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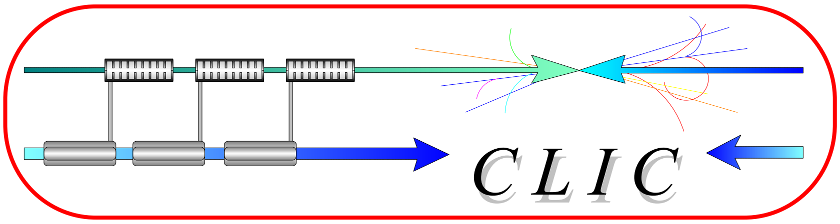

CLIC Note 384

CLIC Study – Activities Report

(Summarised by I. Wilson for the CLIC Study Group)

Geneva, Switzerland
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CLIC Study - Activities Report 1998

(Summarised by I.Wilson for the CLIC study group)

During 1998 the focus of the CLIC study was changed from a 0.5-1 TeV collider to a 0.5-5 TeV collider. The increased energy reach became possible after making several important modifications to the RF power generation system. The parameters have been optimised for a centre-of-mass energy of 3 TeV and follow the general scaling laws for the rational design of an e+e- linear collider that were derived last year. In order to limit the overall extension of the complex to less than 35 km it has been assumed that the collider will operate at a loaded accelerating gradient of 150 MV/m. Such a high gradient is only possible because CLIC has the relatively high RF operating frequency of 30 GHz. The revised CLIC parameter list has a luminosity of $10.6 \times 10^{34} cm^{-2} s^{-1}$ for the 3 TeV machine with 150 bunches per pulse and an overall wall plug power of 206 MW. To obtain this luminosity it has been necessary to allow the mean energy loss during the collision process to go as high as 32% with a beamstrahlung parameter of 8.7. Even with such a strong beam-beam interaction the luminosity spectrum is still acceptable with more than 30% of the luminosity within 1% of the peak colliding beam energy. To reduce transverse wakefield effects the number of particles per bunch and the bunch length have been reduced to 4×10^9 and 30µm respectively for a multi-bunch spacing of 20 cm. Simulations show that under these conditions a normalised vertical emittance at the interaction point of 10^{-8} rad.m can be obtained. The parameters for the lower energy (0.5 and 1 TeV) machines are in general less demanding than for 3 TeV but at 5 TeV the parameter set looks very ambitious but cannot be considered out of reach.

An alternative final focus design with a small crossing angle (5 mrad) which does not require the use of crab-crossing cavities has been proposed for the 0.5 TeV centre-of–mass machine. The design is much simpler but results in a 20% loss of luminosity.

Beam dynamics studies have focused on single and multibunch emittance preservation in the main linacs for the 3 TeV machine. The overall emittance blow-up is kept to a reasonable value by the use of local bumps which are created at about 10 positions along the linac by mis-aligning a few upstream cavities. In order to obtain a good beam stability with small emittances, the lattice has to be optimised to take into account both static and time-varying mis-alignments. Simulations of the effects of ground-motion, and beam and quadrupole jitter show that after a certain time (typically a few days) the use of bumps and the application of the one-to-one correction scheme are insufficient to keep the emittance small and the whole machine has then to be re-aligned using a beam-based remote control system which repositions the support girders. A new analytical treatment of the dynamics of a single bunch in the presence of wakefields has been developed to complement the information provided by simulation programs and to get a better understanding of how the key parameters affect the stability of the main beam. The analysis provides closed expressions for the transverse off-sets inside the bunch, the tune shifts and the emittance growth. To obtain stable beams with multiple bunches requires a careful design of the accelerating structure to obtain a strong damping of the long-range transverse wakefields. Design studies have focused on the new Tapered Damped Structure (TDS). Each cell of the TDS is damped by its own set of radial waveguides resulting in a Q of 16 for the lowest dipole mode. The structure also has a detuning spread of 5.4%. The top two priorities of the study this year have been to develop a suitable waveguide load and to prepare for an experimental verification of the wakefield performance in the SLAC facility ASSET. A suitable low reflection coefficient (< 0.1), inexpensive and robust silicon carbide load has been developed and tested. Special procedures were developed to measure the complex permittivity of materials like silicon carbide and as a result it was possible to design the load directly using computer modelling techniques. The ASSET test will provide a direct measurement of the TDS transverse wake. The electromagnetic and mechanical design of the test structure has been completed and fabrication has begun. The test structure is a times-2 scaled version of the CLIC design to avoid beam aperture limitations in the ASSET facility. A new "wave number" method of calculating the wake has been developed to improve the understanding of the interaction of a beam with a damped periodic structure. The method which is based on the direct computation or measurement of the propagation characteristics of the higher order modes will provide a second independent estimation of the TDS wakefield.

A new multi-drive-beam-generation scheme has been developed which uses a conventional normal-conducting fully-loaded 937 MHz linac to produce the initial bunch trains. An 8A 91 μs beam with an energy of about 1.2 GeV is required and can be generated with an efficiency of about 97%. The bunches are produced by two separate injectors each consisting of a thermionic gun and a small number of normal-conducting buncher/accelerating structures. The two trains of bunches are then combined by a RF deflector to form a continuous beam. The 937 MHz linac is powered by conventional long pulse klystrons. After acceleration, the beam passes through a complex composed of a delay-line combiner and two combiner rings, where groups of leading bunches are delayed to fill in the gaps between trailing bunches. The net effect is to convert the long beam pulse to a periodic sequence of drive beam pulses with gaps in between. Each pulse has 32 times the initial current, while the bunch spacing is 32 times smaller. This sequence of pulses is distributed from the end of the linac against the main beam direction down a common transport line. Pulsed kicker magnets deflect each pulse at the appropriate time into a turn around. After a turn-around each drive beam pulse is decelerated in a 700 m long sequence of low-impedance decelerating structures, and the resulting output power is transferred to the main linac where it is used to accelerate the high-energy beam. At the end of each 700 m long section the drive beam pulse is dumped and a new one takes over the job of accelerating the main beam. The complex can be upgraded or downgraded to other energies by simply changing the initial pulse length.

In the drive beam accelerator beam stability is very important, particular attention has been given to the focusing required, the amount of cavity damping and detuning needed, injection and quadrupole jitter effects, alignment tolerances, and steering. Preliminary layouts of isochronous lattices for the delay-line, the combiner-rings and the turn-arounds have been proposed. The same is true for the chicanes for the path length adjustment and the bunch compressors both of which have special characteristics due to the unusual energy correlation in the drive-beam bunches. For the drive beam decelerator, the studies have focused on the control of the beam size and eventual beam losses for cavities without rotational symmetry, for non-linearly varying wakefields with transverse displacement, for strong energy variations along the train, and for a large bunch energy spread.

Development studies have continued on the 30 GHz power generating transfer structures. The Mafia code work first concentrated on a four-channel structures with inner diameters of 20 and 24 mm and R'/Q's of 100 and 62 Ohm/m respectively. Six-channel and eight-channel structures with larger apertures were also investigated

because they have a better field homogeneity for the decelerating mode. These multi-channel structures are appreciably more difficult to manufacture, especially since damping slits (to damp transverse beam break-up modes) are necessary.
Preliminary studies of all components of this new drive beam generation complex have been completed and are summarised in CLIC Note 364.
Design solutions for the main beam injector are for the moment limited to a centre-of-mass energy collider of 1 TeV with 150 bunches and a repetition rate of 150 Hz. The linacs are now based on 1.5 GHz and 3 GHz normal-conducting accelerating structures. Simulations for the positron production show an adequate yield. Beam simulations indicate that the present design consisting of one pre-damping ring and one damping ring can give the required vertical normalised emittance of 5×10^{-8} rad.m at the entrance to the main linacs. Further studies with a revised damping ring design will be necessary to obtain the even smaller emittances required for the higher energy machines. It has been shown that the required 30µm long bunches can be obtained using a two-stage bunch compressor with a total compression factor of 100.

As in previous years a considerable fraction of the CLIC effort during 1998 was devoted to CTF2. The drive beam RF-gun which was limited to a gradient of about 75 MV/m last year has been replaced by its reserve. This new gun quickly reached a gradient of 110 MV/m on the cathode and this was maintained throughout the year. The 1m long NAS S-band structure of the drive beam accelerator has been replaced by two high charge accelerating structures (HCS). These structures were designed and made in close collaboration with LAL-Orsay. The conditioning of the HCS's was much more difficult. Due to the unusual 11/12π-mode utilised in these structures a transient power reflection occurs, causing considerable problems to the klystrons. This problems was fixed by introducing a sophisticated amplitude and phase program along the RF pulse. Another problem is the overvoltage in the coupling cells, which resulted from the very difficult matching of the couplers to the 11/12π-mode. This limits the average accelerating field in HCS to about 35 MV/m, compared to the design value of 60 MV/m. With the installation of the HCS's the two frequency beam loading compensation for the drive beam accelerator became operational and has produced results which confirm the theoretical predictions. This is the first time that such a scheme has been used for heavy beam loading conditions.

A total charge of 755 nC in 48 bunches has been produced by the drive beam photo-cathode and accelerated in the HCS's. This is more than the design value of 640 nC. The maximum accelerated single bunch charge was 112 nC. Both are unprecedented values for RF-photoinjectors. However, it was not possible to transport more than 374 nC through the 30 GHz drive beam decelerator. Reasons for this are the too low gradient in the HCS's, a still incomplete understanding of the transverse dynamics, and problems with beam diagnostics and radiation at high charges. A systematic study of these problems was hampered by the inability of the laser/photocathode system to provide high charges for periods longer than 2-3 days as explained in more detail below.

The higher drive beam charge (compared to 1997) substantially increased the 30 GHz power transferred to the main beam. The resulting accelerating field in the 30 GHz probe beam accelerator was 59 MV/m using a configuration where the four outputs of a 0.5 m long power extraction structures are used to feed one accelerating structure. Agreement between predicted and measured acceleration was reasonable. In a dedicated test with a 1 m long power extraction structure accelerating gradients of up to 69 MV/m have been achieved. The maximum field was always limited by the drive beam charge and not by breakdowns in the 30 GHz structures and networks.

Secondary emission wires were installed in the two drive beam magnet spectrometers and the end of line probe beam spectrometer to get better quantitative measurements of the beam energy spectra. Using this new equipment it was found that the drive beam deceleration of both single bunch and multibunch beams produced by a four-channel damped power extraction structure were 60% higher than expected. The output power levels (as predicted by structure parameters) were however correct. This discrepancy is a major concern and needs further analysis and experimentation.

No equipment failure or malfunction occurred in the two 30 GHz modules and all systems have functioned correctly in the high radiation CTF environment. In particular the active alignment system held the components in position to within ± 2 microns. During 1998, two more modules were prepared for installation in the CTF in early 1999. This second pair are nearly identical to the first pair but contain a new alignment-motor control system.

Rubidium Telluride photocathodes were successfully tested in the CTF, exhibiting similar performances to the by-now standard Cesium Telluride photocathodes. The new materiel has the advantage that it can be regenerated to a quantum efficiency of about 1% after exposing it to air. The CTF probe beam photocathode (CsI+Ge) is still functioning after two years operation. A photocathode preparation chamber is being assembled for the probe beam gun and will result in several advantages. It will permit a simplified production of photocathodes and allow them to be removed and replaced under vacuum, it will also provide a reliable alignment aid for the laser. In particular it will be possible to activate GaAs photocathodes in situ.

The Optical Parametric Oscillator (OPO) is now being used to produce and test various photo-cathode materials in the laboratory. Developments are now underway to test Gallium Arsenide (GaAs) photo-cathodes at the correct wavelength for the production of polarised electrons.

During 1998 the CTF laser suffered optical damage in several places. It was however possible to continue the CTF program (albeit with a reduced intensity) by a temporary re-configuration of the laser. The reduced intensity limited the time during which high charges could be extracted from the photocathodes to a few days.

Development of the laser energy stabiliser has continued, a Pockels-cell of specially selected UV-grade material and a modified photo-detector will be tested in the next shutdown. These tests are aimed to reduce the intrinsic losses of the electro-optic material and increase the linearity of the system, which will improve the final stability.

A study of a laser for a possible photo-injector for the CTF3 project has been started. Several aspects of the specification place the eventual system far beyond what has been achieved in other laboratories. Laser experts from industry, universities, laser institutes and accelerator laboratories have been contacted to attempt to identify the most appropriate design.

Design studies for a new test facility (CTF3) to demonstrate the feasibility of the new drive beam generation system have started. All major problems associated with the new scheme can be studied by generating only one drive beam and a future installation (CLIC1) to test one complete CLIC drive beam will almost certainly be required before the community is finally convinced. Since this is a very large and expensive installation a much smaller facility is proposed as an intermediate first step. To reduce costs CTF3 differs from the RF power source proposed for CLIC in the following ways. The frequency of the drive beam accelerator is chosen to be 3 GHz instead of 937 MHz. This enables the 3 GHz klystrons, modulators, RF power compression units and waveguides from the LEP Injector Linac (LIL) Complex to be used for power production which is always very costly. With ten of these modulator/klystron units the drive beam energy for a current of 4.1 A (half the nominal CLIC current) is 178 MeV – this is very low compared to the 1.25 GeV for CLIC and obviously makes operation more difficult but should never-the-less work. CTF3 only has the first two stages of the beam combination scheme namely, the times-2 Delay Line Combiner and the 86 m circumference (times-5) Combiner Ring. The second (times-4) 344 m circumference Combiner Ring is very expensive and since it has the same scheme of combination it is not considered to be essential for this first demonstration test facility. The compression factor for the combiner ring has however been increased from 4 for CLIC to 5 for CTF3 to obtain an overall frequency multiplication of 10 for final operation at 30 GHz. The modulators produce a maximum pulse of 4.5 µs which after power compression with LIPS becomes 1.4 µs. This pulse is just long enough after a (x10) power compression to produce the nominal CLIC RF pulse of 140 ns. The drive beam decelerator is limited to a total length of about 15m (7 transfer structures) compared to 687.5m for CLIC. To limit the radiation produced by CTF3 it is proposed to run at 5 Hz instead of 75 Hz. The new facility can be housed in the existing LIL and EPA buildings and can make use of many of the LIL and EPA components.

A list of all CLIC Notes published in 1998 is attached.

CLIC Notes 1998

349 Mustafa Environment Description and User's Guide with Applications to CLIC, January 1998, CERN/SL/98-002, G. Guignard, J. Hagel

350 Active Alignment System for CLIC 30 GHz Modules in CTF2
J-M. Bouché, W. Coosemans, R. Pittin, Fifth International Workshop on Accelerator Alignment, Argonne
National Laboratory, October 1997

351 Design of a Final Focus System for CLIC in the Multi-Bunch Regime
CEA/DAPNIA/SEA-97-17, O. Napoly, CEA

352 Drive Beam Generation for CLIC based on 200 MHz Structures, L. Thorndahl

353 CLIC Study - Activities Report 1997
summarised by I. Wilson for the CLIC Study Team

354 A CLIC Injector Complex for the Main Beams, L. Rinolfi

355 How to obtain a Bunch Length of 50 μ in the CLIC Main Linac
E.T. D'Amico, G. Guignard, T. Raubenheimer

356 The CLIC Main Linac Lattice at 1 TeV, D. Schulte

357 High Performance Electronics for Alignment Regulation on the CLIC 30 GHz Modules, D. Carrica, R. Pittin

358 Modeling a 30 GHz Waveguide Loaded Detuned Structure for the Compact Linear Collider (CLIC), M. Dehler

359 Away-day on 6th February 1998 at Ferney-Voltaire for a Review of the CLIC Parameters at 1 and 3 TeV (5 TeV) in order to redefine New "Target" Parameters, H.H. Braun, R. Corsini, J.P. Delahaye, G. Guignard, C.D. Johnson, A. Millich, D. Schulte, A. Riche, L Rinolfi, R. Ruth, W. Schnell, L. Thorndahl, D.J. Warner, I. Wilson, D.J. Simon

360 CLIC, a 0.5 to 5 TeV e+/- Compact Linear Collider
CERN/PS/98-009 (LP), Jean-Pierre Delahaye for the CLIC Study Team: R.Bossart, H.H. Braun, G.Carron, F. Chautard, W. Coosemans, R. Corsini, E. D'Amico, M. Dehler, J.C. Godot, G. Guignard, J. Hagel, S. Hutchins, C.D.Johnson, E. Jensen, I. Kamber, A. Millich, O.Napoly, P Pearce, J.P. Potier, T.Raubenheimer, A.J. Riche, L.Rinolfi, R.Ruth, D. Schulte, G.Suberlucq, L.Thorndahl, M. Valentini, D.J.Warner, I. Wilson, W. Wuensch
6th European Particle Accelerator Conference(EPAC 98), 22-26.06.98, Stockholm, Sweden and XVII International Conference on High Energy Accelerators, 7-12.09.98, Dubna, Russia

361 Active Alignment Electronic System for CLIC 30 GHz Modules in CTF2
M. Benedetti, D. Carrica, W. Coosemans, R. Pittin

362 Analytical Treatment of Single Bunch Transverse Dynamics in Linacs with Wakefields, CERN-SL-98-015 (AP), G. Guignard, J. Hagel

363 Observations on Tune and ß Functions at the ATF Damping Ring
CERN/PS/98-010 (LP), J.P. Potier, CERN; J. Urakawa, N. Terunuma, T. Mimashi, K. Kubo, T. Korhonen, H. Hayano, KEK, Japan; T. Okugi, Tokyo Metropolitan University, Japan; S. Kashiwagi, The Graduate University for Advanced Studies, KEK, Japan; F. Zimmermann, Stanford Linear Accelerator Center (SLAC), Stanford, USA. First Asian Particle Accelerator Conference (APAC98), KEK Tsukuba, March 23 - 27, 1998

364 The CLIC RF Power Source (will be published as a CERN Yellow Report, consequently not yet available on the WEB)

365 The 30 GHz Transfer Structure for the CLIC Study
CERN/PS/98-012 (LP), G. Carron, A. Millich, L. Thorndahl ICAP98 Conference, September 1998, Monterey, CA. USA

366 Loss Factor Dependence on Group Velocity in Disk-loaded Travelling Wave Structures, A. Millich, L. Thorndahl

367 A New Method of RF Power Generation for Two-Beam Linear Colliders
CERN/PS/98-14 (LP), H.H. Braun, R. Corsini, T. D'Amico, J.P. Delahaye, G. Guignard, C.D. Johnson, A. Millich, P. Pearce, L. Rinolfi, A.J. Riche, R.D. Ruth, D. Schulte, L. Thorndahl, M. Valentini, I. Wilson, 6th European Particle Accelerator Conference(EPAC 98), 22-26.06.98, Stockholm, Sweden

368 Scaling Laws for Normal Conducting e+e- Linear Colliders
CERN/PS/98-015 (LP), J.P. Delahaye, G. Guignard, T. Raubenheimer
XIX International Linac Conference, 23-28.08.98, Chicago, USA

369 Radiation Damage Study of a Monocrystalline Tungsten Positron Converter
CERN/PS/98-017 (LP), X. Artru, R. Chehab, A. Jejcic, B. Johnson, R. Kirsch, P. Keppler, J. Major, L. Rinolfi, 6th European Particle Accelerator Conference(EPAC 98), 22-26.06.98, Stockholm, Sweden

370 Emittance Preservation in the Main Linac of CLIC
CERN/PS/98-018 (LP), D. Schulte, 6th European Particle Accelerator Conference(EPAC 98), 22-26.06.98, Stockholm, Sweden

371 Non-Intercepting Bunch Length Monitor for Picosecond Electron Bunches
CERN/PS/98-019 (LP), H.H. Braun, C. Martinez, 6th European Particle Accelerator Conference(EPAC 98), 22-26.06.98, Stockholm, Sweden

372 The CLIC Main Linac Linac Bunch Compressor
CERN/PS/98-020 (LP), T.E. D'Amico, G. Guignard, T. Raubenheimer, 6th European Particle Accelerator Conference(EPAC 98), 22-26.06.98, Stockholm, Sweden

373 Photocathodes for the CERN CLIC Test Facility
CERN/PS/98-036 (LP), E. Chevallay, J. Durand, S. Hutchins, G. Suberlucq, H. Trautner, XIX International Linac Conference, August 23-28, 1998, Chicago,

374 Analytical Treatment of Single Bunch Stability in a Linac
CERN/PS/98-037 (LP), G. Guignard, J. Hagel, XIX International Linac Conference, August 23-28, 1998, Chicago, USA

375 Demonstration of Two-Beam Acceleration in CTF II
CERN/PS/98-038 (LP), R. Bossart, H.H. Braun, G. Carron, M. Chanudet, F. Chautard, J.P. Delahaye, J.C. Godot, S. Hutchins, I. Kamber, C. Martinez, G. Suberlucq, P. Tenenbaum, L. Thorndahl, M. Valentini, I. Wilson, W. Wuensch, XIX International Linac Conference, August 23-28, 1998, Chicago, USA

376 Mustafa - a Tool for Numerical Simulations of the Beam Behaviour in a Linac
CERN/PS/98-039, G. Guignard, J. Hagel, XIX International Linac Conference, August 23-28, 1998, Chicago, USA

377 A Tapered Damped Accelerating Structure for CLIC
CERN/PS/98-040 (LP), M. Dehler, I. Wilson, W. Wuensch, XIX International Linac Conference, August 23-28, 1998, Chicago, USA

378 The CLIC 30 GHz Two-Beam Test Accelerator
CERN/PS 98-041 (LP),I. Wilson, W. Wuensch, W. Coosemans, C. Achard, XIX International Linac Conference, August 23-28, 1998, Chicago, USA

379 The Drive Beam Accelerator of CLIC
CERN/PS 98-042 (LP), D. Schulte, XIX International Linac Conference, August 23-28, 1998, Chicago, USA

380 The Drive Beam Decelerator of CLIC
CERN/PS 98-043 (LP), A. Riche, D. Schulte, XIX International Linac Conference, August 23-28, 1998, Chicago, USA

381 A long pulse 100 micro seconds Klystron-Modulator for RF power generation in the Drive Beam Linac of the CLIC Two Beam Linear Collider
G. McMonagle, P. Pearce

382 Demonstration of Two-Beam and 30 GHz Power Production in the CLIC Test Facility, CERN/PS 98-060 (LP), R. Bossart, H.H. Braun, G. Carron, M. Chanudet, F. Chautard, J.P. Delahaye, J.C. Godot, S. Hutchins, C.

Martinez, G. Suberlucq, P. Tenenbaum, L. Thordahl, H. Trautner, M. Valentini, I. Wilson, W. Wuensch, October 5-9, 1998

383 Away-Day on 6th November 1998 in the Novotel of Ferney-Voltaire.
A Review of the Preparation of the CTF3 Design : Schedule