundreds of meters, all along the accelerator.

The accelerating structure TD24 shown in Figure 1 is a traveling wave structure designed for high constant gradient of 100MV/m for compact acceleration required at CLIC. It consists of two coupling cells and twenty-four accelerating cells (see Figure 2) whose iris dimensions

decrease gradually in order to compensate the energy given to the beam and ensure constant accelerating gradient. Very precise machining and nanometric tolerances are achieved and demonstrated during the fabrication process of the disks forming the structure. These disks are stacked and assembled by diffusion bonding. The full assembly and bonding process may lead to a geometric deformation of the structure whose tolerances have been established to be less than 1 μm in the case of errors of the iris shape, 5 μm for disk-to-disk misalignment, and a maximum tilt error of 140 μrad .



Figure 1: The TD24 accelerating structure.

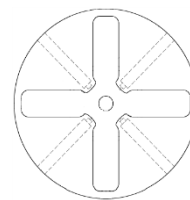


Figure 2: One of the disks of the AS.

The AS is fed in the first coupling cell with a 12 GHz radiofrequency (RF) signal that is coupled from cell to cell through an iris with a mean aperture of approximately 5.5 mm. With such small apertures, the alignment of the electrical centre of each cell in the accelerating structure with respect to the beam axis is extremely important to avoid the excitation of wake-fields. In particular transverse wake-fields might lead to beam instabilities, incoherent transverse kicks in following bunches, and an effective increase of the emittance, which results in a decrease of the luminosity of the collider.

Four waveguides with a cut-off frequency of 15 GHz are installed at the end of every cell in order to extract the high order modes (HOM) without distorting the

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accelerating mode. Each waveguide is terminated with SiC damping material to absorb the HOMs energy. The middle cell of the AS, prior to the absorber, is equipped with four bent waveguides called Wakefield Monitors (WFM), each has two RF pick-ups attached to extract the main TE and TM mode signals (18 & 24 GHz) for measuring the misalignment with beam [5] [6]. Beam dynamics simulations estimate a resolution requirement of $3.5 \mu\text{m}$ of the beam-based WFM system, in order to efficiently minimize the emittance growth along the linac. In a similar way, the minimization of the wakefield effects require a cell-to-cell alignment error below $5 \mu\text{m}$, and a positioning of the structure in its support within $7 \mu\text{m}$.

This work aims to measure these quantities in a laboratory environment, without using the particle beam, to the required level of precision:

- Find the electromagnetic mean axis of the AS and locate the external references (fiducials) on the structure with an accuracy better than $7 \mu\text{m}$.
- Demonstrate the required resolution of the WFM in a laboratory environment.
- Measure the disk-to-disk misalignment and propose a method to be applied during the assembly of the structure.

In this paper we present a stretched-wire based method, together with first preliminary measurements which promises to achieve a precise pre-alignment of the AS on its electromagnetic, i.e. dipole mode properties.

MEASURING PRINCIPLE

We use the lowest order dipole eigenmodes to detect the position of a wire inside the accelerating structure. Exciting a dipole mode in presence of a conductive wire near the centre of the iris will perturb the dipole field, in our case at 18 GHz , and hence alter the transmission between the different ports as measured by a vector network analyzer (VNA). If the wire is precisely moved to the electromagnetic center of the iris, this perturbation is minimized. The tilt of the wire is corrected through the repetition of the method in the first and in the last cell of the structure.

A model of the AS (see Figure 3) is simulated in ANSYS HFSS to find out the sensitivity of the response to the position of the wire and the expected resolution, the influence of the thickness of the wire and the response dependence to tilts.

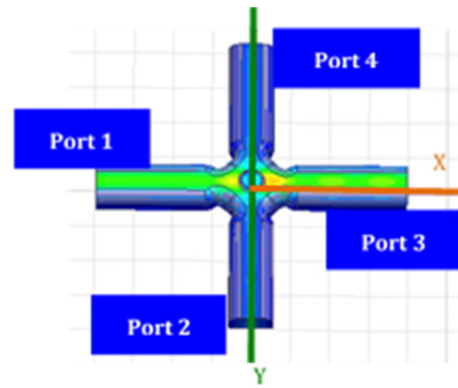


Figure 3: Dipole mode excitation at port 1 in the middle cell.

Different radii of the wire made of different materials were studied in order to select the one that best fits the resolution required for laboratory measurements. The results show, a conductive (metallic) wire is more sensitive to the perturbation created by the wire than a dielectric one; and a 0.1 mm diameter Be-Cu wire is a good compromise between sensitivity and mechanical handling of the wire as experienced by other members of the team. The mechanical and optical characterization of the wire is the subject of another PACMAN work package.

We found, the highest sensitivity to a horizontal movement of the wire is detected as magnitude difference between ports 2 and 4 while applying the RF signal to port 1, see Figure 3. This result is shown in Figure 4. As expected, a minimum of the difference $S_{21}-S_{41}$ is found when the wire is in the centre of the dipole mode. The minimum step found with simulations is $1 \mu\text{m}$ taking into account the 0.01 dB value of uncertainty expected from the VNA.

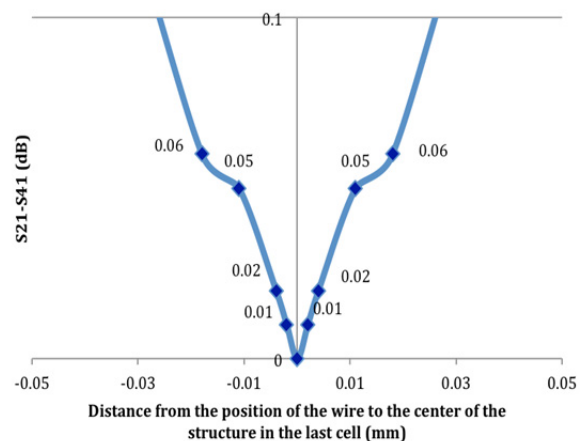


Figure 4: $S_{12}-S_{14}$ (dB) with respect of the position of the wire.

TEST BENCH

A test bench [7] shown in Figure 5 is designed for accurate positioning of the wire wrt. to the AS, to demonstrate 1 μm resolution. It consists out of:

- An active-stabilized optical table to reduce external vertical and horizontal vibrations by 85% or more (above 5 Hz), and by greater than 95% (above 10 Hz), having a flatness of ± 0.1 mm over 600 mm square, and a load capacity of 590 kg.
- A remote controlled hexapod to precisely position the AS. The hexapod offers precise movements of 0.25 μm in six degrees of freedom with a maximum load capacity of 20 kg. The repeatability and precision of the movement was carefully verified with a Leitz Coordinate Measuring Machine (CMM), having an uncertainty of $0.3 + (L/1000)$ μm .
- Two supports that host a fixed and stretched Be-Cu wire of 0.1 mm of diameter.
- A VNA with a frequency range from 10 MHz to 50 GHz.
- A PXI controller running a LabVIEW program to control the motion of the hexapod and performing automatic measurements with the VNA.

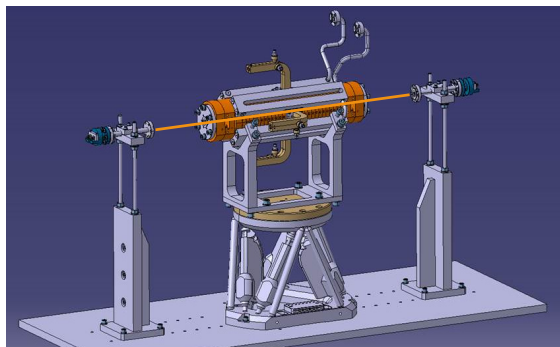


Figure 5: Test bench for accurate positioning of the wire.

FIRST RESULTS

Measurements in an existing vertical test bench without micrometric location were performed in order to validate the principle given by simulations. The bench is shown in Figure 6 and is formed by a marble table with a metal support where the AS is placed vertically. Other elements are a stepper motor with a wire support, a small weight of 0.2 kg for wire straightening using gravity, a 0,1 mm diameter Be-Cu wire, and a four-port VNA with a frequency range from 10 MHz to 24 GHz. The error of the positioning of the wire is ± 0.1 mm and the uncertainty on the VNA measurements is 0.01 dB. The RF ports are defined by the WFM, RF loads have not been installed in the cells for this initial measurement.

The position of the wire was fixed in the center of the last disk, while it was displaced along the cross section axes in the last disk. The results are plotted in Figure 7. The four traces represent four-port S-parameter measurements, with an excitation at each port, as shown in Figure 4. The differences of those traces might due to

mechanical asymmetries, e.g. internal deformation of the structure after bonding, the non-perfect assembly of the WFM, and the uncertainty of the wire position.

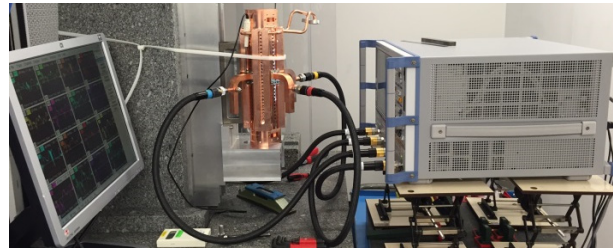


Figure 6: Vertical test bench for a proof of principle.

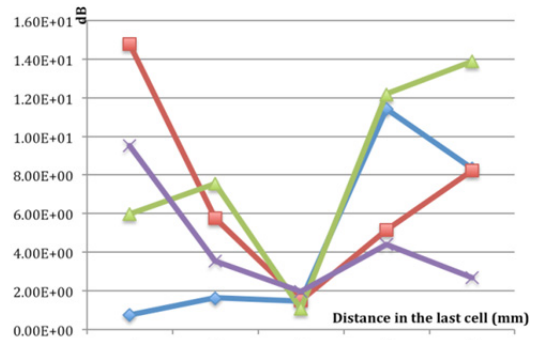


Figure 7: Transmission measurements through ports defined at WFM for different tilts of the wire measured in the last cell in absolute distance.

Figure 8 shows the difference between measurements and simulations to demonstrate the proof-of-principle. It validates a sufficient agreement on course wire displacements. For the final bench setup as shown in Figure 5, we expect results to follow the predicted shape as computed with ANSYS HFSS.

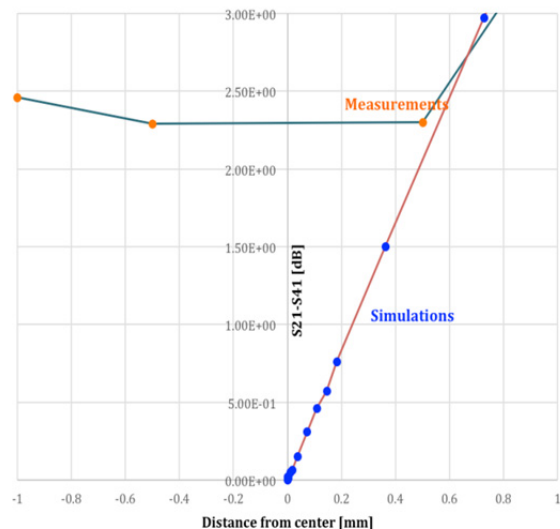


Figure 8: Measurement and simulation results for different tilts of the wire in the middle cell measured in absolute distance in the last cell.

DETAILS ON MEASUREMENT ACTIVITIES

The current activities focus on the development of the best algorithm using a LabVIEW program to perform automatized, two-dimensional measurements in a test bench with micron-accurate positioning.

Precision stretched-wire measurements utilizing the designed test bench are in preparation, and include the following aspects:

Tapered WFM WG Design to Demonstrate the Resolution of the WFM and the Requirements and Fiducialisation of the AS

The WFMs are originally designed to detect parts of the energy of the higher order modes (HOM) propagating to the absorption loads, helping to actively align the AS with the beam. However, RF measurements show considerable reflections when the WFMs were used to detect input power signals. A solution based on a tapered transition between the middle cell and the VNA (see Figure 9) is proposed to improve the signal quality, measured by the VNA. The design was optimized for the range of frequencies of interest (15-20 GHz), and shows the value of the reflection coefficient S_{11} below -40 dB, as shown in Figure 10.

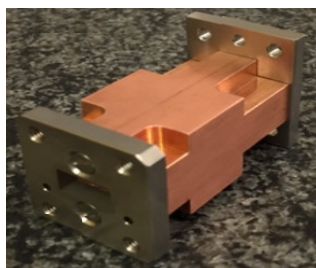


Figure 9: Middle-cell taper to standard waveguide WR-51.

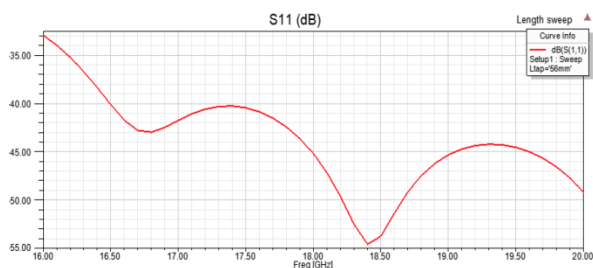


Figure 10: S_{11} (dB) for the designed taper.

Disk to Disk Misalignment Measurement

We plan to use the existing holes at the end of the damping waveguides, whose initial purpose lies on improving vacuum pumping, to host small feedthroughs as shown in Figure 11. In this way we will be able to measure the centre of the cell in a similar way as with the WFM, and establish a handle to analyze the disk-to-disk misalignment on this structure. This could be used as an intermediate acceptance tests during structure manufacturing.



Figure 11: SMA connector for a disk to disk misalignment measurement.

Use of NI-PXI Technology

The control of the hexapod movement and acquisition are currently performed via a LabVIEW software. We are investigating the possibility to extend the 4-port VNA to twelve ports using a switching network using PCI eXtensions for Instrumentation (PXI) (see Figure 12). In this way, we could correct the tilt of the wire. Ports are defined at the first cell, the WFM and the last cell of the AS. NI-PXI modules might also replace the initial VNA setup in order to perform non-linear measurements.

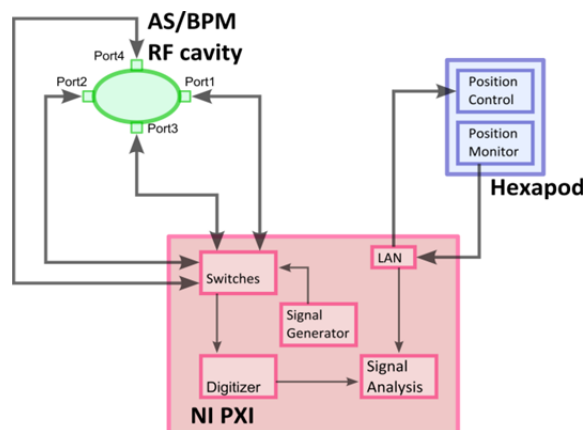


Figure 12: Flux diagram of the system.

CONCLUSIONS

Initial WFM measurements performed on a 12 GHz CLIC accelerating structure demonstrate qualitatively the feasibility of a stretched-wire method to locate the electromagnetic centre of the middle cell of the AS. Still, a long, challenging way is ahead to fiducialise the accelerating structure with an accuracy of less than 7 μm .

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