CLIC PRE-DAMPING AND DAMPING RING KICKERS: INITIAL IDEAS TO ACHIEVE STABILITY REQUIREMENTS

M.J. Barnes, L. Ducimetière, J. Uythoven, CERN, Geneva, Switzerland

Abstract

The Compact Linear Collider (CLIC) study is exploring the scheme for an electron-positron collider with high luminosity (10^{34} - 10^{35} $cm^{-2}s^{-1}$) and a nominal centre-of-mass energy of 3 TeV: CLIC would complement LHC physics in the multi-TeV range. The CLIC design relies on the presence of Pre-Damping Rings (PDR) and Damping Rings (DR) to achieve the very low emittance, through synchrotron radiation, needed for the luminosity requirements of CLIC. In order to limit the beam emittance blow-up due to oscillations the combined flat top ripple and droop of the field pulse, for the DR extraction kickers, must be less than 0.02%. In addition, the allowed beam coupling impedance is also very low: a few Ohms longitudinally and a few MΩ/m transversally. This paper discusses initial ideas for achieving the demanding requirements for the PDR and DR kickers.

INTRODUCTION

The LHC has begun to explore the TeV energy range: it is expected that high-energy e^+e^- colliders, such as CLIC [1], will be needed to help unravel the TeV physics, to be unveiled by the LHC. They would provide very clean experimental environments and democratic production of all particles within the accessible energy range, including those with only electroweak interactions. A schematic of the CLIC proposal is shown in Fig. 1.

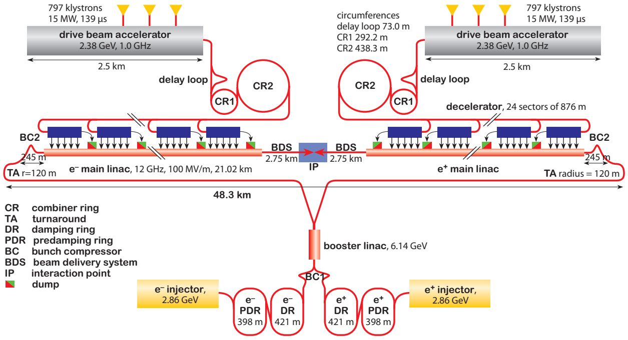

Figure 1: Proposed layout of CLIC facility.

The design of the injectors for CLIC is based on a central complex, housing all the subsystems, to prepare the main beams. The main beams are subsequently transported, via two long transfer lines, to the starting point of each main linac at the extremities of the collider facility. To achieve high luminosity at the Interaction Point (IP), it is crucial that the beams have very low transverse emittance: the Pre-Damping Ring (PDR) and Damping Ring (DR) "cool" the beam to an extremely low emittance in all three dimensions. The PDR is required to decouple the wide aperture requirements for the incoming positron beam from the final emittance requirements of the main linac. The design parameters of the PDR and DR are dictated by target performance of the collider (e.g. luminosity), the injected beam characteristics or compatibility with the downstream system parameters: the emittances of the positrons must be damped by several orders of magnitude [2].

Kickers are required to inject beam into and extract beam from the PDRs and DRs. Jitter in the magnitude of the kick waveform translates into beam jitter at the IP [2]. Thus the PDR & DR kickers, in particularly the DR extraction kicker, must have a very small magnitude of jitter. Table 1 shows the specifications for the PDR and DR kickers [3]: the specified stabilities include all sources of contributions such as ripple and droop. The values in Table 1 will be refined as the optics design progresses.

Table 1: PDR & DR Kicker Specifications

Parameter	**PDR**	**DR**
Beam Energy (GeV)	2.86	2.86
Deflection Angle (mrad)	2	1.5
Aperture (mm)	40	20
Field rise and fall time (ns)	700	1000
Pulse flat top duration (ns)	~160	~160
Flat top reproducibility	$1x10^{-4}$	$1x10^{-4}$
Injection stability (per system)	$\sim 2x10^{-2}$	$\sim 2x10^{-3}$
Extraction stability (per system)	$\sim 2x10^{-3}$	$\sim 2x10^{-4}$
Injection field homogeneity (%)	±0.1	±0.1
Extraction field homogeneity (%)	±0.1	±0.01
Repetition rate (Hz)	50	50
Available length (m)	~3.4	~1.7
Stripline pulse current [50 Ω load] (A)	±340	±250

BEAM COUPLING IMPEDANCE

The requirements for longitudinal and transverse broad band impedance, in the CLIC PDR & DR, are a few Ohms for longitudinal impedance and a few MΩ/m in the transverse plane: these values would result in beam stability against single bunch effects [4].

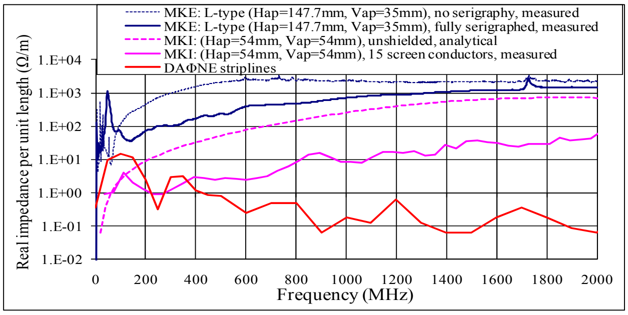

Figure 2: Real longitudinal beam coupling impedance, both with and without beam impedance reduction techniques, for an MKE magnet, an MKI magnet and DAΦNE striplines.

Fig. 2 shows the real part of the longitudinal beam coupling impedance for an SPS extraction (MKE) magnet

[5] and an LHC injection (MKI) magnet [6]. In addition the measured coupling impedance of DAΦNE striplines [7] is shown. Even with serigraphy, to reduce the beam coupling impedance, the MKE magnets are ~700 Ω/m at 1 GHz. The MKI magnets employ a more effective beam impedance reduction technique [6], but are well above the required few Ohms: their measured impedance is ~10 Ω/m at 1 GHz and ~40 Ω/m at 1.5 GHz. The DAΦNE striplines have a real longitudinal impedance of less than ~1 Ω/m for frequencies above 400 MHz: there is, however, a peak in the impedance spectrum of ~15 Ω/m at ~100 MHz. The impedance peak at 100 MHz can be reduced by increasing the length of the stripline taper [8]: computer simulations are planned to study this.

In conclusion, striplines are required to achieve adequately low longitudinal beam coupling impedance (Fig. 2): ferrite loaded kicker magnets are not feasible. Much research has been carried out, for ILC & DAΦNE, into tapered, elliptical cross-section, striplines and wide-band feedthroughs [7]. By tapering the transition between the stripline structure and the adjacent beam pipe it is possible to:

- reduce the non-uniformity of transverse deflection as a function of the transverse position;
- reduce the beam coupling impedance of the striplines;
- reduce the reflection coefficient at high frequency.

An elliptical cross section of stripline minimizes the variation of the vertical dimension of the beam pipe between the injection region and the adjacent dipole region and increases the deflection efficiency [7].

SYSTEM STABILITY

Ripple, Droop & Reproducibility

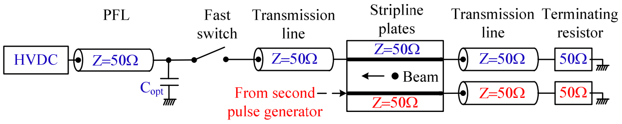

Figure 3: Simplified schematic of stripline kicker system.

Fig. 3 shows a simplified schematic of a stripline kicker system. The two striplines are driven to an equal magnitude of voltage but of opposite polarity. An High Voltage DC (HVDC) power supply charges a Pulse Forming Network (PFN) or a Pulse Forming Line (PFL). The fast switch is then closed to launch a pulse towards the striplines (note: for simplicity, Fig. 3 only shows one of the two HVDC supplies, PFL/PFN and fast switches). The pulse propagates through the striplines and is then deposited in a terminating resistor. The characteristic impedance of the PFL/PFN, transmission lines, striplines and terminating resistors is matched to avoid reflections, which would cause ripple on the flat top of the deflection waveform. Possible sources of ripple, droop and irreproducibility of the deflection waveform include:

- PFN: a PFL will likely give lower ripple;
- HVDC supplies (reproducibility is expected to be acceptable for slow charging of PFL/PFN);
- Attenuation in the PFL and transmission lines;
- Switch (dynamic characteristic, and both short term and long term temperature effects);
- Feedthroughs;
- Terminator (frequency dependence of value, long-term stability and temperature will affect ripple and reproducibility of the waveform);
- Non-ideal impedance matching of the system.

Double Kicker System

Extraction from the DR with a single kicker system requires a very uniform and stable field pulse with ultra-low ripple (see Table 1). A double kicker system (Fig. 4), consisting of two identical ferrite loaded kicker magnets and a single power supply, has been developed at KEK [9]. The first kicker extracts the beam from a damping ring and the second kicker, displaced from the first kicker by a suitable Betatron phase, results in anti-phase ripple to that of the first kicker (Fig. 5).

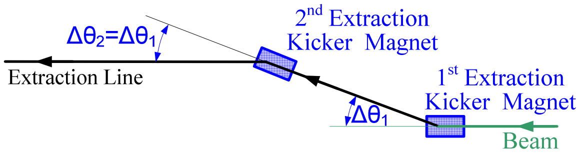

Figure 4: 1st and 2nd kickers separated by a betatron phase of 2nπ: for a betatron phase of (2n−1)π the 2nd kick would be in the other direction.

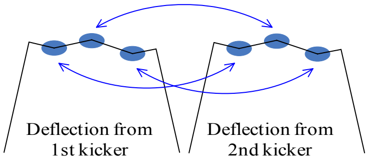

Figure 5: Exactly the same flat top ripple from both kickers ideally results in ripple cancellation.

Theoretically, using a double kicker system, the effect of ripple in the two kickers and small variations in the output of the HVDC supplies can completely cancel: however, the KEK double kicker achieved a factor of ~3.3 reduction in kick jitter angle, with respect to a single kicker [9]. The fact that the improvement was not more is most likely due to errors in both the optics and in estimating horizontal displacement (due to insufficient position resolution of the BPMs [9]). Research is planned at CERN, into double kicker systems, to try and achieve a greater improvement in jitter reduction.

For CLIC, assuming a 10 m separation between the 1st and 2nd kickers, the time of flight is ~33.3 ns for beam and ~50 ns for the kicker current pulse. In order that the beam bunches and kicker field are synchronized in time at the 2nd kicker system either:

- the two kicker systems must be in parallel, or;
- for a series connection a ~16.7ns delay loop is required for the beam.

Feeding two parallel kickers, from a common HVDC supply and single switch (Fig. 6) is the best option.

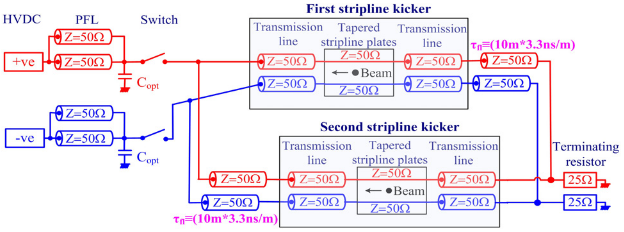

Figure 6: Double kicker system supplied in parallel.

Compensation of Droop

One of several problems, for deflection stability, is PFL droop. PFL gives low ripple pulses, but low attenuation is essential (especially with longer pulses) to control droop and "cable tail". However it is possible to make use of the frequency dependent attenuation, of the transmission line, to compensate for PFL droop (Fig. 7), but increased cable tail is a potential problem.

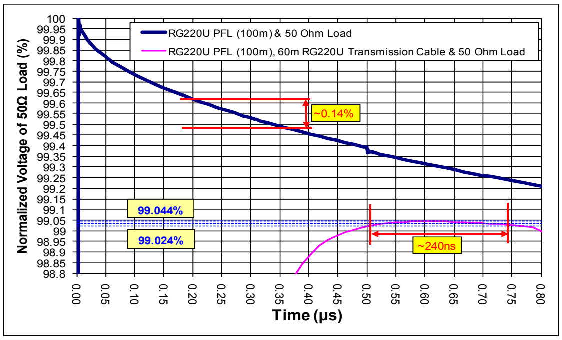

Figure 7: PSpice predictions for load current, for a 100 m long PFL of RG220U coax with a transmission line that is (a) lossless, (b) 60 m of RG220U.

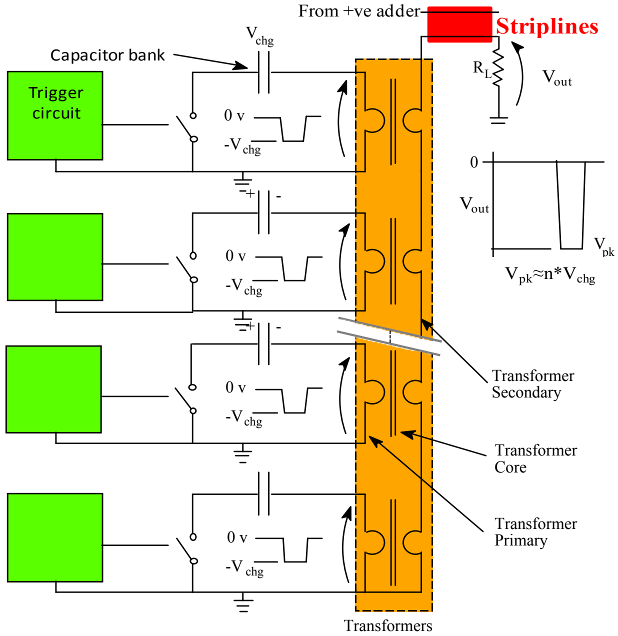

Figure 8: Multi-cell inductive adder.

Fig. 7 shows PSpice predictions for load current, for a 100 m long PFL of RG220U coax, with a transmission line that is firstly modelled as lossless then subsequently is modelled as 60 m of RG220U coax. In both cases an ideal 50 Ω load is modelled. Over a 160 ns period the lossless transmission line gives a predicted droop of 0.14%; when the 60 m of RG220U is modelled, the load current is flat to within ±0.01% over a 240 ns period.

Inductive Adder

An Inductive Adder [10] may be a promising means of compensating for losses in the PFL and transmission lines. The adder (Fig. 8) consists of: a multi-cell primary circuit, a single secondary winding, and a fast pulse transformer with adequate voltage isolation. Each primary circuit has a fast switch. The switches can be turned on and off independently, via trigger circuits, to provide some pulse shaping. Many cells may be required to achieve fine control over the pulse shape (to be studied further). The inductive adder concept is also good for machine protection and reliability (redundancy).

CONCLUSIONS

Striplines are required to achieve adequately low longitudinal beam coupling impedance for the PDR & DR. Several promising ideas, to achieve the very demanding specifications for repeatability and stability, have been discussed: the double kicker system and inductive adder will both be studied in detail, as will the injection and extraction optics.

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