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WAKEFIELD MONITOR EXPERIMENTS WITH X-BAND ACCELERATING STRUCTURES

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Abstract

The accelerating structures for CLIC must be aligned with a precision of a few μm with respect to the beam trajectory in order to mitigate emittance growth due to transverse wake fields. We report on first results from wake field monitor tests in an X-band structure, with a probe beam at the CLIC Test Facility. The monitors are currently installed in the CLIC Two-Beam Module. In order to fully demonstrate the feasibility of using wakefield monitors for CLIC, the precision of the monitors must be verified using a probe beam while simultaneously filling the structure with high power rf used to drive the accelerating mode. We outline plans to perform such a demonstration in the CLIC Test Facility.

INTRODUCTION

In the Compact Linear Collider [1] (CLIC), wakefield monitors (WFMs) are indispensable for preserving the emittance in the main linac. Even with the tight mechanical alignment tolerances of 14 μm for the accelerating structures, the corresponding vertical emittance growth $\Delta\epsilon_y$ would be in the order of 200 %, which is clearly unacceptable. Therefore, the accelerating structures will be aligned to the beam with the help of wakefield monitors. To keep $\Delta\epsilon_y$ around 5 %, the alignment tolerance is 3.5 μm including systematic and random effects.

Wakefield monitors (WFMs) are used to measure the beam position based on transverse wakes from the passing bunches. In CLIC, it is foreseen to use TD26 accelerating structures in the main linac [1], which are tapered, damped travelling wave structures with a fundamental mode at 12 GHz. Each structure consists of 26 tapered cells, as well as two coupling cells. Four waveguides are connected to each cell and damp higher-order modes. For some of the accelerating structures, the waveguides of the first normal cells are extended for the WFMs. The internal geometry of such an accelerating structure is shown in Figure 1.

On the wide sides of each of these waveguides, an antenna is used to pick up a TM-like mode at 16.9 GHz [2]. In a similar way, an antenna at the short side of the waveguide picks up a TE-like mode at 27.3 GHz. Both these modes are dipole modes, where the amplitude has a linear dependency on the beam offset from the center of the structure. Since four waveguides are used around the cell, the beam offset in both transverse dimensions can be found.

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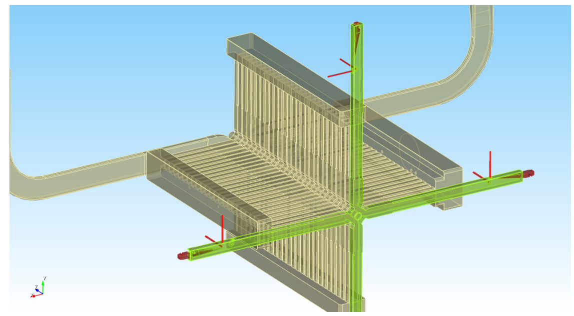

Figure 1: The internal geometry of a TD26 structure except for the first coupling cell. The WFM waveguides are shown in green and the pickup antennas in red.

The CLIC WFMs were first tested in the Two-Beam Test Stand [3, 4], which was formerly located in the same beam line as the present setup. By comparing two accelerating structures, these tests indicated a resolution of < 5μm for beam offsets of < 0.4mm.

WAKE FIELD TESTS AT THE CTF3

In the CLIC Test Facility 3 (CTF3) at CERN [5], a CLIC two-beam module (TBM) is presently installed in the Califes beamline. The CTF3 was built to demonstrate concepts and feasibilities related to CLIC, and Califes uses a probe beam representing the CLIC main beam. The TBM includes four accelerating structures, divided into two superstructures. For each superstructure, the second accelerating structure is equipped with WFMs, resulting in 8 signals for each of the two modes. The TBM also includes 2 Power Extraction and Transfer Structures (PETS), which provide about 90 MW of rf power at 12 GHz and feed the accelerating structures through a waveguide distribution network.

For each WFM signal, a bandpass filter is used to filter out unwanted modes. The signal is then read by a logarithmic detector and a digitizer. Since the time of the TBTS experiments, the mode frequencies are now different, since we now measure wakefields in the first normal cell instead of in the central cell. However, the readout electronics are still looking at the old mode frequencies, since the new bandpass filters have not yet been installed. Therefore, we measure signals at 18 ± 0.25 GHz and 24 ± 0.25 GHz instead of directly at the modes of 16.9 GHz and 27.3 GHz. Because of the low Q factors of the dipole modes, we still believe we pick up a part of the correct modes, but the signals are much weaker than they should be.

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Results

We present some first, preliminary results from the TBM, that were taken during one run using the Califes beam. No drive beam was present in the TBM at this time, therefore the accelerating structures were not powered. One upstream corrector was used to kick the beam with different offsets through the accelerating structures, and the beam position was then recorded by WFMs and downstream BPMs. Since the beam angle was <0.1 mrad and we look at the first normal cell in the structures, we consider the angular effect negligible. Only signals from the 2nd superstructure were used, since we currently do not have the required number of digitizer channels available for all 16 signals.

In Figure 2, we show two of the WFM signals for different horizontal beam offsets in the structure. These are the left waveguide signal measured at 18 GHz, and the up waveguide signal at 24 GHz, which both depend on the horizontal position. For these signals, no correlation was found with the vertical offset, as expected. The dots in the figure represent the WFM signal peaks[1]. Each of these points is averaged over 6 shots for the same position, as well as over 20 different positions spanning 1 mm in the opposite (vertical) plane. Likewise, the error bars represent the standard deviation of the distribution, and not of the means. It is possible to reduce the error bars by around 35 % by correcting for beam position jitter measured in the BPMs.

As expected, we see a V shape for the WFM signals, with the minimum representing the middle of the structure. For the two modes we get a different minimum, and the signal at 18 GHz does not go to zero in the middle. This is primarily because the mode close to 18 GHz is an asymmetric mode, and should be measured using two antennas with a 180° hybrid that is not currently installed. This will filter out the monopole component and improve the desired signal, and we will compare with measurements once the correct hardware installations are in place.

In the same way, in Figure 3 we show the two other signals coming from the same waveguides, where we scanned over vertical beam position offsets. We see the same trend as in Figure 2 for both modes. However, the curves in Figure 3 are more jagged, and based on the postprocessing we see that the corrector magnet did not change fast enough during the scan. When correcting with the beam position measured in the downstream BPM, as in Figure 4, we can however remove this effect.

In Figure 4, we again show the left WFM signals at 24 GHz, corresponding to the green points in Figure 3. Here, the single shots are plotted against the calculated beam positions in the structure, using a downstream BPM. Ideally, the result should be a straight line, but what we observe is a different line for each side of the scan. This occurs because of a disagreement between the BPM and the WFM for the center position, possibly due to misalignment.

[1] For the future we want to save the whole waveform and use the integrated pulse instead of the peak value, since this better represents the energy lost by the beam.

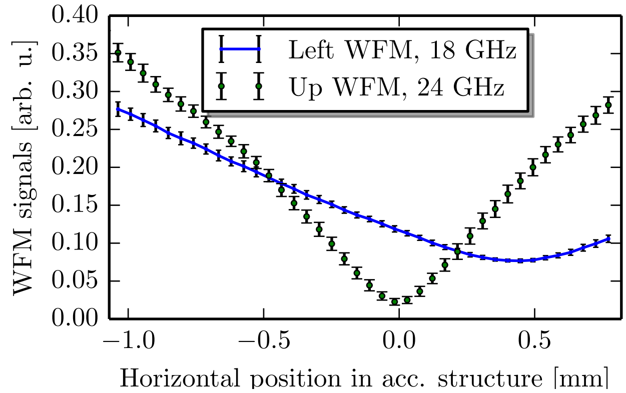

Figure 2: A scan over horizontal positions. The 'Left' signal filtered at 18 GHz and the 'Up' signal filtered at 24 GHz are shown.

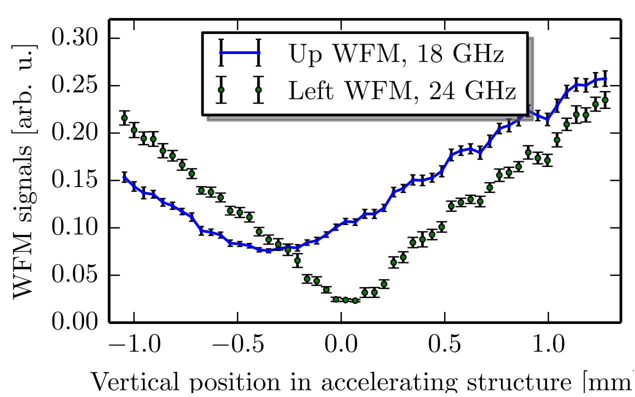

Figure 3: A scan over vertical positions. The 'Up' signal filtered at 18 GHz and the 'Left' signal filtered at 24 GHz are shown.

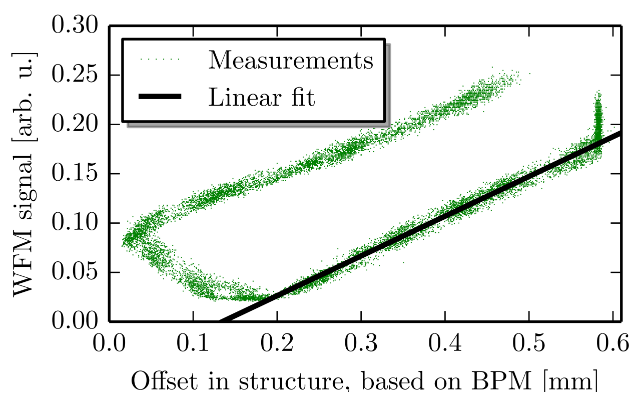

Figure 4: Left WFM signal at 24 GHz as a function of the vertical beam position (green). A linear fit was performed on a portion of the data.

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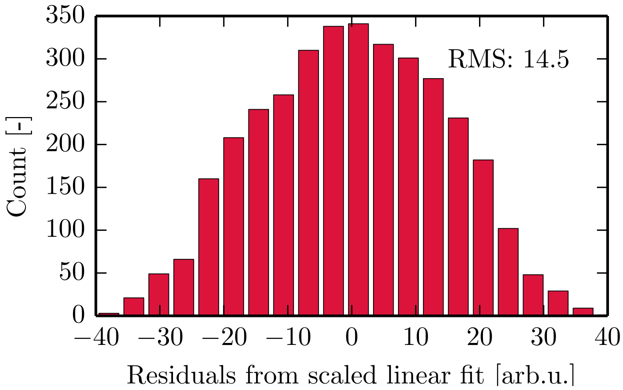

Figure 5: Residuals of the linear fit from Fig. 4, scaled so that the average WFM and BPM measurements give the same value. The RMS of the residuals of 14.5 then gives a merit for the precision.

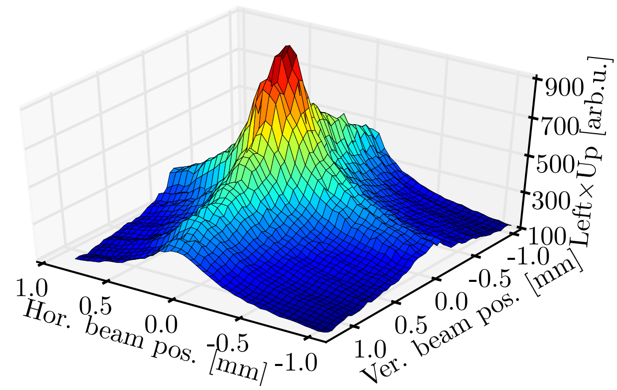

Figure 6: A scan of the WFM signals in both planes. The 'Left' and 'Up' signals at 24 GHz are multiplied, which gives a peak at the position of the center of the structure.

Using the data in Figure 4, we can perform a linear fit using a portion of the data. Since there was a saturation of the BPM electronics in the right part of the figure, we used one side of the signal from 0.20 to 0.57 mm.

From the fit we see a strong linear dependence, as expected. We can also use the residuals from the fit to get a merit for the resolution of a single WFM. To do this, we scale the WFM signals to get a 1-to-1 correspondence between average BPM and WFM signals. Then, the standard deviation of the residuals describe the resolution with which we can measure a certain beam position. The residuals are shown in Figure 5, and we get an RMS value of 14.5, which corresponds to a reading in µm. This is notably higher than the CLIC tolerance of 3.5 µm, furthermore the CLIC requirements must be achieved close to the transverse center of the structure, which is not possible with the current signal level. However, we expect a significant improvement once the proper bandpass filters are installed, since this will improve the signal-to-noise ratio. In addition, the signal in CLIC will be stronger due to a higher bunch charge.

Finally, we can perform a two-dimensional scan over positions, and use two pickups simultaneously to get a two-dimensional representation of the center of the structure. This is shown in Figure 6, where the 'left' and 'up' signals at 24 GHz are multiplied. For this plot, we used the logarithmic signals from the log detectors directly to get a sharp, positive peak.

PLANS FOR FUTURE DEVELOPMENT

We will soon have some upgrades ready for our current measurement setup, most notably the installation of bandpass filters centered at the new mode frequencies. This should improve the WFM signals and allow for a more careful analysis. Also, we aim to improve our software and use full signal waveforms for future analysis. Once these upgrades are in place, we want to investigate which of the two dipole modes that is the most suited for alignment.

A collaboration has started with colleagues at PSI, who have success with an electro-optical front-end for wakefield monitors [6]. This front-end has a good radiation hardness and negligible electromagnetic interference, and we hope to test it with the two-beam module this year.

CONCLUSION

The first results have been obtained from wakefield monitors in the two-beam module in the CTF3. The signals are close to what we expect, however some hardware improvements are necessary in order to do a careful feasibility study. Currently we obtain a resolution of 14.5 µm by scaling the wakefield monitor signals to a downstream BPM, however, we expect the resolution to be ameliorated in the future, when measured in an improved test setup.

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