COMMISSIONING THE PASSIVE STRUCTURE WAKEFIELD DECHIRPER ON CLARA[*]

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Abstract

A passive energy dechirper has been installed on CLARA, a 250 MeV electron beam user facility at Daresbury Laboratory. The device, comprising two orthogonal sets of planar dielectric-lined waveguides, is designed to manipulate the longitudinal phase space of the electron bunch, reducing energy spread and thereby delivering higher quality beams for user experiments. We present preliminary results from initial commissioning of the dechirper with the CLARA beam, including measurements of the wakefields excited and changes in longitudinal phase space due to the dechirper. We outline plans for further measurements and discuss how the dechirper will support upcoming user programs.

INTRODUCTION

CLARA is an advanced medium-energy electron test beam facility, capable of delivering electron bunches with up to 250 MeV/c momentum and 250 pC charge for the requirements of individual user experiments in the full-energy beam exploitation (FEBE) hutch [1]. Longitudinal compression is required for the delivery of high current (~kA) and short (~20 fs RMS) bunches. This is achieved at CLARA using a positive energy chirp (high energy tail) and compression through a 4-dipole variable bunch compressor [2].

Passive wakefield structures are increasingly used at accelerator facilities to cancel residual chirp used for compression. These dechirpers work by using the wakefield excited by the bunch itself in corrugated-metallic or dielectric-lined waveguides to decelerate the tail of the bunch such that the energy is more monotonic across the bunch and increase the 6D brightness [3–5]. A passive wakefield dechirper has been designed and installed on CLARA and a simulation campaign conducted before use to evaluate the optimal working parameters with expected beam parameters [6, 7].

CLARA is currently undergoing the final stages of beam commissioning. In these proceedings we will discuss initial commissioning of the passive wakefield dechirper, evaluating the change in energy spread and demonstrating dechirping for an example beam setup.

CLARA PASSIVE WAKEFIELD DECHIRPER

The CLARA beamline is set out as outlined in Fig. 1 and in Ref. [1]. Optics setting sections are arranged after the first, third, and fourth/final linacs, corresponding to approximate beam momenta of 35, 200, and 250 MeV/c respectively. In the section after the third linac, a variable bunch compressor is positioned to allow for varying bunch lengths for the needs of individual experiments [2]. The compression can be measured after the final linac using an S-band transverse deflecting cavity (TDC); the longitudinal profile and/or the longitudinal phase space measured on screens positioned on the CLARA straight and a dispersive section. To achieve compression the bunch is given an energy chirp by accelerating the bunch off-crest in the second and third linacs. To cancel residual chirp, the passive wakefield dechirper is positioned in the final section, after the final linac, before transport to the FEBE arc to the experimental area. Delivery to user experiments in the FEBE chamber is via an arc with non-zero R_{56}, therefore removal of the beam chirp can allow longitudinal diagnostics before the arc to be directly related to beam parameters for user experiments.

The passive dielectric dechirper is designed for controllable longitudinal phase space manipulation whilst maintaining beam quality. The dechirper comprises of two orthogonally orientated planar dielectric lined waveguides (DLWs), as in Fig. 2 and described in detail in Ref. [7]. As in the schematic we will refer to the first horizontally orientated DLW as DCP1 and second vertically orientated DLW as DCP2. Each DLW consists of two parallel 0.2 m long, 2 cm wide, and 200 μm thick quartz plates, providing a 0.4 m total plate length (with a 10 mm gap between the two DLWs). Each plate can be controlled with two actuators along the plate, allowing for gap and tilt control. Together with the controls for the parallel plate it is possible to control the dechirper gap, transverse centre, and tilt. This reduces constraints on beam trajectory into the dechirper. The minimum gap in each DLW is 1.0 mm and the dechirper is considered out of the beam path when set to an 11 mm gap.

Two DLWs are arranged orthogonally to cancel quadrupole-like wakefields excited in each structure. Quadrupole-like wakefields (focusing and defocusing in orthogonal planes) introduce longitudinal variation in the transverse phase space (i.e. longitudinally varying Twiss parameters), increasing the projected emittance. The defocusing/focusing planes switch in orthogonal DLWs so the two DLWs effectively cancel each other and conserve the beam emittance [6].

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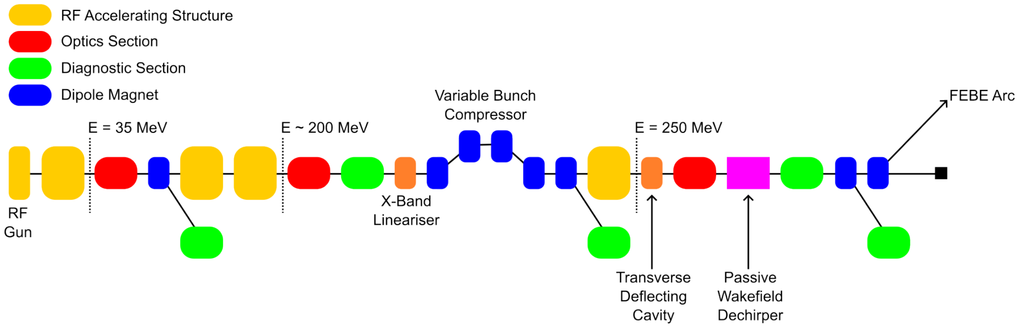

Figure 1: Schematic of the CLARA beamline. The position of the passive wakefield dechirper is highlighted in pink.

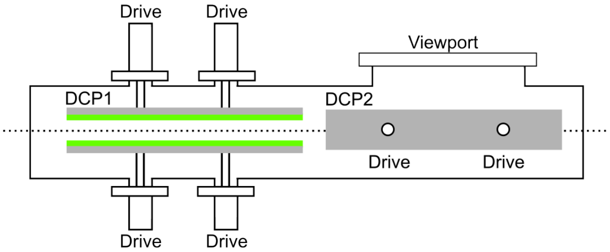

Figure 2: Schematic of the passive wakefield dechirper. Driving stages are labelled for the first, horizontally orientated, DLW (DCP1). The same controls exist for the second, vertically orientated, DLW (DCP2).

INITIAL RESULTS

The dechirper was commissioned with CLARA delivering bunches with parameters as listed in Table 1. The energy spread quoted contains both correlated (chirp) and uncorrelated energy spread, the magnitude and shape of which depends on the off-crest acceleration phase in each linac. The chirp determines the level of compression possible with the variable bunch compressor and compression requires a positive chirp (higher energy tail). Away from maximum compression, the energy spread can mostly be characterised by its chirp with a positive chirp when under-compressed and negative chirp (higher energy head) when over-compressed. Optics were set before the dechirper to ensure beam transport through the dechirper across the full range of gaps; with a minimum gap size of 1 mm this required a beam envelope with sizes ~ 100 µm across the 0.4 m total dechirper length.

Table 1: Beam parameters in the final section of the CLARA straight. The quoted bunch length limit is the measured bunch length at maximum compression at 250 pC [2].

Parameter	
Bunch Charge	250 pC
Beam Energy	250 MeV
RMS Energy Spread	~ 1%
RMS Bunch Length	> 140 fs
$\sigma_{x,y}$ at DCP1	> 50 µm

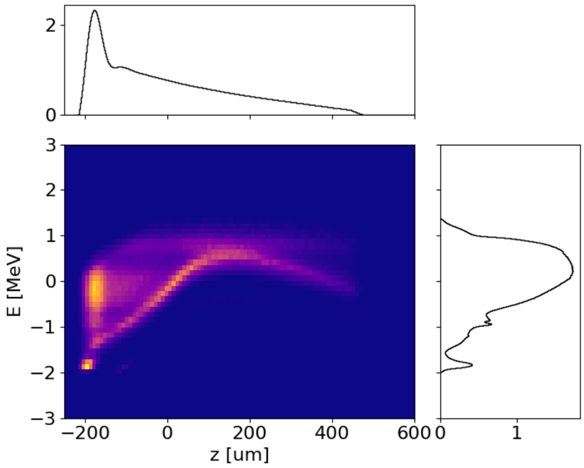

Figure 3: Reconstructed longitudinal phase space with the dechirper out. The central beam energy (zero on the energy spectra) is 258 MeV.

Energy Dechirping

The longitudinal profile was measured using the TDC and method outlined in Ref. [8]. The energy spectra, with the dechirper in and out was measured in a dispersive section after a dipole, 2 m downstream from the dechirper exit. The longitudinal wakefield excited by the measured profile is calculated using the method in Ref. [9], and the change in energy spectra used to reconstruct the LPS.

Dechirping requires the bunch to have a positive chirp. An under-compressed bunch was used for initial testing with 550 fs RMS bunch length. The reconstructed longitudinal phase space is shown in Fig. 3. For initial testing, the gaps in DCP1 and DCP2 were kept equal. The measured changed in energy spread (full-width half and 10% max widths) as a function of dechirper gap is shown in Fig. 4. A minimum FWHM energy spread was observed with a 1.25 mm gap, reducing by 90% (1.46 to 0.15 MeV). The full energy spread, defined as the full width at 10% max reduced by 25% (2.65 to 1.99 MeV). The FWHM significantly reduces, however the full energy spread does not reduce by the same magnitude; this can be explained by the large energy spread at the head seen in Fig. 3 which cannot be reduced by the dechirper. The dechirper is designed to increase the beam brightness; the longitudinal profile is unchanged and assuming that the

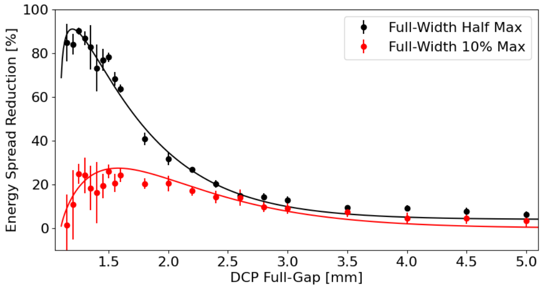

Figure 4: Measured 50% and 10% full width energy spread as a function of dechirper gap, with equal DCP1 and DCP2 gaps. Measured spectra are the sum of 10 shots with error bars representing the standard deviation of individual shot measurements. Lines are smooth fits to the measurements.

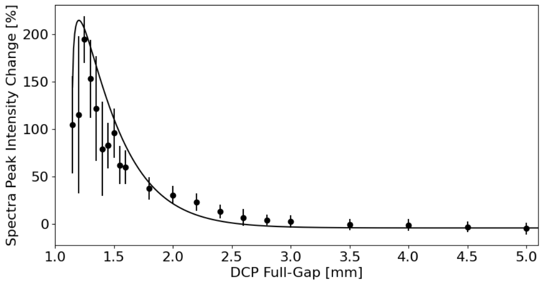

Figure 5: Percentage increase in peak energy spectra intensity (measured with 0.014 MeV bin widths) compared to the dechirper out as a function of dechirper gap. Error bars represent the standard deviation of 10 shots and plotted line is a smooth fit of the measurements.

transverse beam quality is preserved the peak brightness can be approximated as proportional to the peak intensity of the energy spectra. The measured change in peak spectra intensity is shown in Fig. 5; the maximum 200% increase was measured at a 1.25 mm gap. From the FWHM and peak intensity, the optimal dechirping is with a 1.25 mm gap. The measured and simulated spectra at this gap are shown in Fig. 6 with good agreement between measurement and simulations.

Transverse Beam Quality Preservation

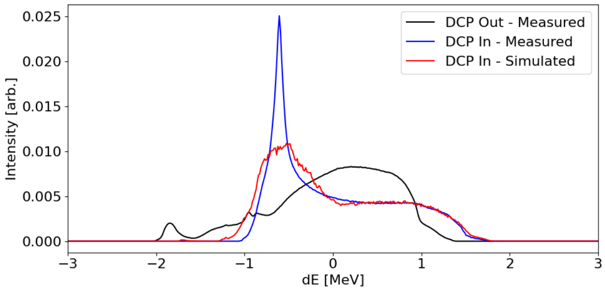

Figure 6: Measured energy spectra with the dechirper out (black) and 1.25 mm DCP1 and DCP2 gap (blue) and simulated energy spectra with the same gap (red).

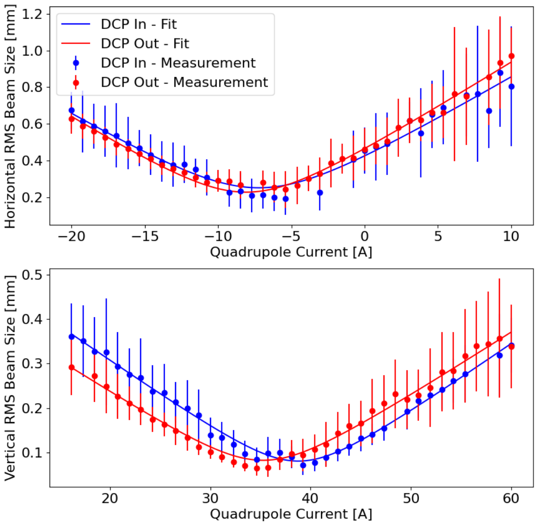

Figure 7: Horizontal (top) and vertical (bottom) RMS beam size as a function of scanning quadrupole current with the dechirper set with 1.8 mm gap and out. Error bars represent the standard deviation of 10 shots, and smooth fit lines from the beam size squared are plotted for each set of measurements.

The effectiveness of the orthogonal DLW design was tested by comparing the emittance measured at the end of the CLARA straight with the dechirper in and out. If quadrupole wakefields are cancelled, there should be no changes to the beam optics and the same quadrupole current range can be used for an emittance measurement. Using a different machine setup to the dechirping results quoted above, both dechirper plates were set to a 1.8 mm gap. For each quadrupole current, 10 shots were collected with the dechirper in and out and the RMS beam size calculated using a Gaussian fit to the transverse profile of each shot. The results of each quadrupole scan are shown in Fig. 7; with the fit used to calculate the emittance plotted for each dataset. The normalised emittance, $(\epsilon_{n,x}, \epsilon_{n,y})$, with the dechirper in was measured as $(3.08, 2.60) \pm (0.26, 0.14)$ mm mrad and with the dechirper out measured as $(2.94, 2.46) \pm (0.16, 0.22)$ mm mrad. Emittance is preserved with the dechirper in both planes with equal minimum measured beam sizes with the dechirper in and out.

CONCLUSIONS

The results presented in these proceedings demonstrate the successful commissioning of the passive dielectric dechirper at CLARA. Initial results show that the dechirper operates as expected with agreement seen between simulations and measurements and a reduction in energy spread when using the dechirper without increasing transverse emittance. Future measurements will focus on the usability of the dechirper as a standard part of CLARA operation. This will require the development of standard setups with repeatable beam parameters both at the end of the CLARA straight and through the FEBE arc to user experiments.

REFERENCES

[1] E. W. Snedden *et al.*, “Specification and design for full energy beam exploitation of the compact linear accelerator for research and applications”, *Phys. Rev. Accel. Beams*, vol. 27, no. 4, pp. 041602, 2024. doi:10.1103/PhysRevAccelBeams.27.041602

[2] J. Jones *et al.*, ”Compression and linearisation studies on CLARA”, presented at IPAC’26, Deauville, France, May 2026, paper THP2100, in these proceedings.

[3] Z. Zhang *et al.*, “Electron beam energy chirp control with a rectangular corrugated structure at the linac coherent light source”, *Phys. Rev. ST Accel. Beams*, vol. 18, pp. 010702, 2015. doi:10.1103/PhysRevSTAB.18.010702

[4] S. Bettoni *et al.*, “Beam Manipulation Using Self-Induced Fields in the SwissFEL Injector”, in *Proc. IPAC’18*, Vancouver, Canada, May 2019, pp. 3401-3404. doi:10.18429/JACoW-IPAC2018-THPAK074

[5] Y. W. Gong *et al.*, “Beam performance of the SHINE dechirper”, *Nucl. Sci. Tech.*, vol. 32, no. 3, p. 29, 2021. doi:10.1007/s41365-021-00860-8

[6] B. Higuera Gonzalez *et al.*, “Detailed simulation study of wakefield induced beam dynamics in the dielectric dechirper at CLARA”, in *Proc. IPAC’24*, Nashville, TN, USA, May 2024, pp. 2207-2210. doi:10.18429/JACoW-IPAC2024-WEPG14

[7] M. I. Colling *et al.*, “Mechanical design of a dielectric wakefield dechirper system for CLARA”, in *Proc. IPAC’19*, Melbourne, Australia, May 2019, pp. 1912-1915. doi:10.18429/JACoW-IPAC2019-TUPRB108

[8] P. Emma, J. Frisch, and P. Krejcik, “A transverse RF deflecting structure for bunch length and phase space diagnostics”, SLAC National Accelerator Laboratory, Menlo Park, CA, USA, Reps. SLAC-PUB-8864 / LCLS-TN-00-12, 2000. doi:10.2172/784939

[9] S. S. Baturin *et al.*, “Transverse operator method for wakefields in a rectangular dielectric loaded accelerating structure”, *Phys. Rev. ST Accel. Beams.*, vol. 16, pp. 051302, 2013 doi:10.1103/PhysRevSTAB.16.051302