STATUS OF WAKEFIELD MONITOR EXPERIMENTS AT THE CLIC TEST FACILITY

R. L. Lillestol*, E. Adli, J. Pfingstner, University of Oslo, Oslo, Norway
W. Farabolini, S. Doebert, R. Corsini, W. Wuensch, A. Grudiev, CERN, Geneva, Switzerland
N. Aftab, S. Javeed, Pakistan Institute of Nuclear Science and Technology, Islamabad, Pakistan

Abstract

For the very low emittance beams in CLIC, it is vital to mitigate emittance growth which leads to reduced luminosity in the detectors. One factor that leads to emittance growth is transverse wakefields in the accelerating structures. In order to combat this the structures must be aligned with a precision of a few µm. For achieving this tolerance, accelerating structures are equipped with wakefield monitors that measure higher-order dipole modes excited by the beam when offset from the structure axis. We report on such measurements, performed using prototype CLIC accelerating structures which are part of the module installed in the CLIC Test Facility 3 (CTF3) at CERN. Measurements with and without the drive beam that feeds rf power to the structures are compared. Improvements to the experimental setup are discussed, and finally remaining measurements that should be performed before the completion of the program are summarized.

INTRODUCTION

CLIC is a proposed multi-TeV e^+e^- collider, where the acceleration energy is provided by a high-current, low-energy electron drive beam [1]. The CLIC beams will have very small emittances in order to provide sufficient luminosity to the experiments. One factor that can lead to emittance growth along the machine is transverse wakes in the accelerating structures. Therefore the structures must be aligned with a precision of 3.5 µm, including systematic and random effects.

Wakefield monitors (WFMs) will be used for measuring the beam position in the tapered and damped accelerating structures. In the current design, two structures are combined as a superstructure, and the WFMs measure the beam position in the first normal cell of the second structure, after the coupling cell. In this cell, the four damping waveguides have two antennae each, that are able to measure two different dipole modes. From simulations we expect a TM-like mode at around 16.9 GHz and a TE-like mode at around 27.3 GHz [2]. However, the bunch train length influences the wakefield frequencies, as shown in measurements in this paper.

The tests of the WFMs are performed in the CLIC Test Facility 3 at CERN [3], which was set up to demonstrate the feasibility of key concepts of the CLIC scheme. Here, the Califes beamline provides an electron beam that emulates the CLIC main beam. This beam is sent together with the CTF3 drive beam to a prototype CLIC module. An earlier design of the CLIC WFMs was tested in the Two-Beam Test Stand experiment [4], and the present setup was first commissioned in 2015 [5].

* reidar.lunde.lillestol@cern.ch

EXPERIMENTAL SETUP

The prototype CLIC module in the CTF3 has two superstructures, each with one set of WFM pickups. Each set of pickups has two antennae for the TM-like mode and two antennae for the TE-like mode in each plane. Hence there are altogether 16 signals for both superstructures. Most of the time the signals have been measured using logarithmic detectors, due to the large dynamic range. However, due to only having 8 detector channels available, not all signals can be measured simultaneously. Recently, we have looked at other detector possibilities, including downmixing the signals with a local oscillator. We can currently measure a maximum of two downmixed signals simultaneously, due to the number of filters and splitters available.

When operating the module in 2015 with the drive beam present, we observed a large amount of noise in the WFM signals, that was sometimes stronger than the signal amplitude. The amount of noise was found to increase with the drive beam current. After this observation the superstructures were carefully grounded, and high performance cables were used for some of the signals. This reduced the noise level significantly, and now we can not see significant noise coming from the drive beam, as shown in Fig. 1. Some log detector signals still have some noise that is likely coming from the Califes klystron, and work is ongoing to eliminate this. For the downmixed signal we cannot observe any effect of noise at all, and have zero signals when only the drive beam is used.

SPECTRAL ANALYSIS OF SIGNALS

For the future CLIC machine we want to investigate the best possible operating conditions of the wake field monitors, and one aspect is the choice of the WFM operating frequency. It is of interest to study the signal level at various frequencies, but we do not have instrumentation for measuring spectra in the K and K_a bands. Therefore we have scanned in frequency using what will be called *downmix scans*. This method

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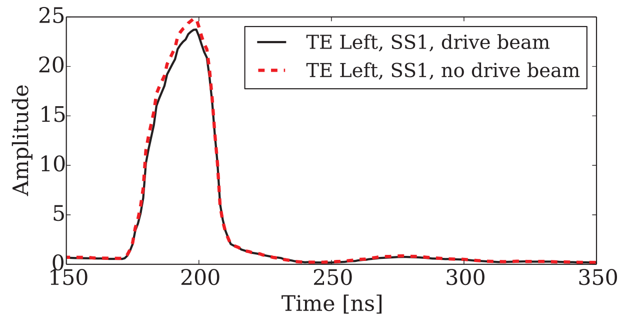

Figure 1: One WFM signal of the TE-like mode, averaged over 200 pulses with and without drive beam.

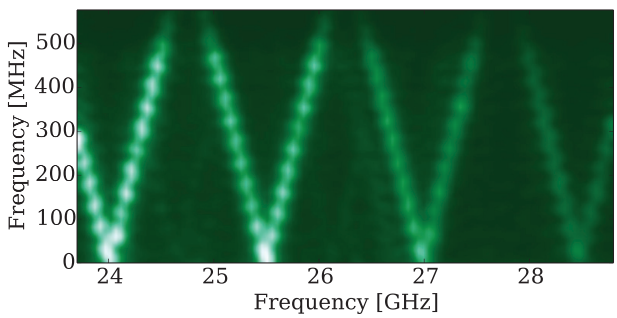

Figure 2: Downmix scan image, for the pickup of the TE-like mode with a beam of 40 bunches.

has also been used on various signals for finding noise sources.

Consider a mode in the accelerating structure with central frequency f_0, that is picked up by the WFM antenna. By mixing the WFM signal with a local oscillator frequency $f_0 + \delta_f$, we are left with a downmixed sinusoidal signal peaked at δ_f in the frequency domain. By changing the local oscillator frequency, the spectral peak will move in one direction depending on the change of frequency.

This can be exploited to find the spectrum of the signal that is picked up, by scanning through a whole range of local oscillator frequencies and computing the discrete Fourier transform of the WFM signal at each step. This gives us a 2D matrix of frequencies, that can be shown as an image as in Fig. 2. In the experimental setup it is important to lowpass filter the downmixed signal, in order to avoid aliasing from other parts of the spectrum.

The simplest form of analysis of the scan is to focus on a single Fourier transform frequency near the base band, and use this along the scan range to find the spectrum of the signal. However, this can have a significant amount of noise, and we therefore do a more careful analysis. By looking at Fig. 2, we see that we get 'V' shapes as the spectral peak changes position. These will always have the same angle, due to the relation between the two axes that are both frequencies. We can therefore create a set of image masks, each with two lines forming a 'V' with different positions. By

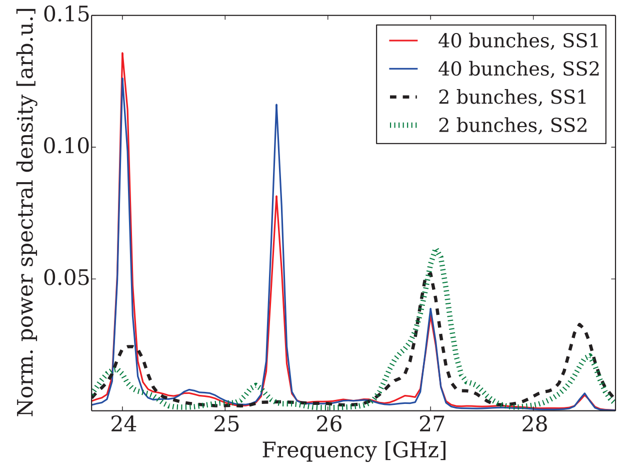

Figure 3: Spectra of the signal for the TE-like mode, which can be compared to Fig. 2. The spectra with beams of 40 bunches and 2 bunches are shown for both superstructures.

multiplying and averaging an image like Fig 2 with all the image masks, we are left with a spectrum with less noise.

Some results of this technique are shown in Fig. 3. Firstly, the blue and red lines show the spectra for the pickup of the TE-like mode for a large number of bunches, which is the most common operating mode in Califes. Here we see sharp peaks at harmonics of the bunch frequency at 1.5 GHz, for both superstructures in the prototype module. However, using only two bunches, we have a different spectrum that more closely resembles the single-bunch spectrum seen in simulations, with a broadband peak slightly above 27 GHz [2]. In CLIC, one should choose a frequency that it useful for the number of bunches used during machine tuning.

The three largest multi-bunch peaks in Fig. 3 have been studied at different beam positions, and all modes depend on the beam position. At the pickups for the TM-like mode, we have similar observations as for the TE-like mode. We have not been able to measure 1–2 bunches with the TM-like mode, but for tens of bunches we see peaks at 15.0, 16.5, 18.0 and 19.5 GHz that each depends on the beam position.

WFM RESOLUTION ESTIMATES

As mentioned earlier, the required WFM resolution in CLIC is 3.5 μm in order to avoid severe emittance growth along the machine, and this needs to be achieved in the presence of a drive beam. In this section we will discuss results with and without drive beam present.

When measuring WFM signals, the beam steering and focusing are generally set up before the module, and quadrupoles and correctors near the module are turned off. By that we can compare signals from several devices without complication from kicks. Firstly, a simple estimation of resolution can be done by com-

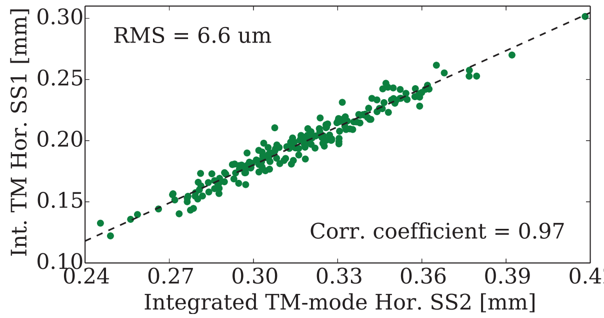

Figure 4: Correlation of WFM signals between superstructures, which can be used as a simple estimation of resolution.

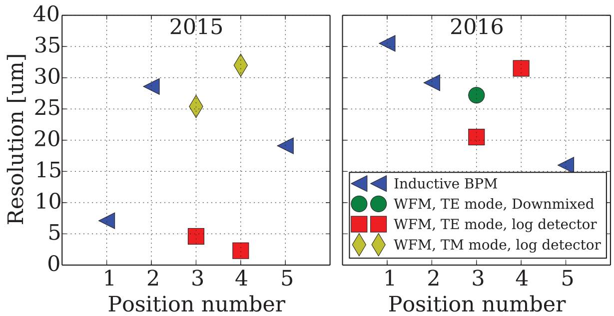

Figure 5: Resolution estimates of several devices after performing an SVD analysis on 200 bunch trains, for data from 2015 (no drive beam) and 2016 (drive beam). The worse resolutions from 2016 are also measured when the drive beam is not used, and the reason is likely something else that must be investigated.

paring measured positions to the ones expected. We will first discuss data from the end of 2015 with only the Califes beam (i.e., no drive beam), where the beam was kept still for 200 pulses near the centre of the structure. The estimated positions in two superstructures, as measured by WFMs, were compared and are shown in Fig. 4. The deviation from a linear fit was here 6.6 μm for the horizontal TM-like mode. The TE-like mode had a higher spread at 15.1 μm, and all vertical signals had a spread of around 20 μm due to more jitter in that plane.

A more detailed analysis can be performed by using a model-independent analysis using singular value decomposition [6] (SVD). All horizontal WFM signals were analyzed together with nearby BPMs, and the first two singular values were omitted since their eigenvectors represent long-term drifts of the machine. The results of all signals are summarized to the left in Fig. 5. Surprisingly, here we see very low resolutions for the TE-like mode signals of 4.6 and 2.3 μm for the first and second superstructure, respectively. The TM-like mode here shows resolutions around 30 μm, and are in fact not well correlated with some of the other signals.

There was a short run in 2016 that included the drive beam in addition to the Califes beam, and an SVD analysis is shown to the right in Fig. 5. We again excluded the first two singular values. The estimated resolutions are here worse at 20–30 μm for the WFMs. For this run we had started to use a downmixed signal, however the TM signals had to be left out since they peaked as 'bad BPMs' during the SVD analysis, driving a mode of their own. It should be mentioned that the higher resolutions have been measured for all the data sets taken in 2016, where most were taken without drive beam. There has generally been a large amount of jitter in 2016, with peak-to-peak jitter of 0.5 mm or more around the module. The worse resolution estimates are therefore believed to originate from another source than the drive beam, and further work is needed. Finally, it is important to mention that the sample size of 200 pulses for each of the data sets is considered low in model-independent analyses, where usually thousands of pulses are used.

CONCLUSION

The Califes beamline has been used to study signals in wakefield monitors. A frequency scan of downmixed signals was used to find the WFM spectra, and for long bunch trains we find harmonics of the bunch frequency rather than the simulated single-bunch impedance. Some estimations of resolution were given, where the best was 2.7 μm without the presence of a drive beam. Recently 20 μm was measured with the drive beam, however such estimates are seen both with and without drive beam, and the worse results are therefore believed to have another reason. The statistics are quite low in the resolution estimates and more data are required for a complete analysis.

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