MEASUREMENT OF BEAM POSITION USING HIGHLY-DAMPED ACCELERATING STRUCTURES

J. Prochnow, RWTH Aachen, Germany / CERN, Geneva, Switzerland
E. Jensen, W. Wuensch, CERN

Abstract

Active alignment algorithms for linear colliders such as the Compact LInear Collider (CLIC), require measurements of beam positions inside accelerating structures in order to control short and long-range transverse wakefields. Highly-damped accelerating structures offer the possibility that damping waveguides can provide position signals so the accelerating structure itself can be used to make these position measurements. A demonstration of beam position measurement using a 3 GHz slotted iris structure with a dipole mode Q≈16 was made in CTF II (CLIC Test Facility) and results are compared to computations using HFSS and GdfidL.

INTRODUCTION

The development of multi-bunch accelerating structure for the CLIC main linac is driven to a large extent by strict constraints placed on the long- and short-range wakefields. Beam dynamics simulations have shown that to minimise emittance blow-up along the linac, the amplitude of the transverse wakefield must decrease by two orders of magnitude in the time between bunches in the train. The solution adopted for CLIC structures to achieve this wakefield suppression includes strong damping accomplished via four waveguides coupled to every cell.

The position of the beam inside the structure can be determined from the power in these waveguides generated by the excitation of the lowest order dipole mode in the structure. For this mode, the induced voltage is proportional to transverse beam position and charge. A measurement of the mode's excitation can be used as input to active alignment systems and wakefield minimisation algorithms [1].

The use of heavily damped accelerating structures as beam position monitors has been demonstrated in the experiments described in this report. They also provide benchmarks for the theoretical models developed to describe the coupling of a beam to a heavily damped periodic structure [2]. A confirmation of the simulations by the measurement also gives confidence in the wakefield simulations which were done with the same techniques. The experiment is thus complementary to a direct wakefield measurement such as at ASSET [3]. It is an extension of the ideas presented in [4, 5, 6, 7].

The structure used in the experiment was a 3 GHz Slotted Iris Constant Aperture (SICA) accelerating structure. In both the CLIC main beam accelerating structures [8] and the CTF 3 drive beam accelerating structures, SICA [9], damping is achieved by coupling waveguides but the waveguides have a different topology. In the SICA accelerating structure damping is achieved by four slots in every iris which extend to double ridged waveguides which are terminated by individual SiC loads. The lowest dipole mode of the SICA has a maximum in the coupling to the beam at 4.3 GHz and a quality factor of about 16. The beam position dependency of this dipole mode was studied experimentally by exciting the structure with the 4 ps, 0.5 nC probe beam of the CTF II [10].

SETUP

The SICA accelerating structure used in this experiment was manufactured for high power tests and consists of four damped and two coupler cells. A drawing of the exploded structure is shown in Fig. 1. In order to measure the dipole mode excitation, the SiC load of one damping waveguide was replaced by an impedance matched transition to coaxial cable to which the read-out electronics was connected. The simulated spectrum of the signal in the damping waveguide shows a resonance with a frequency of 4.25 GHz and a half power width of 205 MHz corresponding to a quality factor of 21. The transition was designed with HFSS to have a better impedance match than the SiC load over four times the bandwidth of the dipole signal. The dipole mode excitation in the two coupling cells was sensed by waveguide directional couplers installed between power couplers and loads that terminated the waveguides. The power couplers and the damping waveguide sense the same polarisation of the dipole mode. A photo of the in-

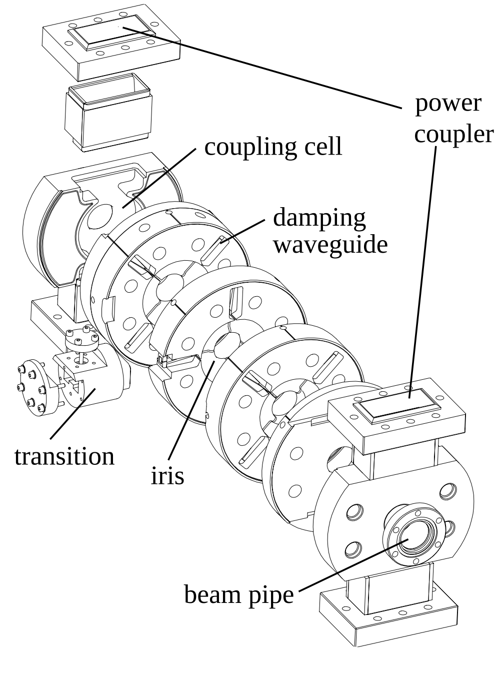

Figure 1: The SICA accelerating structure prototype.

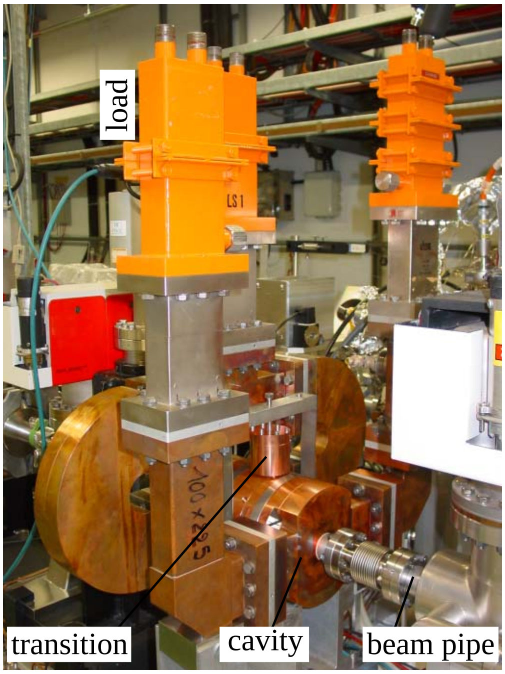

Figure 2: Photography of the accelerating structure installed in the CTF II.

stallation in the CTF II is shown in Fig. 2.

As the cells are so strongly damped (35.9 dB per cell for the lowest dipole mode), the modes do not extend over the whole structure. Therefore measuring the dipole mode at three locations (the two power couplers and one damping waveguide) provided independent position measurements, allowing beam position jitter and measurement resolution to be distinguished. The signals from the two couplers and the damping waveguide were normalised for beam charge variations by a wall current monitor signal.

The beam position dependency of the dipole mode was studied by transversely displacing the beam with a dipole magnet located 1.205 m upstream of the accelerating structure.

MEASUREMENTS

The first measurement was to study the properties of the signal from the damping waveguide in time and frequency domain. The measured time domain signal at the transition from the damping waveguide for a beam offset of 2 mm is shown in Fig. 3. The fast decay of the signal within a few nanoseconds confirms that the damping works well. The Fourier transformation of the signal is shown in the right plot of Fig. 4. The shape of this spectrum was confirmed by measurements with a spectrum analyser. The spectrum shows the dipole mode signal resonance at 4.41 GHz and a second peak at 3.6 GHz caused by the cutoff frequency of the damping waveguide. The whole spectrum was found to be position dependent as expected. The dashed lines are fits with a resonance curve. A quality factor of 33 was found for the dipole mode signal.

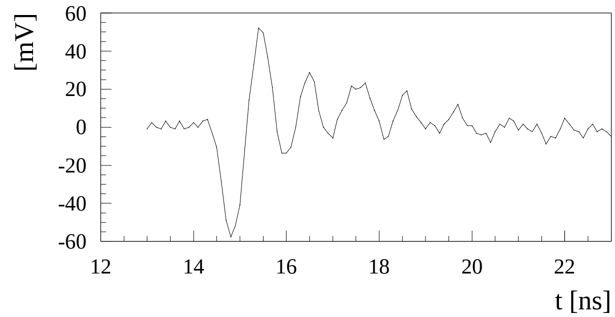

Figure 3: Measured time domain signal from the damping waveguide after mixing with a 3.498 GHz local oscillator.

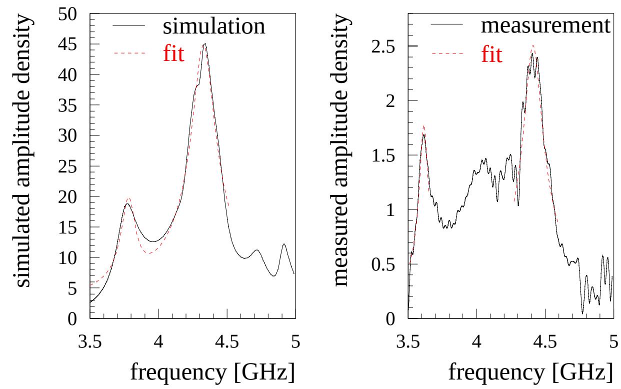

Figure 4: The spectrum of the signal from the damping waveguides after the transition as it was simulated with HFSS (left) and as it was measured (right).

This signal and the ones from the couplers were low pass filtered and mixed down to a DC - 1.5 GHz baseband. The local oscillator signal (3.498 GHz) was generated from the CTF II master clock (249.877 MHz) so that the signals' phase was maintained during the mixing. The wall current monitor and the three intermediate frequency position signals were displayed on a four channel, 3 GHz bandwidth oscilloscope with a sample rate of 10 GS/s. The scope was triggered on the CTF II master clock.

The second measurement was to study the beam position dependency of the signal. The real and imaginary part of the excitation signal both linearly depend on beam position [11]. Fits to these two linear functions provide the parameters for the hyperbolic and arctangent relations of the signal's amplitude and phase respectively. Amplitude and phase of the signal are plotted as a function of beam position in Fig. 5. The representation of the signal in the complex plane is shown in Fig. 6. The error bars equal the r.m.s. value of 100 successive measurements. The measurement is in good agreement with the theoretical curves. The solid curves are hyperbolic and arctangent fits, the dashed curves are the curves derived from the linear fits to the real and imaginary parts. The advantage of the latter is that the parameters of the two linear fits are orthogonal. A mean r.m.s. of 5.7 μm was found. Fig. 5 shows that the beam position dependency of the amplitude in the centre of the cavity is weak, however, the beam position information is

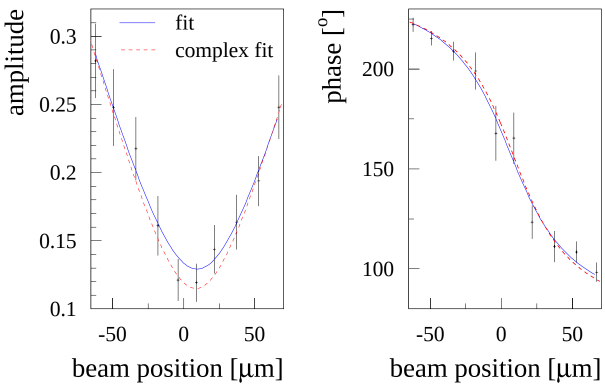

Figure 5: Amplitude (left) and phase (right) of the signal from the damping waveguide as a function of beam position.

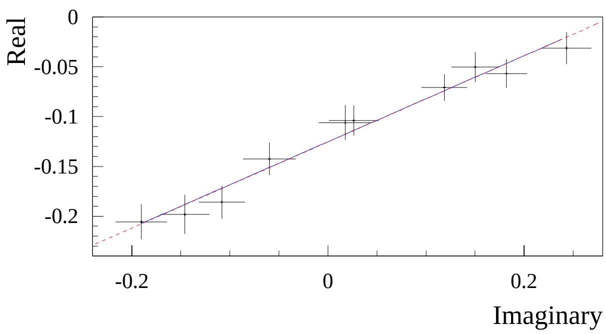

Figure 6: The same data as in Fig. 5 plotted in the complex plane.

contained in the phase which has a strong beam position dependency around the centre.

The same analysis was performed on the signal from the coupler cells. The variations of the beam position signal for unchanged corrector magnet currents have two sources: firstly, the beam position of the CTF II probe beam is known to jitter due to imperfections in the flash-lamp pumped laser which drives the photo-injector. Secondly, there is a noise on the beam position measurements. The coefficient of determination indicates the proportion of variance in one variable explained from knowledge of the second variable. For 100 successive measurements where the beam position signal varied with an r.m.s. of 6 µm, the coefficient of determination between the signal from the damping waveguide and from one coupler cell equals 18 %. This means that 18 % of the signal variation are due to real beam position jitter and the rest is caused by limitations of the experiment. Such limitations are likely to be caused by the electronics that was not sufficiently shielded against signals from the CTF II accelerator.

SIMULATIONS

In preparation for the experiment the response of the structure to the excitation with a short bunch was studied with HFSS [12] and GdfidL [13]. The beam leaves a certain voltage in the cavity which results in a certain power in the damping waveguides. In the HFSS simulation, this was reversed: Power at different frequencies was fed into the structure via the damping waveguide and the voltage calculated by path-integration of the electric field along the particle trajectory. The ratio of the squared voltage and the power provides the impedance as a function of frequency. This spectrum of the signal in the coaxial cable of the transition is shown in the left plot of Fig. 4. The complex sum of two resonance curves was fitted to the spectrum. For the dipole mode signal a resonance frequency of 4.33 GHz and a quality factor of 26.0 was found. The relative deviation of theses values compared to the measurements are 1.8 % for the resonance frequency and 24 % for the quality factor.

The GdfidL program calculates the fields in time domain. The spectrum is derived as the Fourier transformation of this signal and was found to agree very well with the result found by HFSS simulations.

More details can be found in [14].

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