PRE-ALIGNMENT OF ACCELERATING STRUCTURES FOR COMPACT ACCELERATION AND HIGH GRADIENT USING IN-SITU RADIOFREQUENCY METHODS

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Abstract

To achieve a high accelerating gradient of 100 MV/m, the CLIC project under study at CERN uses a 23 cm long tapered normal-conducting travelling wave Accelerating Structure (AS) operating at 12 GHz. Minimisation of the long-range wakefields (WF) is assured by damping of the HOM through four radial waveguides in each cell without distorting the accelerating mode. As an extension of them, there are four bent waveguides called WF monitors (WFM) in the middle cell with two RF pick-ups. To obtain a small beam emittance in the collision point, micro-metric pre-alignment of the AS is required. We work to find the electrical centre of the AS through the use of the asymmetry in the RF scattering parameters created by an off-centre conductive wire, stretched along the axis. The accuracy required is of 7 µm with a resolution of 3.5 µm for the WFM signals including the acquisition electronics. Our simulations have shown that a resolution of 1 µm is possible using a calibrated VNA. Measurement results and improvements of the final accuracy will be presented and discussed.

INTRODUCTION

The CLIC study [1] aims to collide electron and positron beams at a centre-of-mass energy of 3 TeV with a vertical beam dimension of 1 nm at the collision point. One of the main issues is to preserve a very small beam emittance at the main linac which heavily depends on the overall alignment of the accelerator components. The PACMAN† project [2] is currently developing new methods and tools to improve the pre-alignment accuracy of the major components of the accelerator [3]: quadrupole magnets, Beam Position Monitors (BPM) and Accelerating Structures (AS).

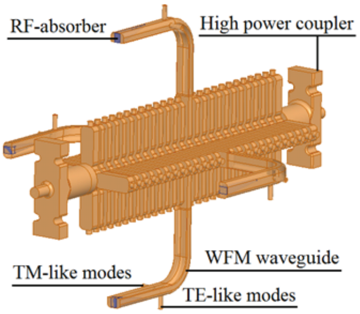

Figure 1: Accelerating Structure TD24 with wakefield monitors (WFM).

This paper concerns the development of a direct measurement technique for the in-situ internal alignment of the AS in Figure 1 [4, 5] in a laboratory environment [6]. A dedicated test bench has been developed where a stretched wire is used to materialize the electromagnetic axis in the AS and serves as a reference to fiducialise the structure in the accurate environment of a 3D Coordinate Measuring Machine (CMM). In the following sections, we will introduce the methodology used for measuring the electromagnetic centre of the structure supported by simulation work; the experimental setup; and finally the recent experimental results in the test bench.

METHODOLOGY

An eigen-mode study performed with the three-dimension full-wave electromagnetic field solver based on finite element called HFSS [7], shows that the first dipole mode present in each disk of the structure is around 18 GHz (see Fig. 2). This first dipole mode is excited with a Vector Network Analyser (VNA) though the RF pick-ups in the WFM. The port numbers and axes are defined as in Fig. 2.

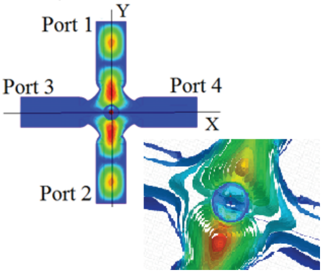

Figure 2: Dipole mode at 18 GHz in the middle disk of the AS simulated with HFSS.

We simulate a 0.1 mm diameter stretched Be-Cu wire inside the structure to perturb the electromagnetic field. The perturbation of the field changes the transmitted and reflected power signals between the RF pick-ups in terms of Scattering (S) parameters. When the wire is in the electromagnetic centre of the dipole mode, the transmission should be symmetric. Moving the wire breaks this symmetry and allows to measure the displacement by measuring the difference in transmission. The transmission between adjacent ports is most affected as the wire gets closer to one of them as seen in Figure 3.

We choose the following combination of S parameters measured in amplitude for maximum sensitivity:

- S_{41}-S_{31} (1) and S_{42}-S_{32} (2) when moving the wire

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along the X axis.

- S_{14}-S_{24} (3) and S_{13}-S_{23} (4) when the wire moves along the Y axis.

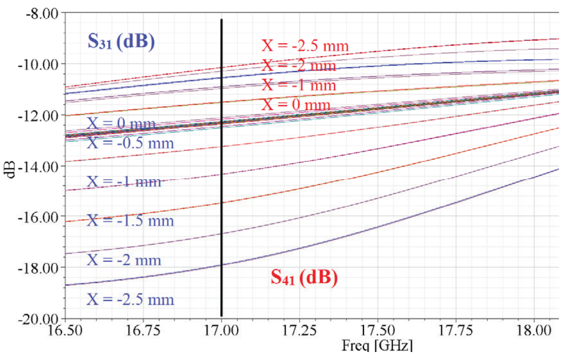

Figure 3: S parameters for different wire displacements.

We simulate alternative scans in the X and Y axes. In Figure 4 we show the results of a horizontal scan. When doing a linear fit of the simulated measurements, the straight line crosses zero at the position of the electromagnetic centre of the AS which in this ideal case is also the mechanical centre. The slope of the line will represent the sensitivity of our measurements to the displacement of the wire. From the simulations, we can expect a sensitivity of 3.2 dB/mm and a resolution of around 3 µm assuming that in the experimental measurement the resolution of the VNA is 0.01 dB without applying filtering or averaging.

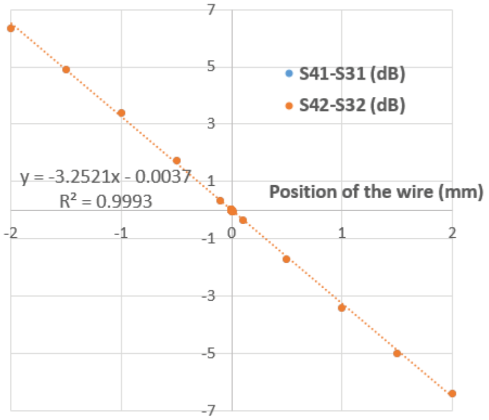

Figure 4: S parameters of interest when the wire is moving along the X axis in the AS.

EXPERIMENTAL SET-UP

We perform stretched wire measurements in a set-up[1] where the AS is vertically positioned in a position stages system with three degrees of freedom. The test bench, shown in Fig. 5, consists on the following elements:

- The wire elements. The 0.1 mm diameter Cu-Be wire is positioned with a reproducibility of 1.5 µm thanks to a wire positioning system [8] made of two ceramic spheres of 1 mm diameter currently being manufactured. Stretching tools and two fiducials are installed at the top and bottom of a square frame made of aluminium which will allow to measure the absolute position of the wire.
- Micro-mover stages. Two linear translation stages are orthogonally mounted providing horizontal and vertical displacement of the AS. We use a CMM to measure a perpendicularity between them of 13 µm over a length of 51 mm with an error of (0.3±L/1000) µm. On top of them, a metallic platform holds a rotation stage allowing AS-wire relative rotations. The stages have a high performance precision micro-movers driven by DC motors. The linear travel range of the translation stages is 100 mm having an on-axis accuracy of 4 µm in this range and, for the position readout, features and encoder with integrated linear scale providing a 0.1 µm resolution. The rotation stage has a 360 degrees motion with a high-precision rotary encoder yielding an accuracy of 0.012° in the bi-directional angular positioning, and a resolution of 0.0005°. The load capacity is 30.6 kg for each stage.
- Supporting mechanical elements. The bench is placed over a heavy rectified aluminium base platform. The aluminium case supporting the rotation stage is placed on top of the translation stages, allowing the free motion in both planes. All the system is mounted on a granite table in a temperature controlled room.
- The acquisition system is a 4-port VNA with a frequency range from 10 MHz to 50 GHz.

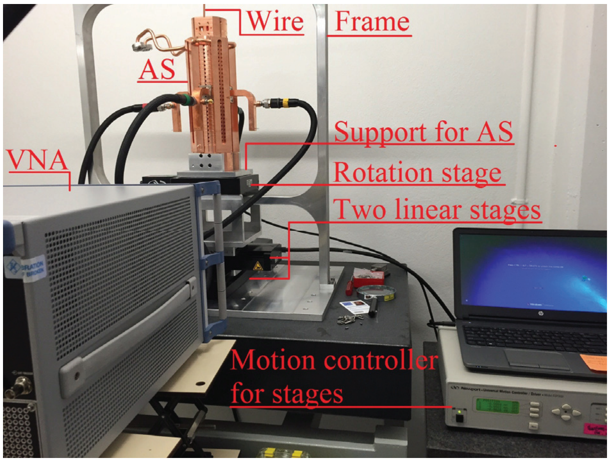

Figure 5: Experimental set-up.

The development environment LabVIEW is used to code a user platform for automatic measurements. The movement of the stages are controlled based on the acquisition from the VNA and the signal processing done by the program.

FIRST RESULTS

We first perform a frequency sweep between the cut-off frequency of the damping waveguides and a frequency

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high enough to include the first dipole mode (from around 16 GHz to 24 GHz) using the VNA. We can see in Figure 6 that around 17 GHz the variation of S parameters with the wire displacement is maximized. We choose this as our reference frequency which give us the highest sensitivity and linearity, of about 7.5 dB/mm in the X axis and 10 dB/mm in the Y axis.

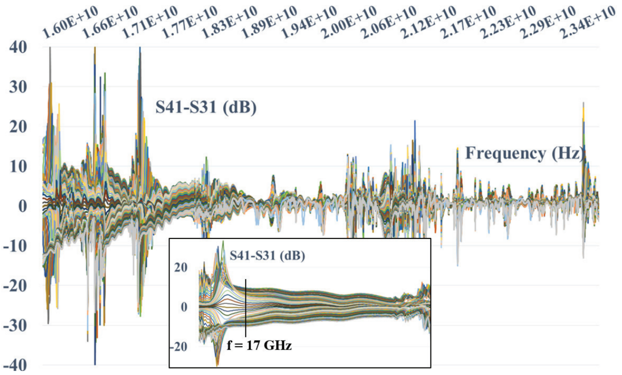

Figure 6: S_{41}-S_{31} (dB) with respect to the frequency for different positions of the wire inside the AS.

The current algorithm for the experimental measurements consists on alternative scans in the X and Y axes. Coarse AS displacements are done at first in the horizontal plane of the AS at a random vertical position while we measure the difference between the transmission coefficients from adjacent ports. In Fig. 7, we represent S_{14}-S_{24} and S_{13}-S_{23} with respect to the position of the wire in the vertical axis When we linear-fit each data series we obtain two different values for the zero crossing. We can assume this represents two independent measurements of the electronic centre. We choose for the next iteration the value for which the linear fit has a better R^2 and then iterate in the horizontal axes.

For the first two iterations in Fig.8, 61 points are measured along 6 mm to roughly locate the central area of the structure with a 100 µm resolution. Then, the step is changed to 50 µm and the range reduced for the following two iterations. For the last scans we measured 401 points along 0.4 mm with a step of one um.

Indeed, as seen, after the first interactions, the centre as measured by each port converges into a unique value. However, the difference between the horizontal and vertical plane are 5 µm and 30 µm respectively. The origin of this discrepancy can be explained by the lack of matching between the WFM and the structure. Indeed, these ports were designed to extract HOM power and not to input RF signals. This could also explain why the sensitivity is different in the horizontal and vertical plane.

New tapered transitions have been designed and manufactured with low reflection coefficient which will allow us to recover the symmetry and perform new measurements in a near future. Nevertheless, we can see that the accuracy and resolution given by the wire are in the same range as our requirements even with a non-optimal system.

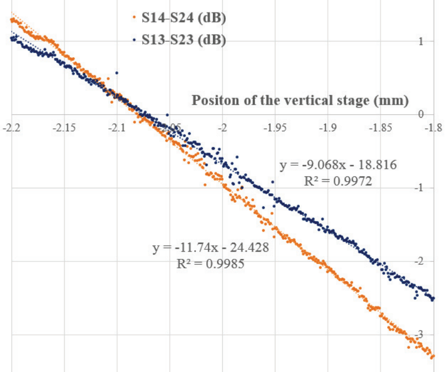

Figure 7: S parameters measured for AS displacements with in the vertical axis.

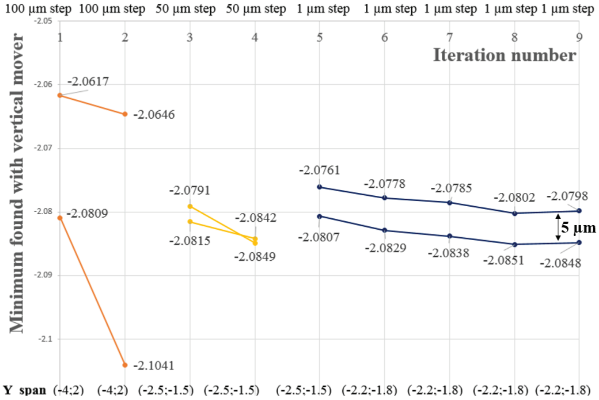

Figure 8: Perturbation minima found in the Y axis.

CONCLUSIONS

We have proven that we can locate the centre of the electromagnetic field inside the middle cell of the structure by means of a stretched wire and a network analyser. We have a sensitivity in the micron range and use two different measurements of the transmission parameters to locate the centre with very similar results. Future developments will aim to investigating the effect of the relative tilt between the structure and the wire as well as assessing reproducibility. The impact of averaging and filtering also needs to be addressed.

In order to reference the electromagnetic axis with respect to the outside fiducials of the structure we need to implement a wire positioning system which will allow to precisely located in space the wire with the help of a CMM or other metrological equipment. This system is currently under fabrication and will be implemented in the next months.

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