CERN – EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CLIC – Note – 965

CONCEPTUAL DESIGN OF THE CLIC DAMPING RINGS

Papaphilippou, Y (CERN) ; Antoniou, F (CERN) ; Barnes, M (CERN) ; Calatroni, S (CERN) ; Chiggiato, P (CERN) ; Corsini, R (CERN) ; Grudiev, A (CERN) ; Koukovini, E (CERN) ; Lefevre, T (CERN) ; Martini, M (CERN) ; Modena, M (CERN) ; Mounet, N (CERN) ; Perin, A (CERN) ; Renier, Y (CERN) ; Russenschuck, S (CERN) ; Rumolo, G (CERN) ; Schoerling, D (CERN) ; Schulte, D (CERN) ; Schmickler, H (CERN) ; Taborelli, M (CERN) ; Vandoni, G (CERN) ; Zimmermann, F (CERN) ; Zisopoulos, P (CERN) ; Boland, M (ASCo, Clayton, Victoria) ; Palmer, M (Cornell U., CLASSE) ; Bragin, A (Novosibirsk, IYF) ; Levichev, E (Novosibirsk, IYF) ; Syniatkin, S (Novosibirsk, IYF) ; Zolotarev, K (Novosibirsk, IYF) ; Vobly, P (Novosibirsk, IYF) ; Korostelev, M (Cockcroft Inst. Accel. Sci. Tech.) ; Vivoli, A (Fermilab) ; Belver-Aguilar, C (Valencia U., IFIC) ; Faus-Golfe, A (Valencia U., IFIC) ; Rinolfi, L (JUAS, Archamps) ; Bernhard, A (Karlsruhe, Inst. Technol.) ; Pivi, M (SLAC) ; Smith, S (SLAC) ; Rassool, R (Melbourne U.) ; Wootton, K (Melbourne U.)

Abstract

The CLIC Damping rings are designed to produce unprecedentedly low-emittances of 500 nm and 5 nm normalized at 2.86 GeV, with high bunch charge, necessary for the performance of the collider. The large beam brightness triggers a number of beam dynamics and technical challenges. Ring parameters such as energy, circumference, lattice, momentum compaction, bending and superconducting wiggler fields are carefully chosen in order to provide the target emittances under the influence of intrabeam scattering but also reduce the impact of collective effects such as space-charge and coherent synchrotron radiation. Mitigation techniques for two stream instabilities have been identified and tested. The low vertical emittance is achieved by modern orbit and coupling correction techniques. Design considerations and plans for technical systems, such as wigglers, transfer systems, vacuum, RF cavities, instrumentation and feedback are finally reviewed.

Presented at: 3rd International Particle Accelerator Conference 2012, New Orleans, LA, USA, 20 - 25 May 2012

Geneva, Switzerland
Date 20/05/2012

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN – ACCELERATORS AND TECHNOLOGY SECTOR

CERN-ATS-2012-176

Conceptual Design of the CLIC Damping Rings

Y. Papaphilippou, F. Antoniou, M. Barnes, S. Calatroni, P. Chiggiato, R. Corsini, A. Grudiev, E. Koukovini, T. Lefevre, M. Martini, M. Modena, N. Mounet, A. Perin, Y. Renier, S. Russenschuck, G. Rumolo, D. Schoerling, D. Schulte, H. Schmickler, M. Taborelli, G. Vandoni, F. Zimmermann, P. Zisopoulos, CERN, Geneva, Switzerland, M. Boland, ASCo, Clayton, Victoria, M. Palmer, CLASSE, Ithaca, New York, A. Bragin, E. Levichev, S. Syniatkin, K. Zolotarev, P. Vobly, BINP SB RAS, Novosibirsk, M. Korostelev, Cockcroft Institute, Warrington, Cheshire, A. Vivoli, Fermilab, Batavia, C. Belver-Aguilar, A. Faus-Golfe, IFIC, Valencia, L. Rinolfi, JUAS, Archamps, A. Bernhard, KIT, Karlsruhe, M. Pivi, S. Smith, SLAC, Menlo Park, California, R. Rassool, K. Wootton, The University of Melbourne, Melbourne

Abstract

The CLIC Damping rings are designed to produce unprecedentedly low-emittances of 500 nm and 5 nm normalized at 2.86 GeV, with high bunch charge, necessary for the performance of the collider. The large beam brightness triggers a number of beam dynamics and technical challenges. Ring parameters such as energy, circumference, lattice, momentum compaction, bending and superconducting wiggler fields are carefully chosen in order to provide the target emittances under the influence of intrabeam scattering but also reduce the impact of collective effects such as space-charge and coherent synchrotron radiation. Mitigation techniques for two stream instabilities have been identified and tested. The low vertical emittance is achieved by modern orbit and coupling correction techniques. Design considerations and plans for technical systems, such as wigglers, transfer systems, vacuum, RF cavities, instrumentation and feedback are finally reviewed.

Presented at the International Particle Accelerator Conference (IPAC'12) –

May 20-25, 2012, N. Orleans, USA

Geneva, Switzerland, May 2012

Conceptual Design of the CLIC Damping Rings

Y. Papaphilippou, F. Antoniou, M. Barnes, S. Calatroni, P. Chiggiato, R. Corsini,
A. Grudiev, E. Koukovini, T. Lefevre, M. Martini, M. Modena, N. Mounet, A. Perin,
Y. Renier, S. Russenschuck, G. Rumolo, D. Schoerling, D. Schulte, H. Schmickler,
M. Taborelli, G. Vandoni, F. Zimmermann, P. Zisopoulos, CERN, Geneva, Switzerland
M. Boland, ASCo, Clayton, Victoria, M. Palmer, CLASSE, Ithaca, New York,
A. Bragin, E. Levichev, S. Syniatkin, K. Zolotarev, P. Vobly, BINP SB RAS, Novosibirsk,
M. Korostelev, Cockcroft Institute, Warrington, Cheshire, A. Vivoli, Fermilab, Batavia,
C. Belver-Aguilar, A. Faus-Golfe, IFIC, Valencia, L. Rinolfi, JUAS, Archamps,
A. Bernhard, KIT, Karlsruhe, M. Pivi, S. Smith, SLAC, Menlo Park, California,
R. Rassool, K. Wootton, The University of Melbourne, Melbourne

Abstract

The CLIC Damping rings are designed to produce unprecedentedly low-emittances of 500 nm and 5 nm normalised at 2.86 GeV, with high bunch charge, necessary for the performance of the collider. The large beam brightness triggers a number of beam dynamics and technical challenges. Ring parameters such as energy, circumference, lattice, momentum compaction, bending and superconducting wiggler fields are carefully chosen in order to provide the target emittances under the influence of intrabeam scattering but also reduce the impact of collective effects such as space-charge and coherent synchrotron radiation. Mitigation techniques for two stream instabilities have been identified and tested. The low vertical emittance is achieved by modern orbit and coupling correction techniques. Design considerations and plans for technical systems, such as wigglers, transfer systems, vacuum, RF cavities, instrumentation and feedback are finally reviewed.

LAYOUT AND DESIGN PARAMETERS

The CLIC Damping Rings' (DRs) purpose is to "cool" the incoming beams to the very small emittances needed for collisions. Their design goals are guided by the main parameters of the collider and the requirements of the upstream and downstream systems. In order to achieve this, four rings are necessary schematically shown in Fig. 1. Two pre-damping rings (PDRs) are needed due to the large input emittance especially coming from the positron source and the high repetition rate. Due to the huge positrons' emittance to be captured, their design targets a large transverse dynamic aperture and momentum acceptance [1]. Most of the parameter choices of the CLIC main DRs are driven from the ultra-low emittance requirements at their output.

The high bunch intensity of 4.1×10^9 has to be delivered with ultra low horizontal and vertical normalised emittances of 500 nm.rad and 5 nm.rad. These low emittances, although unprecedented, are rapidly approached by modern light sources in operation or in construction [2]. What diversifies the required beam characteristics is the very small longitudinal normalised emittance of 6keV.m, imposed by the bunch compression requirements [3]. This increased beam density triggers a number of single bunch collective effects. Two stream phenomena such as ions or electron cloud build up can be amplified by the short bunch spacing of only 0.5 ns, making the vacuum technology and the photon absorption scheme quite demanding. The short bunch spacing is also creating a high peak current as seen by the RF cavities, which needs a very challenging low level system to cope with the beam loading transients. In addition, a high frequency (2GHz) pulsed RF power source is not technologically available. For relaxing this, two trains are injected with half the RF frequency and then recombined with an RF deflector in a common delay loop. The small emittance has to be extracted in a very stable and reproducible way imposing tight stability tolerances in the extraction systems. The DR design parameters are summarised in Table 1. The two columns correspond to the different parameters for the 2 and 1 GHz RF frequency options.

BEAM DYNAMICS AND TECHNOLOGY

It was revealed at an early stage of the design [4] that, due to the very high bunch charge and small 3D beam size, the steady state emittances are dominated by Intra-beam scattering (IBS). The design strategy followed [5–8] was

Figure 1: A schematic view of the DRs' complex, with blue the DRs for positrons and red for electrons. A single delay and recombination loop (black) is used for both species.

Table 1: Design parameters for the main DRs.

Parameters, Symbol [Unit]	2 GHz	1 GHz
Energy, E [GeV]	2.86	
Circumference, C [m]	427.5	
Bunch population, N [10^9]	4.1	
Basic cell type in the arc/LSS	TME/FODO	
Number of dipoles, N_d	100	
Dipole Field, B_0 [T]	1.0	
Norm. gradient in dipole [m^{-2}]	-1.1	
Hor., ver. tune, (Q_x,Q_y)	(48.35,10.40)	
Hor., ver. chromaticity, (ξ_x,ξ_y)	(-115,-85)	
Number of wigglers, N_w	52	
Wiggler peak field, B_w [T]	2.5	
Wiggler length, L_w [m]	2	
Wiggler period, λ_w [cm]	5	
Damping times, (τ_x, τ_y, τ_l) [ms]	(2.0,2.0,1.0)	
Momentum compaction, α_c [10^{-4}]	1.3	
Energy loss/turn, U [MeV]	4.0	
Norm. hor. emittance, $\gamma\epsilon_x$ [mm·mrad]	472	456
Norm. ver. emittance, $\gamma\epsilon_y$ [mm·mrad]	4.8	4.8
Energy spread (rms), σ_δ [%]	0.1	0.1
Bunch length (rms), σ_s [mm]	1.6	1.8
Long. emittance, ϵ_l [keVm]	5.3	6.0
IBS factors hor./ver./long.	1.5/1.1/1.2	1.5/1.1/1.2
RF Voltage, V_{RF} [MV]	4.5	5.1
Stationary phase [^{o}]	62	51
Synchrotron tune, Q_s	0.0065	0.0057
Bunches per train, n_b	312	156
Bunch spacing, τ_b [ns]	0.5	1
RF acceptance, ϵ_{RF} [%]	1.0	2.4
Harmonic number, h	2851	1425

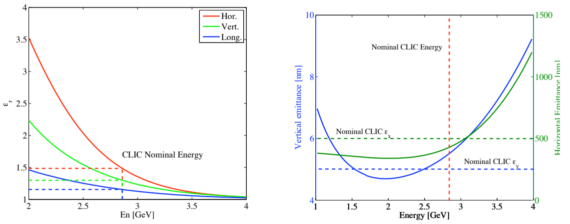

Figure 2: Dependence of the IBS growth factor, i.e. ratio between steady state and equilibrium emittances (left) and steady state emittances (right) with energy.

to raise the ring energy, change the optics, adapt the wiggler parameters and increase slightly the longitudinal emittance in order to mitigate as much as possible the IBS effect, down to a factor of 1.5, with respect to the equilibrium horizontal emittance. In particular, the scaling of the ratio between the steady state and zero current emittances with the energy is shown in the left part of Fig. 2. The IBS effect is reduced for higher energies as expected. The dependence of the steady state emittances to the energy is displayed on the right part of Fig. 2. A broad minimum is observed around 2.0 GeV for the horizontal and vertical emittances, where the IBS effect also becomes weaker. Although higher energies may be also interesting for reducing further collective effects, the output emittance is strongly increased due to the domination of quantum excitation. In this respect, the energy of 2.86 GeV was chosen which is close to a steady state emittance minimum but also reduces the IBS impact [5].

The optics functions of a quarter of the ring, are shown in Fig. 3. Each arc is filled with 48 TME cells and 2 half cells at either side for the dispersion suppression. A series of optimisation steps was followed in order to rationalise the TME cell and, at the same time, to reduce the effect of IBS [6]. A defocusing gradient in the bending magnet can reduce further the emittance but also reverses the behaviour of the vertical beta at the centre of the dipole, hence reducing the IBS growth rate. As the final emittance of the ring can be further reduced by the use of damping wigglers in the straight sections, which provide also the fast damping, a detuned TME cell was designed, which is more flexible, easier to achieve and has lower chromaticity. Due to the very small beam size especially in the vertical plane, the space charge tune-shift can also be quite important. For reducing it to around 0.1, and apart from the short ring circumference, the bunch length had to be increased to the maximum acceptable level, by tuning the TME cell to an increased momentum compaction factor.

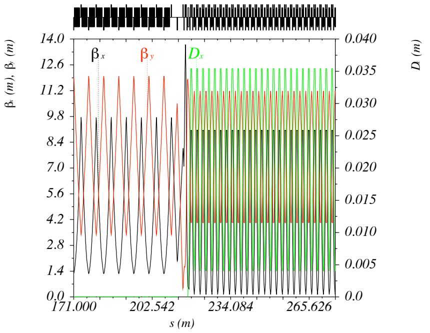

Figure 3: Horizontal (black) vertical (red) beta functions and horizontal dispersion (green) of a quarter of the DR.

The long straight sections are filled with FODO cells and accommodate the damping wigglers. There are 13 FODO cells per straight section with two wigglers per cell. Further emittance minimisation can be made by properly choosing the lattice functions in the wiggler [7]. The highest wiggler field and relatively short period is needed in order to reach the target emittances [8] and the only way to combine both parameters is by using super-conducting technology. A simulation was performed by computing the IBS effect on the emittance for different wiggler peak fields and periods, while keeping the final vertical and longitudinal ones fixed (Fig. 4). The highest field and the shortest period is indeed necessary for reaching the smallest emittance possible (right plot). On the other hand, the effect of IBS in that case becomes extremely strong (left plot). For reducing the blow-up due to IBS, still the highest fields are interesting but for moderate period lengths.

A short prototype with 2.5 T peak field and 50 mm period, based on NbTi technology, was developed and measured at Budker Institute achieving the field requirements. Another mock-up with more challenging design (2.8 T field, with 40 mm period) wound with Nb_3Sn wire is also under testing at CERN [9]. Around 9kW of total power is produced by each wiggler and an absorption system is nec-

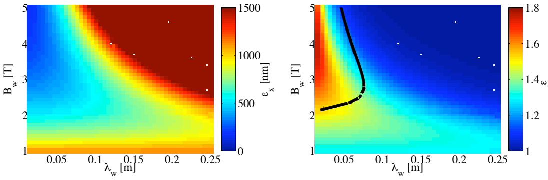

Figure 4: Dependence of the steady state emittance (left) and its ratio with the equilibrium emittance (right) as a function of the wiggler peak field and period.

essary and critical to protect machine components and wigglers against quench, but also to lower the photo emission yield for reducing the e-cloud effect in the positron ring. The power limit is set between 1 and 10 W/m, depending the wire technology and the vacuum chamber cooling. A series of horizontal and vertical absorbers are placed downstream of the wigglers [10]. Full wiggler prototypes with similar magnetic characteristics are expected to be built at BINP and installed at a straight section of the ANKA synchrotron for tests under beam conditions.

The vertical emittance at "zero current" is dominated by vertical dispersion and less by coupling, so in order to achieve it, apart from tight alignment tolerances, a very good correction and control of the orbit is necessary [11]. The geometrical target emittance of less than 1 pm is the present achieved record in synchrotron light source storage rings for similar energies and bunch currents [12]. The dynamic aperture (DA) of the DRs is comfortable, although a more detailed working point optimisation is needed with simulations including the non-linear effect of wigglers and the space charge tune-shift [13]. An enlarged DA can potentially allow the elimination of the e^- PDR.

The very high peak and average current corresponding to the full train of 312 bunches spaced by 0.5ns presents a big challenge due to the transient beam loading, especially for a 2GHz RF system. In this respect, it was decided to consider two trains with 1ns bunch spacing. This reduces significantly the beam loading, the RF system with frequency of 1GHz is more conventional and an extrapolation from existing designs is possible [18]. Nevertheless, the trains have to be recombined in a delay loop downstream the DRs with an RF deflector. The increased bunch spacing has also a positive impact with respect to collective effects and associated feedback systems.

High bunch density in combination with the short bunch spacing triggers two stream instabilities. In the electron ring, the fast ion instability can be avoided with ultra-low vacuum pressure [14]. This necessitates coating of vacuum chambers with getters like NEG for increasing pumping in addition to vacuum conditioning. In order for the electron cloud build up to be reduced and the instability not to occur in the positron ring, it is necessary that the vacuum chambers present a low secondary electron and photoemission yield (SEY and PEY) [15]. The low SEY can be achieved with special chamber coatings such as amorphous carbon [16], whereas the low PEY is already imposed by the required absorption efficiency to reduce the heat deposition in the super-conducting magnets. In addition, the increased bunch spacing with the two trains scheme, indeed relaxes the above requirements.

Regarding single bunch instabilities, a transverse impedance budget of 4 MΩ/m was computed based on a broad-band resonator model, for different chromaticities [17]. Wigglers made from copper showed higher instability thresholds than for stainless steel and the use of aC or NEG does not seem to be critical in terms of instabilities. The rise time of the coupled bunch modes caused by resistive wall were estimated by an analytical formula to be around 0.3 ms for the 1GHz case corresponding to about 210 turns and can be damped with a transverse feedback. The rise time computed by a multi-particle simulation was even larger by about a factor 5-10, as the simulation takes into account the real lattice and train length.

An extraction kicker ripple produces a beam size jitter which is propagated up to the collider IP. On the other hand, injection kicker jitter is translated to reduction of the beam stay clear, during the injection process. For both processes, a typical tolerance of 10% of the beam size at extraction or injection is considered). The relative deflection stability requirement translates to a kicker stability tolerance of the order of 10^{-4}. Strip-lines are required for achieving low longitudinal coupling impedance. The kicker systems are technologically challenging and significant R&D is needed for PFL (or alternative), switch, transmission cable, feedthroughs, strip-line and terminator. A strip-line is currently prototyped under the Spanish Program "Industry for Science" and collaboration is set-up with ALBA and ATF for beam tests [19].

REFERENCES

[1] F. Antoniou, Y. Papaphilippou, EPAC 2008, Genova, 2008.

[2] LER Workshops, http://ler2010.web.cern.ch, http://lowering2011.web.cern.ch.

[3] F. Stulle et al., IPAC 2010, Kyoto, 2010.

[4] M. Korostelev, PhD thesis, EPFL, Lausanne 2006.

[5] Y. Papaphilippou et al., EPAC 2008, Genova, 2008.

[6] Y. Papaphilippou et al., PAC 2009, Vancouver, 2009.

[7] H. Braun, et al., CLIC-Note-849, 2010.

[8] F. Antoniou, et al., WEPW085, IPAC2010, Kyoto, 2010.

[9] D. Schoerling et al, PRST-AB 15, 042401 (2012).

[10] K. Zolotarev, et al., CLIC Note, 2009, in preparation.

[11] K.P.Wooton, et al., IPAC 2011, San Sebastian, 2011.

[12] M. Aiba et al., preprint.

[13] Y. Renier et al., IPAC 2011, San Sebastian, 2011.

[14] G. Rumolo, et al., EPAC 2008, Genova, 2008.

[15] G. Rumolo, et al., EPAC 2008, Genova, 2008.

[16] C. Yin Valgren, et al., PRST-AB 14, 071001, 2011.

[17] E. Koukovini et al., IPAC 2011, San Sebastian, 2011.

[18] A. Grudiev, TUPPR026, these proceedings.

[19] C. Belver-Aguilar et al., TUPPR016, these proceedings.