

STATUS OF THE CLIC-UK R&D PROGRAMME ON DESIGN OF KEY SYSTEMS FOR THE COMPACT LINEAR COLLIDER

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Abstract

Six UK institutes are engaged in a collaborative R&D programme with CERN aimed at demonstrating key aspects of technology feasibility for the Compact Linear Collider (CLIC). We give an overview and status of: 1) Drive-beam components: quadrupole magnets and the beam phase feed-forward prototype. 2) Beam instrumentation: stripline and cavity beam position monitors, an electro-optical longitudinal bunch profile monitor, and laserwire and diffraction and transition radiation monitors for transverse beam-size determination. 3) Beam delivery system and machine-detector interface design, including beam feedback/control systems and crab cavity design and control. 4) RF structure design. In each case we report on the status of prototype systems and performance tests with beam at the CTF3, ATF2 and CESRTA test facilities, including plans for future experiments.

INTRODUCTION

The Compact Linear Collider (CLIC) [1] is a novel approach to the design of a linear electron-positron collider for achieving centre-of-mass energies up to the TeV scale. We report briefly on systems being developed in the UK for solving key technical challenges for CLIC.

DRIVE BEAM COMPONENTS

Zero-Power Tuneable Optics

We have developed tuneable permanent magnet (PM) quadrupoles for the Decelerator. Two families of magnets are needed to cover the full field range. A prototype of each has been built and tested. Figure 1 shows both types. The high-energy quadrupole uses four PMs, which are moved (by up to 60mm) in pairs along a vertical axis. The resulting air gap reduces the gradient from nominal by up to a factor of ~ 4 (14.4-60.7 T/m). The prototype met most of the specifications [2]. The low-energy quadrupole has two PMs which are magnetised horizontally and moved independently of the poles. In the fully-out configuration magnetic flux is shunted through an outer shell which acts

to reduce the gradient further and increase the tuning range. The movement range is 75 mm, with a factor of around 12 between minimum and maximum gradients (3.5-43.4 T/m). The prototype meets the specifications for gradient and tuning range, but the field quality needs to be improved [3]. We are also developing adjustable PM-based dipoles for the Turnaround Loop. These will yield a maximum field of 1.6 T and be tuneable by a factor of 2.

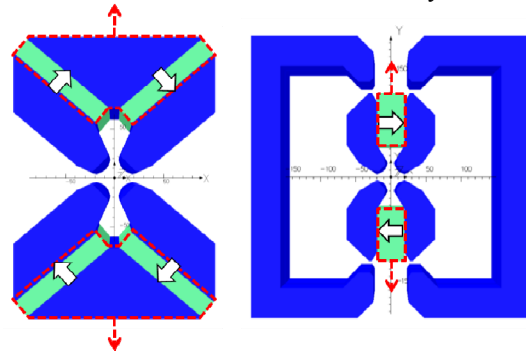


Figure 1. High- (left) and low-energy (right) quadrupoles. PM easy axes (block arrows); moveable sections (dashes).

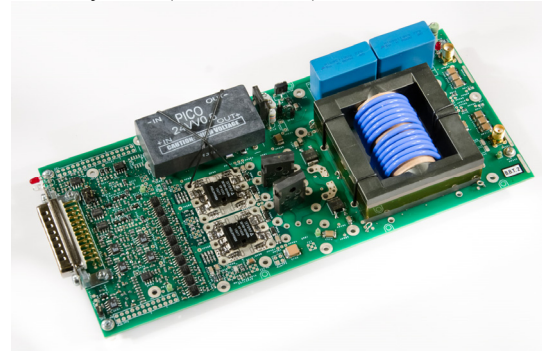


Figure 2. Photograph of the drive amplifier.

Phase Feed-Forward System

A beam-based feed forward system is envisaged for stabilising the phase of the drive beam with respect to the main beam to within 50 fs rms. One such system will be situated in each of the drive beam decelerator sections, comprising a phase measurement system at the entrance to a beam turnaround and a correction system at the

turnaround exit consisting of fast kickers within a magnetic chicane. A prototype [4] is being developed at CTF3, in order to demonstrate the required phase stabilisation for CLIC, comprising a high-bandwidth, high-resolution phase monitor, two kickers situated around a dog-leg chicane, driven by high-power, high-bandwidth amplifiers and a fast digital feed forward controller. A photograph of the amplifier is shown in Figure 2. Beam tests will start in June 2014.

BEAM INSTRUMENTATION

Stripline BPMs

We have developed a stripline BPM signal processing scheme capable of delivering position signals accurate to the sub-micron level on a timescale of the order of 10 ns. The prototype system makes use of 3 12 cm stripline BPMs, which are located in the diagnostics section of the ATF extraction line at KEK. The BPMs are connected to specially developed analogue processing electronics in order to deliver appropriate position signals to an FPGA-based digital hardware module that digitizes the signals and returns the sampled data to a computer where they are logged. A resolution of $0.43\mu\text{m}$ has been obtained [5].

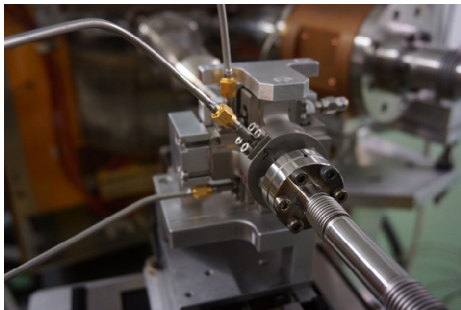


Figure 3: CLIC prototype cavity BPM.

Cavity BPMs

A prototype main beam cavity BPM has been manufactured and tested at CTF3. The pickup is made of stainless steel and consists of two cavities: a position sensitive dipole mode cavity and a monopole mode cavity for charge normalisation and a reference phase. The resonant frequency of both modes is 15 GHz. Receiver electronics, with variable gain and a single down-conversion stage to an intermediate frequency of 200 MHz, were assembled for the beam tests and were installed close to the pick-up. A single-bunch position sensitivity of $20.99\pm 0.06\text{V/mm/nC}$ was estimated from measurements of 60ns long bunch trains (about 90 bunches) with a typical bunch charge of 0.05nC. Position measurements were also made and a minimum measured position jitter of $13\mu\text{m}$ RMS was observed with a 2.1ns train of few bunches. The BPM response to CLIC-like bunch trains of more than 100 bunches was also investigated. A second iteration of the prototype pick-up made from copper and with a modified feed-through antenna design is currently in production. Once the design is verified, three pick-ups will be manufactured along

with improved electronics in order to measure the spatial resolution and demonstrate the target performance of 50nm resolution and multiple position measurements within a single 150ns long bunch train [6].

'Electro-Optic Transposition' Longitudinal Profile Monitor

We are developing a high resolution diagnostic based on nanosecond laser systems [7]. In 'EOT' a narrow bandwidth optical probe has the Coulomb field temporal/spectral profile imposed on it. Amplification of the signal enables single-shot characterisation using a FROG technique. Lab-based EOT measurements of THz pulses (Coulomb field mimics) have confirmed the technique, and established parameters for the CLIC system. Fig. 5 shows excellent agreement between EOT and THz-TDS spectra of a THz pulse. The amplification stage has been tested with 50fs FWHM optical pulses, verifying the bandwidth and 1000x gain. To overcome the bandwidth limitation of EO materials we are developing approaches that splice data from several crystals or use surface nonlinear frequency mixing.

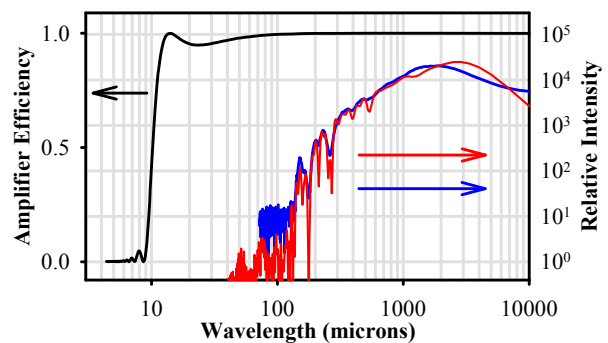


Figure 4: Spectra retrieved via THz-TDS (red) or via EOT (blue). An overlay of the ± 30 THz amplifier bandwidth is shown for comparison (black).

Laserwire And Diffraction/Transition Radiation Monitors

The extraction line laserwire system at the ATF2 at KEK is a system developed to precisely measure micrometre-sized electron beams. The system uses a high power laser with a visible wavelength, permitting a transmissive focussing geometry that provides a greater scanning range and allows direct calibration as compared to a reflective one. Transverse profile measurements have been made demonstrating a minimum measured beam size of $1.07\pm 0.06\pm 0.05\mu\text{m}$ (Fig. 5). The measurements were made with a 1/100 aspect ratio electron beam where Rayleigh range effects are thought to limit the use of a laserwire. It has recently been demonstrated that these can be overcome and the same 1D system was used to measure a horizontal beam size of $119.0\pm 2.4\pm 0.01\mu\text{m}$. This has successfully demonstrated the resolution and methodology required for a linear collider laserwire, but research is ongoing to provide advanced efficient laser sources for high-precision intra-train measurements [8].

The laser-wire measurements were crosschecked with a sophisticated, but invasive, sub-micron resolution OTR monitor utilising spatial properties of so-called Point Spread Function. A typical image is shown in Fig. 6. The contrast ratio of the OTR PSF is used to extract the information about beam size with sub-micron resolution [9]. Such consistency demonstrates reliability of both methods. On the other hand the system represents a prototype of a transverse electron beam diagnostics station for future linear colliders.

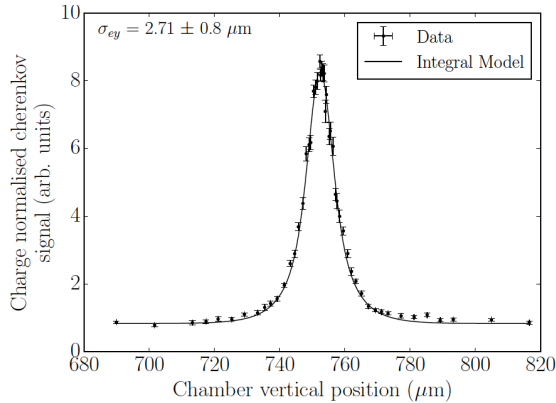


Figure 5: Laserwire vertical beam size measurement.

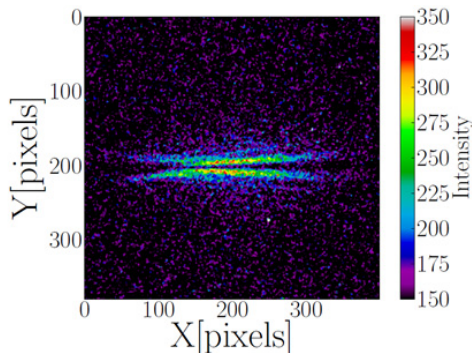


Figure 6: Measured OTR signal.

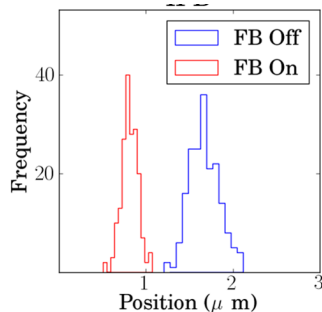


Figure 7: Beam jitter stabilisation with IP feedback.

BEAM DELIVERY/MDI

IP Feedback System

A low-latency, intra-train, beam feedback system utilising a cavity beam position monitor (BPM) has been developed and tested at the final focus of the Accelerator Test Facility (ATF2) at KEK. A low-Q cavity BPM was

utilised with custom signal processing electronics, designed for low latency and optimal position resolution, to provide an input beam position signal to the feedback system. A custom stripline kicker and power amplifier, and an FPGA-based digital feedback board, were used to provide beam correction and feedback control, respectively. The system was deployed in single-pass, multi-bunch mode with the aim of demonstrating intra-train beam stabilisation on electron bunches of charge $\sim 1\text{ nC}$ separated in time by $c. 280\text{ ns}$. The system has been used to demonstrate beam stabilisation to below the 100 nm level (Fig. 7). Results of the latest beam tests, aimed at even higher performance, are presented in [11].

RF STRUCTURE DESIGN

An X-band crab cavity with a 2.4 MV peak deflecting voltage [11] is to be used to rotate the bunches prior to collision to remove the effect of the 20 mrad crossing. Phase errors in the RF system will translate to a transverse offset at the IP and degrade the luminosity; for the X-band cavity the phase tolerance is $<20\text{ mdeg}$. The short bunchtrains do not allow time for feedback hence a feedforward scheme is adopted. A single klystron will be used for both cavities to avoid differential phase errors. In deflecting cavities the beam loading is proportional to the beam offset. A passive solution to beam loading caused by beam offset must be adopted, whereby a high group velocity structure ($0.03c$) is used to ensure the beam loading is small compared to the power travelling down the structure. The structure incorporates waveguide dampers for HOMs. Prototypes have been developed, (Fig. 8), and high gradient testing is in progress [11]. An RF interferometer has been developed to correct for path length changes in the 50 m of RF transmission line from the klystron to the cavities; a key component is a wide bandwidth phase noise measurement.

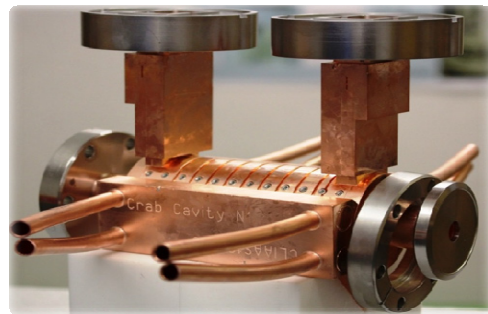


Figure 8: Crab cavity prototype without dampers

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