CERN - European Laboratory for Particle Physics

CLIC Note 290
3 October 1995

509543

CERN LIBRARIES, GENEVA

CLIC-NOTE-290

Recent Results of the CLIC Test Facility

H. Braun for the CTF Team

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After reaching the CTF objectives in terms of 30 GHz power production in 1994 the present CTF work focuses on bunch compression studies, photocathode measurements and on the preparation of CTF phase II. An overview of the present CTF experiment and of the future CTF phased II upgrade is given. Achieved CTF performances, first results from magnetic bunch compression and results from quantum efficiency measurements of Cs_2Te photocathodes are reported. The design of the S-band RF gun and accelerating structures under construction for CTF II is shown.

This paper has been presented at the Microbunch Workshop,
Brookhaven National Laboratory, Upton NY.,
28 - 30 September 1995,

Geneva (Switzerland)

Recent Results of the CLIC Test Facility

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CERN, 1211 Geneva, Switzerland

Abstract. After reaching the CTF objectives in terms of 30 GHz power production in 1994 the present CTF work focuses on bunch compression studies, photocathode measurements and on the preparation of CTF phase II. An overview of the present CTF experiment and of the future CTF phase II upgrade is given. Achieved CTF performances, first results from magnetic bunch compression and results from quantum efficiency measurements of Cs₂Te photocathodes are reported. The design of the S-band RF Gun and accelerating structures under construction for CTF II is shown.

Introduction

The CLIC Test Facility (CTF) serves as an experimental test bench for the CLIC study for a linear collider (1). CTF phase I as it is presently in operation (2) was built with the objectives to study the production of the CLIC drive beam and to act as a source of 30 GHz high power pulses to test CLIC prototype RF structures. Figure 1 shows the layout of the present installation. A S-band RF gun produces single bunches or trains of up to 48 bunches from a photocathode illuminated by an YLF high power laser system (3), with the light output frequency quadrupled to 262 nm wavelength. The maximum laser pulse energy at this wavelength is 1 mJ at the laser output and the pulse length is 8 ps fwhm. The time structure of the bunch train is formed by a train generator consisting of a system of optical splitters. A load lock system mounted to the RF gun allows photocathodes to be changed under vacuum. A magnetic chicane, together with a longitudinal correlation introduced by the RF gun phasing, is used for longitudinal bunch compression. After compression a 1 m long S-band section boosts the electron energy to 65 MeV. This section is borrowed from LAL/Orsay where it was built and used for high gradient experiments (4). The gun and the structure are powered by two klystrons, one of them equipped with RF pulse compression. The gun and the structure are powered by two klystrons, one of them equipped with RF pulse compression.

Figure 1. Schematic layout of CTF as it is 1995

With typical power levels of 18 MW for the first and 27 MW for the second klystron we run well below their maximum power of 35 MW. A drift space between the S-band section and a magnetic spectrometer is used to test beam-monitor and 30 GHz RF structure prototypes with beam. The sections CAS1 and CAS2 are identical prototypes of CLIC 30 GHz accelerating structures. While CAS1 is used to produce 30 GHz power due to the beamloading from the electron beam, CAS2 reaccelerates the electrons. The achieved accelerating gradients in CAS2 can be readily computed from the magnetic field values in the 180° bend and in the second beam spectrometer. The 30 GHz output from CAS1 is also used for high power tests of other CLIC 30 GHz components. Magnetic focusing elements and beam diagnostic elements are omitted in figure 1.

The present RF Gun

The present RF Gun consists of a 1½ cell RF gun similar to the gun developed at BNL (5) and a 4 cell booster cavity (6). The gun is running now routinely with a peak cathode field of 110 MV/m. Operation at 120 MV/m is also possible but leads to frequent RF-breakdowns. A drawing of the gun together with plots of the field distribution and the beam functions is shown in figure 2. The onset of beam losses at the gun aperture occurs for bunch charges higher than 12 nC. This leads to a less than linear growth of the bunch charge with respect to the laser energy for charges higher than this. Nevertheless, single bunch charges of up to 35 nC were measured at the output of the gun. This charge was achieved with a increased laser pulse length of 16 ps fwhm.

Photo Cathodes

Cs₂Te is normally used as the photocathode material (7). Recently improved lifetimes and higher average quantum efficiency values than before were measured after more strict interlock conditions were put on the RF-gun klystron with respect to sparking in the gun, and a molybdenum layer between the Tellurium and the copper substrate was introduced. Figure. 3 shows a lifetime plot of a cathode used during several weeks this spring. After a fast drop of QE over the first 30 h of operation the QE stays at a level of about 2% over several weeks with very little additional degradation. It was further found that only the time with RF on affects the lifetime; however, it is not yet clear if the RF fields or the worse vacuum conditions with RF on are causing this. The QE is not only a function of time but also of the applied field. Figure 4 shows the results of a measurement of QE as a function of the field on the cathode. It has to be mentioned that the laser pulse hits the cathode at a phase angle of 30°; therefore the peak field on the cathode is a factor 2 higher than the values shown in figure 4.

Figure 2. The presently used RF Gun together with plots of the field distribution and the beam functions for 0 nC and 12 nC bunch charge. The two curves in the E_z plot show the maximum field and the field seen by the bunch.

Figure 3. Quantum efficiency of Cs_2Te cathodes as a function of RF hours. During the use of this cathode different RF field levels were applied as indicated.

Figure 4. Quantum efficiency of Cs_2Te cathodes as a function of RF field on the cathode. The line is a parabolic fit to the experimental points.

Figure 5. Comparison of measurements and PARMELA simulations of bunch length as a function of the deflecting angle in the magnetic chicane.

Bunch Compressor

For the effective production of 30 GHz power, it is mandatory to have a bunch length of less than 8 ps fwhm, preferably 5 ps. With bunch charges of less than about 7 nC, such bunch lengths can be achieved by phase focusing in the first half cell of the RF gun, while for higher charges the longitudinal space charge forces dominate the RF focusing forces leading to electron bunches longer than the original laser pulse length (compare figure 2). Since in the CLIC scheme as well as in CTF phase II bunch charges in the order of 20 nC are envisaged, we study the reduction of the bunch length with a magnetic chicane in combination with off crest acceleration in the 4-cell cavity of the RF gun. Figure 5 shows the results from a scan of the magnetic field in the chicane for bunch charges of 2 and 17 nC in comparison with PARMELA simulations. The bunch length was measured with a streak camera observing the Cerenkov radiation of the electron beam passing through a thin quartz sheet. The strong discrepancy between simulated and measured values in the 2 nC case can be explained by the resolution of our streak camera, which is known to be about 5 ps. The different location of the minima with 17 nC for the measured and simulated curves is probably due to the uncertainty in the knowledge of the absolute phase of the 4-cavity. However, it is evident that because of space charge effects compression is much less effective at high charges than at low charges.

Charge and 30 GHz Power Performances

We achieved 30 GHz power levels of up to 76 MW with a 48 bunch train and 3.0 nC bunch charge, and 75 MW with a 24 bunch train and 3.3 nC bunch charge. This power corresponds to a mean accelerating field of 94 MV/m in CAS2 and a peak decelerating field of 123 MV/m in CAS1. Despite of these high field levels we didn't observe any signs of RF breakdown in these structures. The nominal field of the CLIC accelerating sections is 80 MV/m. Thus we have proven that our structures can handle field levels much higher than needed for CLIC operation. The maximum measured charges in single and multibunch operation are listed in table 1. The charge limitations for the gun are space charge forces in single bunch and laser energy in multibunch operation. In the 3 GHz section the beam loading limits the multibunch charge and single bunch charge is limited again by space charge. The limits of transmission through the CAS (2 mm aperture radius!) are due to emittance growth caused by space charge forces, transverse wakefields and chromatic errors in focusing quadrupoles due to beamloading.

Table 1. Maximum measured charges

position in beamline	single bunch [nC]	48 bunches [nC]
RF Gun exit	35	450
Exit 3 GHz section	20	160
Exit CAS1	7	81

CTF phase II

It is planned to finish the experiments with the present CTF configuration at the end of 1995 in order to set up the CTF phase II experiment. The objectives of this experiment are:

1. Demonstration of the feasibility of the CLIC two beam accelerator scheme and its 30 GHz technology.
2. Build and test prototypes of CLIC modules. A CLIC module, which is a building block for the CLIC accelerator, consists mainly of accelerating structures for the main beam, transfer structures to extract 30 GHz power from the drive beam, and the support girders with their active alignment system.
3. To study the dynamics of a high charge, multibunch drive beam.
4. To test the active alignment system with beam.
5. To test CLIC beam monitoring.

Figure 6. Sketch of CTF phase II. BPM's and focusing elements are omitted here, except of the quadrupoles in the CLIC modules.

A sketch of CTF phase II is shown in figure 6. The drive beam of 48 bunches with 10 cm bunch spacing and a total charge of 1 μC is generated in a new gun and accelerated by two traveling wave structures optimized for high charge acceleration (HCS1 and HCS2). The design and construction of these structures is conducted by LAL/Orsay. To compensate for the very high beamloading, the structures run at frequencies slightly different from the bunch repetition frequency. The frequencies and phases are chosen so that the phase change from bunch to bunch compensates for the field reduction due to beam loading. After acceleration the beam passes through a transverse matching section with a total of 12 quadrupoles (not shown in figure 6) and the three bending magnets of the magnetic chicane for bunch compression, before it is injected into the string of CLIC modules. A similar bunch compressor as in CTF I is used but due to the higher beam energy of 45 MeV space charge effects are reduced. The probe beam is generated in the same $1\frac{1}{2}$ cell RF gun as presently used, but without the 4-cell booster. Afterwards it is accelerated in a 4.5 m traveling wave structure (LAS), which is of the same type as the structures used in the LEP injector linac. Downstream of this structure 4 quadrupoles (not shown) are used to match the beam into the CLIC modules. The probe beam charge will be very low in the beginning since no second load lock system for the probe beam gun will be available, thus prohibiting the use of high QE photocathodes. However, the main issues in the beginning will be the measurement of energy gain and stability, for which a single low charge bunch is sufficient. The 30 GHz modules will be as similar as possible to those foreseen for CLIC. However, due to the low beam energies in CTF, the density of focusing elements has to be much higher than in CLIC.

Figure 7. Drawing of the high charge accelerating structure

The CTF II high charge accelerating sections

The sections HCS1 and HCS2 are S-band structures optimized for the acceleration of high charges (8). Figure 7 shows a drawing of one section, in table 2 the parameters of the sections are listed. With an iris diameter of 30.5 mm, a low r/Q can be realized to minimize the energy spread due to beamloading. The large iris gives also a strong reduction of the transverse wakepotentials, thus reducing the danger of beam break up. However, the large irises cause a strong cell to cell coupling and as a consequence a high group velocity. To reduce this velocity to the desired value, a phase advance from cell to cell close to π was chosen, and the iris thickness was increased to reduce the coupling. Symmetrical input and output couplers avoid unwanted beam deflection due to the excitation of non-axis symmetric modes in the coupling cells.

Table 2. Parameters of HCS

mechanical length	852 mm
electrical length	653 mm
iris diameter	30.5 mm
phase advance	$11/12 \pi$
filling time	$0.73 \mu\text{s}$
r'	$29.1 \text{ M}\Omega/\text{m}$
Q	13100
gradient	60 MV/m
input power	120 MW
frequency	$2998.55 \pm 7.81 \text{ MHz}$
v_z profile	const. impedance
v_z/c	0.0031
rel. beamload. for $1 \mu\text{C}$	35 %

Figure 8. The RF Gun for the drive beam of CTF II with plots of the field distribution and the beam functions for 0 nC and 60 nC bunch charge. The two curves in the E_z plot show the maximum field and the field seen by the bunch.

The CTF II drive beam RF Gun

The RF Gun that will be used to produce the CTF phase II drive beam is shown in figure 8 together with plots of the field distribution and the beam functions. It is a 3 cell gun with the waveguide coupled to the second and third cell. The cell irises have a diameter of 40 mm, twice as much as the present CTF gun. This large diameter allows for large beam diameters to reduce the current density of high charge bunches. The large iris also reduces the r/Q and thereby the energy spread due to beam loading. However, as a consequence the S-band RF power required for the gun only will be as high as 20 MW. The first cell has a conical backplane with a 10° angle to improve transverse RF-focusing. The length of the first cell is 33 mm and the other two cells are 46 mm each. It was found that this combination gives a good compromise between transverse and longitudinal beam dynamics in high charge operation. Simulations show (compare fig. 8) that this gun should be capable to deliver single bunch charges of more than 60 nC, three times more than what is needed for CTF phase II.

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