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MECHANICAL DESIGN OF A DIELECTRIC WAKEFIELD DECHIRPER SYSTEM FOR CLARA

M. I. Colling†, T. H. Pacey[1], Y. M. Saveliev[1], B. D. Fell, D. J. Dunning[1],
STFC Daresbury Laboratory, Warrington, UK
[1]also at Cockcroft Institute, Warrington, UK

Abstract

STFC Daresbury Laboratory are developing a compact electron beam energy dechirper system, based on dielectric wakefield structure, for the on-site electron accelerator CLARA (Compact Linear Accelerator for Research and Applications). CLARA will be an experimental free electron laser (FEL) facility operating at 250MeV and will be a test bed for a variety of novel FEL schemes. The dechirper dielectric quartz plates will induce wakefields within the structure which can remove the beam chirp that is initially introduced to compress the electron bunch longitudinally. Removing or adjusting the amount of chirp enables researchers to reduce or adjust the bunch energy/momentum spread, expanding the FEL capabilities. The attachment and alignment of the quartz plates present numerous mechanical design challenges that require high precision manufacturing and quartz plate positioning via fiducialisation. This paper will review the dechirper specifications, the chosen design solutions, measured mechanical performance, and the expected effect of the dechirper on CLARA FEL operation.

INTRODUCTION

High peak current electron bunches are required for free electron lasers (FEL) operation. This is usually achieved by introducing a linear energy chirp along the bunch with subsequent magnetic compression to sub-ps bunch length. Such a chirp is however undesired because it reduces the FEL efficiency and increases its radiation bandwidth. Several methods have been proposed to eliminate the chirp with induced short-range wakefields using, for example, metallic corrugated structures [1]. The same effect can be achieved using dielectric lined waveguides (DLW) [2]. We have adopted this type of structure for the development of a compact dechirper for CLARA, the 250MeV FEL test facility being developed at Daresbury Laboratory. Simulations demonstrated that the energy chirp could be drastically reduced and FEL performance enhanced with the use of relatively compact device [3, 4]. This contribution presents a brief overview of the CLARA dechirper simulations and describes the chosen mechanical design and its performance.

CLARA DECHIRPER SIMULATIONS

The simulated effect of the CLARA dechirper can be observed in Fig. 1. A plate separation of a = 1.6 mm was used to effectively linearise the core of the bunch. The FWHM momentum spread was reduced by a factor of 10 from 3.3 MeV/c to 0.3 MeV/c. This simulation was performed in ELEGANT using a Green's function approach to calculate the wakefield [3], building on the previously presented work [4, 5].

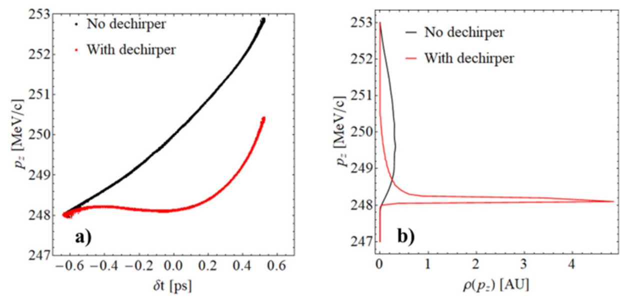

Figure 1: a) Longitudinal phase space with head of the bunch on the left. b) Bunch momentum distribution.

DECHIRPER DESIGN REQUIREMENTS

The CLARA dechirper concept comprises of two sets of two parallel dielectric plates; each set positioned orthogonally and in series (Fig. 2). The dielectric plates are 200mm long providing an effective total plate length of 400mm. Each plate can be manoeuvred inside the vacuum vessel via two external to vacuum drive systems attached to either ends of the plate; allowing both the gap between the parallel plates and the plate angle (pitch) to vary in-situ.

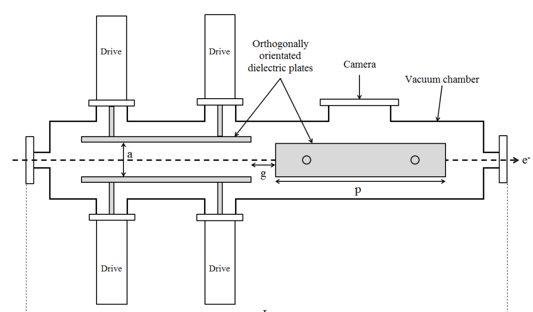

Figure 2: Schematic of the CLARA dechirper concept (see Table 1 for dimensions).

Table 1: Dechirper Concept Dimensions

Description		Dimension
Plate length	*p*	200 mm
Plate width	*w*	20 mm
Plate thickness	t	0.2 mm
Orthogonal plate gap	*g*	10 mm
Parallel plate separation	*a*	0.8 – 20 mm
Plate angle (pitch)	*δ*	0 - 0.58°

† miriam.colling@stfc.ac.uk

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To achieve accurate positioning of the plates relative to each other, a full dechirper design has been developed based on the use of high precision machined reference surfaces in combination with fine adjustments to the plate positions before insertion into the vacuum vessel.

The dechirper can be set in either of two configurations: fully extracted (Fig. 3) - vacuum vessel is open and the plates are driven out and accessible - and fully inserted (Fig. 4) – vacuum vessel is sealed and pumped down and the plates can only be driven within a 10 mm range.

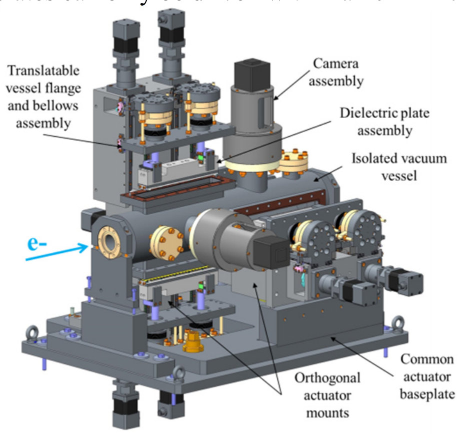

Figure 3: CLARA dechirper system with plates extracted.

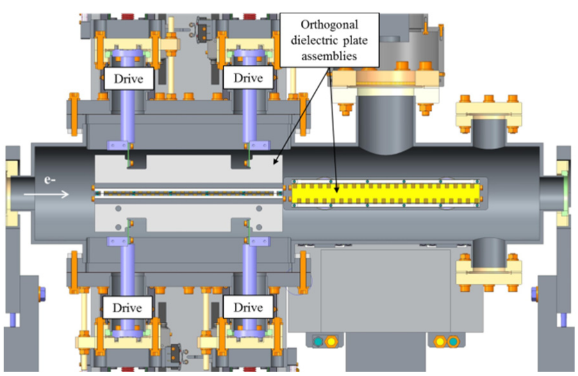

Figure 4: Cross section through z plane, showing the dielectric plate assemblies in fully inserted position.

IN-VACUUM ASSEMBLY

The quartz plates will move within a cylindrical vacuum vessel of ID 100mm, with all driving and diagnostic mechanisms operating external to the vacuum, thus avoiding the need for complex and costly vacuum compatible systems. The CAD model in Fig. 5a highlights features of the in-vacuum assembly. Flexures connect the drive systems to either end of the plates, allowing a 4 mm angular adjustment to be achieved. The design allows for the ability to exchange/replace the dielectric quartz plate efficiently through the detachable substrate feature. This substrate is diamond milled to a flatness <10µm. Attachment of the quartz plates to the detachable aluminium substrate is achieved using stainless steel spring clips which also act to press the quartz flat against the precision machined substrate. The geometry of the spring fingers ensure they can interleave on the opposite drive surfaces and thus achieve a minimum plate separation of 0.8mm between the parallel plates (Fig. 5b).

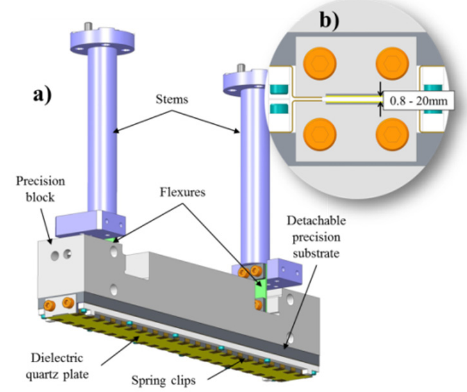

Figure 5: a) One of two parallel plate assemblies. b) Min./max. separation between parallel plate assemblies.

PLATE ASSEMBLY MOTION

NEMA 17 motors coupled with a 3:1 gearbox provide the necessary torque (with a safety factor of 5) to withstand the vacuum exerted force on the edge welded bellows and the mass of the internal plate structure. Plate positional feedback is achieved through absolute encoders applied to each actuator system. This will provide not only reliable positional data but also retain the information should power be lost. Additional limit switches have been incorporated to avoid damage to components should an error occur in the encoders. Baumer switches will act to protect the quartz plates should they overdrive their minimum gap allowance of 0.8mm. Finally, hardstops have been integrated into the quartz substrate assembly to ensure the fragile quartz plates never collide.

PLATE ALIGNMENT

Positional alignment of the plates is performed in the dechirper fully extracted position (Fig. 3). Before the flexure screws are tightened - thus fixing the plate assembly into position - the plate roll adjustment can be conducted via two methods. The first method involves the insertion of gauge blocks between the base of the stem and the plate assembly, adjusting the roll accordingly by inserting micron level shims. A precision spirit level fixed to the plate assembly will provide a visual measure of the change in roll. The second method involves a kinematic screw mechanism, allowing the plate to rotate about a round ended screw by adjusting the height of two screws either side; a precision spirit level will measure the roll, as described in method 1. The flexure screws are then tightened to hold the plate into position.

The resulting position of the plates when inserted into the vessel (Fig. 4) is then primarily dependent upon three factors: the aforementioned alignment process, the accuracy of the guide rails and the precision manufacture of the surfaces the rails are mounted to. The position of the orthogonal plates with respect to each other is dependent on the high tolerance manufacture of the mounting faces between the actuator block and the common baseplate.

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The deviation from parallelism of faces A and C in Fig. 6 are guaranteed to be <20µm as a result of the high precision machining tolerances and post-manufacture inspection via CMM. Therefore, measuring at the more accessible face C, ensures parallelism is achieved at the required dielectric mounting face, which is far less accessible. The same principle applies in the horizontal direction, with the side faces B manufactured perpendicularly to A.

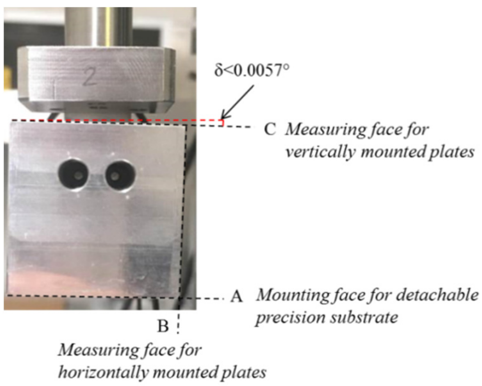

Figure 6: View of precision block down the beam path.

MECHANICAL TESTS

The dielectric plate's critical dimension of movement is its roll, specified to be <20µm (<0.057°) over the plate width (with respect to the other 3 plates). An out of vacuum drive test was performed to observe the roll behaviour of the plates over the full drive length (Fig. 7a), the results of which can be seen in Fig. 8.

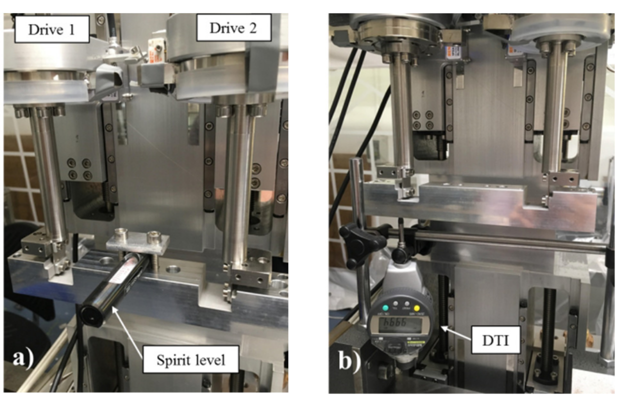

Figure 7: a) Plate roll test. b) Encoder accuracy test.

The x axis represents the plate position from fully extracted (100mm) to fully inserted (0mm). Tests were performed both without and with 150N of vacuum force applied to each drive (achieved using equivalent weights applied to the drives). The tests consistently showed repeatability in the roll behaviour. Without vacuum load, a maximum roll deviation of -0.0114° is observed towards the end of travel; a factor of 5 less than specified. With vacuum load applied, the maximum roll deviation reduces to 0.006° which may be due to the load removing any slack experienced in the drive mechanism.

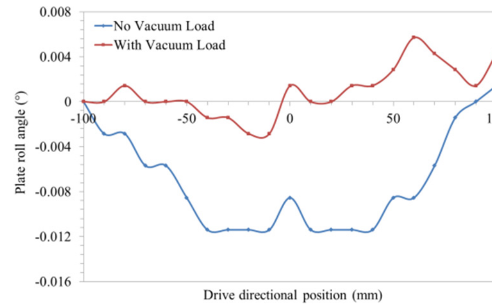

Figure 8: Plate roll behaviour over full drive length.

A second test was performed to ensure the absolute encoders (+/-1µm accuracy) deliver accurate plate positional readings (Fig. 7b). A dial test indicator (DTI) (+/-3µm accuracy) was fixed to either end of the plate and positional data was recorded over the last 10mm of travel (the critical movement range over which the plates will affect the passing electron beam). The results of this test are shown in Fig. 9. Zero mm represents the plate fully inserted and at the position where plate alignment with the beam occurs. As the plate drives out, a difference in the order of microns is observed between the DTI and the encoder readings. Plate movement accuracy was specified at 20µm over the range of 1-2 mm. The maximum difference between encoders and DTI readings over this 2 mm range is 3µm, a factor of 6 less than specified.

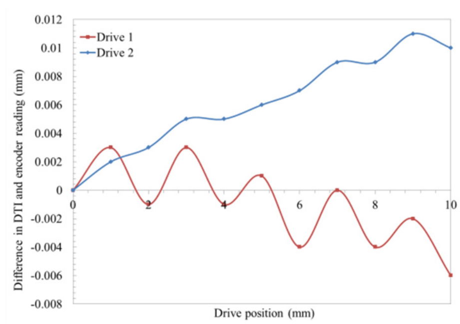

Figure 9: Difference between DTI and encoder readings.

CONCLUSION

The proposed design for the CLARA dechirper has been presented and described. Mechanical drive tests have demonstrated the ability to achieve the required level of accuracy in plate positioning. It was confirmed that the precise roll alignment of the plates can successfully be performed external to the vessel and continue to maintain a high level of positional accuracy once inserted. Additional mechanical tests have also validated the ability of the absolute encoders to provide accurate plate positioning to better than the required <20µm over the 2mm operating range.

Future work includes the mechanical testing of the 3 remaining plates to confirm positional conformance, moving onto the cleaning and assembly of the full dechirper system. Finally, the mechanical testing of the plate movement within the vacuum vessel will be performed, using cameras to obtain visual confirmation of the plate positions.

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