OPTICS AND PROTECTION OF THE INJECTION AND EXTRACTION REGIONS OF THE CLIC DAMPING RINGS

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Abstract

The optics design of the injection and extraction regions for the CLIC damping rings is presented. The design defines the parameters for the kicker magnets and septa in these regions and has been optimised to minimise the length of the insertions within the parameter space of the system. Failure modes of the injection and extraction elements are identified and their severity assessed. Protection elements for the injection and extraction regions are optimised based on the conclusions of the failure mode analysis.

INTRODUCTION

The CLIC design luminosity of 5.9×10^{34} $cm^{-2}s^{-1}$ requires extremely low emittance bunches [1]. The main beam complex relies on pre-damping rings (PDRs) and damping rings (DRs) to achieve this by synchrotron radiation damping. Well-designed injection and extraction systems for the DRs are vital for maintaining the small damping ring emittances. A poorly injected beam can lead to instabilities in the ring, resulting in beam losses, whereas a poorly extracted beam will lead to beam blow-up and jitter resulting in luminosity loss at the interaction point.

The main beam complex consists of 2 PDRs and 2 DRs; one of each is required for the separate electron and positron beams. The PDRs and DRs will both have a circumference of ~400 m and beam energy of 2.86 GeV; the PDRs require a larger aperture than the DRs to allow for the larger beam emittances in the PDRs.

The injection and extraction systems are situated on opposite sides of the CLIC DRs, just after the arc sections and before the long straight sections [1].

DAMPING RING INJECTION AND EXTRACTION

The injection and extraction systems each consist of a FODO cell with kickers and septum magnets in the drift spaces to deflect the beam (Fig. 1). For the CLIC DRs, the injection and extraction systems are identical save that the order of the kickers and septa are reversed favouring the high degree of symmetry required to achieve a low equilibrium emittance. The larger emittance at injection implies tighter aperture constraints; this is the critical system to optimise in terms of aperture. However stringent requirements have been placed on the performance of the kickers and septa, particularly for extraction [1].

The design of the injection and extraction systems is governed by many constraints. Table 1 shows the important parameters; these have been optimised to minimise the lengths of the injection and extraction systems without exceeding physical limitations of the kickers and septa.

Table 1: DR Injection and Extraction Design Parameters

Kicker parameters	
Full horizontal aperture	12 mm
Voltage	±12.5 kV
Deflection angle	2.6 mrad
Available length	2.58 m
Thin septum parameters	
Full vertical aperture	5 mm
Gap field	0.19 T
Deflection angle	16 mrad
Available length	0.85 m
Thick septum parameters	
Full vertical aperture	5 mm
Gap field	0.91 T
Deflection angle	207 mrad
Available length	1.99 m
Cell lengths	
Inj/ext cell	9.36 m
Matching cell	3.09 m
Total	12.45 m

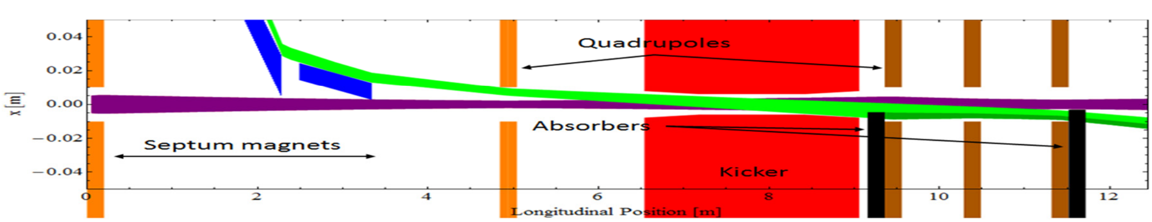

Figure 1: Diagram of the horizontal plane of the CLIC DR injection system and post injection absorbers.

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FAILURE MODE ANALYSIS

In order to design a suitable machine protection system for the PDRs, DRs and extraction lines, it is important to consider the prominent failure modes.

Failures can be separated into two categories: fast and slow failures. Fast failures lead to potentially unsafe beam conditions before a dynamic protection system can react; passive protection is required such as spoilers and absorbers. Slow failures occur over a long enough timescale that injection can be aborted or the beam can be dumped before any beam losses occur.

The injection and extraction kickers are powered by inductive adders which consist of a series of 20 layers providing up to 700 V each to the stripline kicker [2]. A failure of one or more of these layers and a complete misfire due to trigger mistiming are foreseen as the only potential fast failures. Estimated failure rates for the MOSFETs on the inductive adders suggest that three inductive adder layers failing simultaneously would constitute an 8σ event; therefore it is considered the worst case scenario for this type of failure. Tracking simulations in MADX have shown that the injection system can tolerate one inductive adder layer failing with no beam losses; for 2 or more layers failing, protective absorbers are required. The extraction system can tolerate two layers failing simultaneously due to the larger clearance. In the case of a complete misfire, the injected beam will hit the DR beam pipe shortly after the injection kicker; however a misfire on the extraction kicker is fail-safe as the beam will continue to circulate in the machine.

Slow failures include failures of the DC power supplies for the septum magnets and inductive adders. These failures would take of the order of 10-100 ms before they pose any risk to the machine, longer than the 2 ms response time for the proposed interlock system [3].

MACHINE PROTECTION SYSTEMS

The proposed machine protection for the CLIC DRs and extraction line will involve a passive protection system in the PDRs and DRs and an external dump system. The passive protection system consists of spoilers and absorbers and is designed to protect against mis-injected or extracted beams. The dump system will be used both during machine set-up and to remove potentially dangerous beams from the DRs (Fig. 2).

Passive Protection System

The most important criterion for the passive protection system is that it must be able to stop the entire bunch train in the event of a total injection kicker failure. In addition the protection system must be capable of preventing errant particles from hitting the DR aperture before the dump system can react; this is estimated to be 3-4 revolutions of the DR.

Absorbers situated just downstream of the injection kicker are foreseen to protect the machine in the event of a kicker misfire (Fig. 1); the first absorber is required to prevent particles colliding with the DR aperture before the second absorber. Due to the large injection emittance and low beam energy, spoilers are not required. An identical system of absorbers is placed in the matching cell downstream of the extraction system and spoilers are placed upstream of the septa in both the injection and extraction cells. Tracking simulations in MADX have shown that this is sufficient to protect against mis-injected beams. The spoiler upstream of the extraction septa is used to protect the septa in the event of an extraction kicker failure.

Figure 3 shows the phase space coverage of the DR passive protection over 4 turns of the ring; the tracking simulation was performed assuming 3 inductive adder layers failing simultaneously. The green points represent the mis-injected particles, the blue represent the properly injected particles and the red represent the mis-injected particles which are not absorbed.

External Dump System

In the CLIC DRs, the injection and extraction regions are the only suitable locations for a beam dump. A dedicated cell for the dump system would introduce an unacceptable increase in DR circumference; thus it is proposed to use the existing extraction system also as a beam dump.

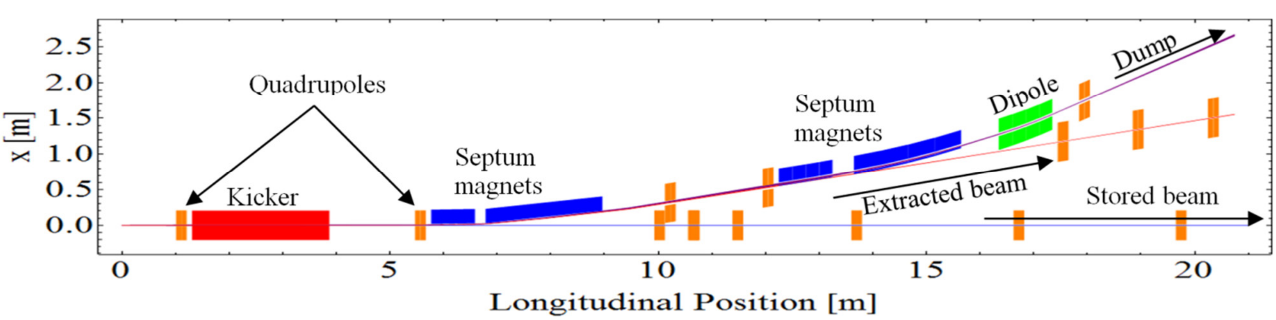

Figure 2: Diagram of the DR extraction system, extraction line and dump line.

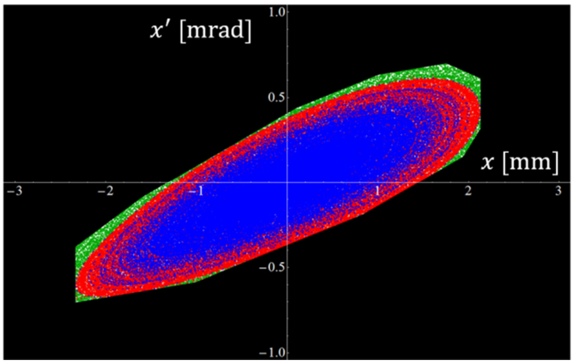

Figure 3: Phase space coverage of the DR passive protection system.

A combined extraction-dump system requires a kicker which can fire in two modes. The modular nature of the inductive adder design makes it ideal for such a purpose. The inductive adder layers would be separated into two banks. Bank 1 would be fired to extract the beam while both banks would be fired to dump the beam. An additional 5 kV provided by bank 2 ensure that the “dumped” and “extracted” trajectories are sufficiently separated. The potential effect of the second back upon ripple etc. of the extraction system requires further study.

In the extraction line, defocussing quadrupoles are used to enhance the trajectory separation such that septum magnets can be used (Fig. 2). The dumped beam is absorbed by a downstream dump block. To minimise cost the proposed septum magnets are identical to those used in the injection and extraction systems.

Further studies are required to determine whether the two inductive adder banks can be reliably triggered with a low failure rate; a summary of the failure modes is shown in Table 2. It is also important to design a suitable, redundant, triggering system to avoid occurrences of the potentially unsafe dump-mode failures.

Consideration of Absorber Material

Limited space in the CLIC DRs necessitates the use of a material with a short radiation length (X_0) for the spoilers and absorbers. However radiation due to Rutherford backscattering and secondary emission should also be minimised; this requires a low density material. Titanium coated with copper was chosen as the optimal compromise between radiation length, density and thermal properties; the copper coating reduces the beam coupling impedance. $5X_0$ has been calculated as the minimum suitable length for absorbers in the DR; this is approximately 20 cm for titanium.

The external beam dump is not limited by space, thus graphite is chosen due to its thermal properties and low density. A minimum of $10X_0$ should be used; this is approximately 1 m length of graphite.

Table 2: Summary of Failure Modes for a 2-mode Kicker

Mode: Expected:	**Extraction:** Bank 1 fires	**Dump:** Banks 1 and 2 fire
Bank 1 fires	Expected result: safe	~±0.5σ extracted: unsafe
Bank 2 fires	Hits septum spoiler: safe	Hits septum spoiler: safe
Banks 1 and 2 fire	Dumped: safe	Expected result: safe
Neither bank fires	Remains in DR: safe	Remains in DR: unsafe

EXTRACTION STABILITY REQUIREMENTS

To keep beam jitter below 0.1σ at the start of the Ring To Main Linac (RTML) transfer line, very tight tolerances are required for the stability of the kicker and septa at extraction; ±0.1% for the kickers and ±0.01% for the septa over a good field region of ±1 mm [1]. At present it is unlikely that these requirements can be met; this will ultimately lead to large emittance growth and jitter amplification at the entrance of the main linacs. Feed forward systems in the RTML are being proposed as a solution to relax the constraints on the kickers and septa [4].

CONCLUSIONS

The design of the injection and extraction systems has been optimised while minimising the length of the insertions. The optics has been matched to the existing optics and betatron tunes have been corrected.

Failure modes of the injection and extraction systems have been considered and the conclusions used to design appropriate machine protection. This consists of passive protection in the DRs and a novel combined function extraction-dump system. Further studies are needed to determine the feasibility of the 2-mode kicker required for the dump system.

The minimum achievable stability of the kickers and septa needs to be determined to define the requirements for possible RTML feed forward systems.

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