BEAM-BASED MEASUREMENTS OF LONG RANGE TRANSVERSE WAKEFIELDS IN CLIC MAIN LINAC ACCELERATING STRUCTURE

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Abstract

The baseline design of CLIC (Compact Linear Collider) uses X-band accelerating structures in the main linacs. Every accelerating structure cell has four waveguides, terminated with individual RF loads, to damp the unwanted long-range transverse wakefields in order to maintain beam stability in multi-bunch operation. In order to experimentally verify the calculated suppression of wakefields, a prototype structure has been built and installed in FACET test facility at SLAC. The results of the measurements of the wakefields in the prototype structure, by means of positron and electron bunches, are presented.

INTRODUCTION

The main linac of the Compact Linear Collider (CLIC) uses X-band normal conducting structures operating at an accelerating gradient of 100MV/m [1]. In order to increase luminosity and minimize power consumption, multiple bunch trains are accelerated in each RF pulse. The multi-bunch trains however introduce a demanding beam stability issue because transverse misalignments between the beam and the rf structures result in the excitation of long-range transverse wakefields, which kick transversely the following bunches. Beam dynamics calculations indicate that a transverse wakefield kick of a bunch on the following bunch must be suppressed to less than 6.6 V/pC/m/mm, in order to maintain the beam stability in the main linac [2].

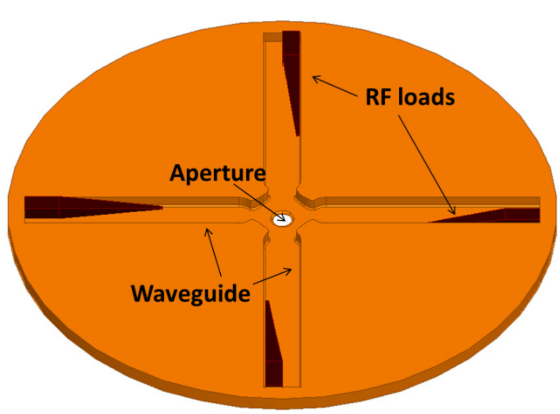

Figure 1: Geometry of single CLIC-G cell.

Figure 1 shows geometry of one CLIC accelerating structure disk. This geometry was well designed for both the high power performance and the wakefield suppression [3]. Given the availability of both electron and positron bunches simultaneously, the time-domain long-range wakefields of X-band structure could be measured at the FACET facility in SLAC National Accelerator Laboratory [4]. Figure 2 shows the measurement setup: NRTL (North -Ring-To-Linac) and SRTL (South-Ring-To-Linac) are independent beam lines and provide relativistic electron and positron bunches respectively. Both beam lines merge at LINAC02, where the test structure is located. The positron beam (drive bunch) was set to travel the test structure with a transverse offset to excite a transverse wakefield; the following electron bunch (witness bunch) is deflected by this wakefield.

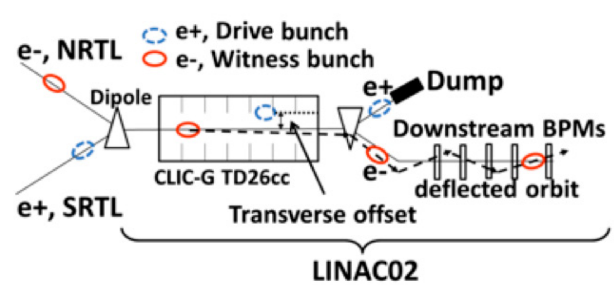

Figure 2: Layout of the experiment.

Downstream of the structure a dipole magnet splits the trajectories of the witness and drive bunches: the positron bunch is dumped, and the wakefield is inferred from the deflection of the electron orbit as measured by the downstream beam positron monitors (BPMs). Similar experiments have previously been performed at the FACET facility [5-7] and at the AWA facility in Argonne National Laboratory [8].

A dedicated prototype structure was built to carry out this experiment. The geometry of such prototype was the one of the CLIC 3 TeV baseline accelerating structure: the so-called CLIC-G TD26cc design, which contains 26 regular cells and compact input and output power couplers [3]. The structure cells were made of aluminium disks clamping together with long bolts. This simplified construction is acceptable for this experiment since the loaded Q of the dipole mode is very low, of the order of 10. The damping waveguides were terminated by silicon

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carbide RF loads, assembled in groups in a comb-like structure. The total length of the structure was 1.6 m, which corresponds to six identical structure units. Such total length was chosen to give a wakefield strong enough to be resolved in the FACET facility even after the two orders of magnitude suppression expected.

EXPERIMENT SETUP

In the measurement, the positron bunch is excited to travel in the structure with a chosen transverse offset in order to induce a dipolar transverse wakefield. The offset of the positron bunch was controlled using orbit bumps excited by correctors in the SRTL line, and then measured using BPMs. During the measurement the BPMs preceding the structure are excited by both the electron and the positron bunches and cannot be used when both beams are present, because the two opposite signals cancel each other. The effect of the upstream correctors on the orbit must be pre-calibrated before introducing both beams. This was done using tools previously developed for the Beam-Based Alignment (BBA) experiment described in [9] to accurately measure the response matrix R_{12}^{+}containing the response of the positron BPMs to the upstream correctors. The strength of the correctors needed to give a desired transverse offset can be calculated from this trajectory response matrix.

In order to measure the long-range transverse wakefield with a fine time resolution and to reconstruct the wakefield spectrum up to 50GHz, a control and knowledge of the longitudinal spacing between the electron and positron bunches at the level of 3mm was needed. In the FACET facility, one can change the positrons "kick-out" RF bucket and the synchronized RF phase in the SRTL to control this relative spacing, while the timing of the electron bunch is left unchanged. The "kick-out" RF bucket determines the timing of the positron delivery into the linac in steps of S-band periods, i.e. 350ps, providing the coarse timing control. A finer, continuous timing control within an S-band period is achieved by varying the synchronous phase. The RF phase control system has been measured to be very stable pulse to pulse at sub pico-second level [5].

The transverse wakefield is calculated from the measured offsets of the electron bunch in the downstream BPMs according to Eq. (1). In the formulaQ_p is the positron charge (~3nC), E_e is the kinetic energy of the electron bunch in the structure (~1.19GeV); and L is the total active length of the structure under test (1.38m). $\Delta y_p$is the transverse offset of the driving positron bunch and Δy_e is the measured deflection of the electron beam in the downstream BPMs. R_{12}^{-} is the response matrix of the BPMs to a transverse kick:

$$\Delta y_e = \Delta y_p \frac{R_{12}^{-}}{E_e} Q_p L W_{\perp}(s), \qquad (1)$$

$W_{\perp}$is the unknown wakefield expressed in units of length. The absolute value of transverse wakefield relies on knowing all variables in Eq. (1) before measuring the wakefield. The termR_{12}^{-}represents the response of the downstream electron BPMs to a kick located in the middle of the structure. However, since there were no correctors in the centre of the structure, $R_{12}^{-}$was not directly measurable. We computed such response by interpolation, sampling the orbit response to the upstream correctors (see Figure 3) and inferring the response to a hypothetical kicker located in the centre of the structure from the downstream BPMs. The nearest upstream and downstream BPMs were used to calibrate the virtual kick. Two quadrupoles were located very close to the BPMs (5cm), however this distance is far smaller than the distance of two BPMs, 3m, and thus the effect of quadrupoles could be neglected. In the downstream beam line, 26 BPMs were used to measure the deflected electron bunch orbit (so-called "calibration orbit"). Thus,$R_{12}^{-}$of all 26 downstream BPMs were measured. The slope of linear fit on BPM readings and corresponding R_{12}^{-} gives the value of kick referenced to the centre of the structure.

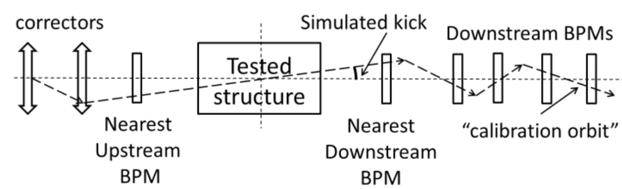

Figure 3: R_{12}^{-}measurements by simulating the wake kick using upstream correctors.

Dispersion Free Steering (DFS) was applied to the entire beamline, in order to reduce the effects of energy jitter on the electron bunch orbit through residual dispersion. The dispersion correction is performed using the technique described in [10] i.e., by adjusting the strength of the correctors to cancel any dispersive effects due to misaligned magnets. Since the positron beam is equivalent to an electron beam with negative energy, which effectively gives a very large dispersion, measuring the positron bunch orbit in the tested area improved the precision of calculated electron dispersion. The dispersion in the downstream part of LINAC02 was measured by changing the klystron phase. Almost all correctors in LINAC02 were used for dispersion correction. A measure of the dispersion after correction, showed that the dispersion in the downstream part of LINAC02 was reduced by 2/3 after DFS.

With the preliminary calibration of the orbits completed, the measurement of the long range transverse wakefield could be done. These measurements took two night shifts. The vertical transverse wakefield was sampled at 252 different bunch distances. For each spacing several transverse offsets of positron were used, ranging from -1.2mm to +1.2mm in steps of 0.4mm or 0.6mm. The electron orbit was measured, average over 100 pulses, in order to reduce the noise due to fast jitters and gain in resolution. Since the positron bunch charge could not be measured when the electron bunch was present, the electron bunch was switched off periodically to check the positron charge using the BPMs. This measurement, in agreement with a FACET monitor displaying the charge profile, showed that the positron charge varied by less than 5%; this was within the acceptable level for our kick reconstruction.

RESULTS

Figure 4 shows the final plots of measured time-depended transverse wakefield on two different timescales. The measured values are also compared with Gdfidl simulations of the same geometry, using positron and electron bunch lengths equal to the experimental ones. The wakefield was measured at such high resolution that the error bars are barely visible in the plots (but they are displayed). A resolution of 0.1~3 V/pC/m/mm was achieved. At the CLIC bunch spacing of 0.15m, the measured transverse wakefield kick is 5 V/pC/m/mm and meets the requirement determined by beam dynamics. The wakefield continues to fall rapidly and at larger numbers of bunch separations the wakefield potential drops to the range of 0.01~0.1 V/pC/m/mm, which corresponds to the resolution limit of the measurement. The agreement between the measured wakefield and simulated one seems excellent. It verifies that the design of CLIC-G accelerating structure fit the requirement of long-range wakefield suppression.

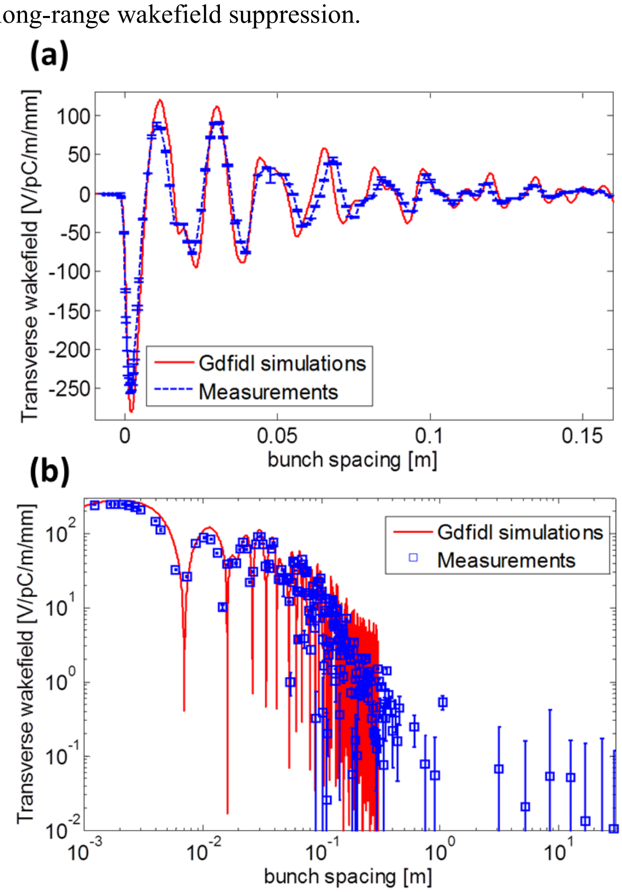

Figure 4: Measured time-depended wakefield: (a) partial data (linear scale); (b) full data (log scale).

CONCLUSIONS

The long-range transverse wakefield in CLIC accelerating structure was directly measured using beam-based techniques at the FACET facility with an unprecedented resolution of0.1~3 V/pC/m/mm. The conclusions are:

(1) An excellent agreement between the measured and simulated wake was demonstrated, increasing the trust in simulation codes;

(2) The wakefield suppression of the CLIC structure design was shown to meet beam dynamics specifications. This addressed a potential feasibility issue for the CLIC project.

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