CLIC TEST FACILITY DEVELOPMENTS AND RESULTS

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INTRODUCTION

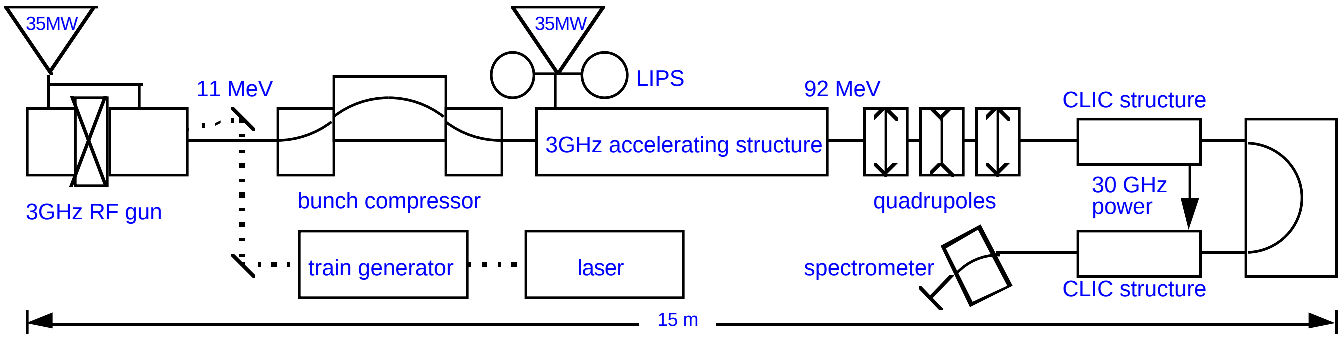
The objectives of the CLIC Test Facility (CTF) are to study the generation of short intense electron bunches using a laser driven photocathode in an RF gun, to generate 30ÊGHz RF power for high gradient tests of prototype CLIC components, and to test beam position monitors. The performance of the CTF has improved dramatically in the course of the past year and highlights are presented here. The layout of the CTF is shown in Fig.Ê1.

The RF gun now has a Cs_2Te photocathode, enabling the use of the fourth harmonic of the YLF laser system (262Ênm). Laser pulse lengths down to 8Êps full-width-half-height (FWHH) and energies of 0.5ÊmJ have been produced. The CTF operates with a repetition rate of 10ÊHz with either single bunches or trains of up to 48 bunches. Trains are produced by splitting the laser pulse. The RF gun consists of a 1 1/2 cell cavity, a photocathode, a focusing solenoid and a 4 cell booster cavity. The beam exits the gun with a momentum of 4.5ÊMeV/c and is then accelerated up to 92ÊMeV/c by the S-band travelling wave accelerating section. 30ÊGHz power is generated when the beam is passed through the - un-powered - prototype CLIC main linac accelerating section [1]. The power is fed to the second prototype main linac accelerating section and the accelerating gradient produced in it is directly measured by reaccelerating the lead bunch of the drive train.

PERFORMANCES

In the 1994 run, the CTF produced 30ÊGHz powers of up to 76ÊMW, which corresponds to a peak gradient of 123ÊMV/m in the 30ÊGHz decelerating section and an average gradient of 94ÊMV/m in the 30ÊGHz accelerating section. Consistency between accelerating fields determined through RF power measurement and reacceleration was confirmed up to 76ÊMV/m. There has never been any sign of RF breakdown in either accelerating section, any 30ÊGHz component or waveguide at any power level achieved so far. In addition, the output periodically loaded waveguide of a prototype transfer structure was tested to 60ÊMW without RF breakdown. These results show that CLIC can be operated at nominal field levels with little or no conditioning.

The maximum power achieved in the 1994 CTF run was almost a factor 2 higher than that achieved in the 1993 run [2]. This improvement is mainly due to an increased beam energy of 92ÊMeV which reduces the detrimental effect of long range transverse wakefields in the decelerating section. A second modulator and klystron allowed the generation of the extra 3ÊGHz power. Further improvement came from raising the number of bunches to 48 which increased the charge passing through the decelerating section. This was made possible by an upgrade of the laser pulse train generator. The train generator upgrade has also given the capability to vary the laser pulse lengths. A longer laser pulse length reduces the effect of space charge in the RF gun and has given a single bunch charge at the gun output to 35ÊnC. This charge is more than twice the previous CTF record. The electron bunch length at this charge was σ_{z}Ê= 2.4Êmm and thus further improvement can be expected. The maximum charges achieved in the CTF are summarized in TableÊ1. The single bunch charge is limited by space charge effects in the gun and short range transverse wakefields in the 3ÊGHz structure. Multibunch charge at the RF gun exit is limited by the available laser energy. The downstream charge is further limited by long range transverse wakefields and chromatic effects due to beam-loading in the S-band accelerating structure. The highest 30ÊGHz powers were produced by a 48 bunch train with a total charge of 80ÊnC transmitted through the 30ÊGHz decelerating section. For this charge the measured bunch length was σ_{z}Ê∪Ê1Êmm which corresponds to the resolution limit of the streak camera.



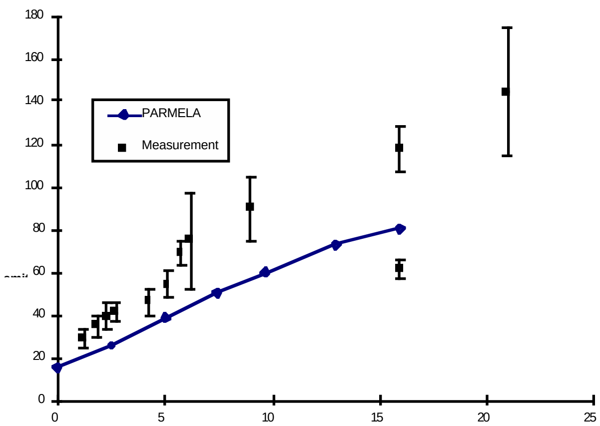
FigureÊ1: Layout of the CTF planned for 1995

position in beamline	single bunch [nC]	48 bunches [nC]
RF Gun exit	35	450
3GHz structure exit	20	160
30GHz structure exit	7	81

TableÊ1: Maximum measured charges

EMITTANCE MEASUREMENTS

Emittance measurements were performed with single bunches by varying the strengths of two quadrupoles downstream of the 3ÊGHz structure and measuring the beam profiles on a transition radiation screen just upstream of the 30ÊGHz accelerating section. The measurement results together with simulation results from PARMELA are shown in Fig.Ê2Ê[3]. The normalized, 1Êσ, rms emittance is used. For these measurements the laser spot on the photocathode had a radius of 5Êmm and a duration of 8Êps FWHH. The phase difference between the zero crossing of the electric field in the gun and the arrival of the laser pulse was 30ϒ. Although the variation of emittance with bunch charge is qualitatively similar for measured and computed values, the measured emittances are systematically higher. This effect is not understood. The large error bars on measured emittances at high charges are caused by unstable beam conditions.



FigureÊ2: Emittance as a function of bunch charge

RF PULSE COMPRESSION

The 3ÊGHz accelerating section is powered by a 35ÊMW klystron with a 4.5Êμs long pulse compressed to 1.2Êμs by two LIPS cavities as shown in Fig.Ê1. This type of pulse compression requires a phase shift near the end of the klystron output pulse [4]. Using a new programmable 3ÊGHz low level RF phase shifter, three phase shift schemes were tested.

A: A phase jump of 180ϒ 1.2Êμs before the end of the RF pulse. This has been the standard mode of operation before the programmable phase shifter was available.

B: A phase jump of +68ϒ 1.2Êμs before the end of the RF pulse, followed by a gradual phase shift from +68ϒ to +180ϒ during the remainder of the pulse.

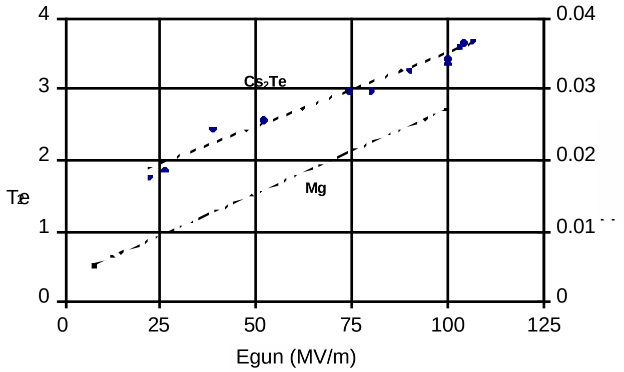
C: A linearly decreasing phase by -30ϒ during the first 3.3Êμs, then 3 a jump of +68ϒ , followed by a linear phase shift of +112ϒ during 1.2Êμs.

Scheme A produced a sharp rise followed by an exponential decay with an overshoot 2.5 times larger than the average pulse power. Scheme B delivered a nearly flat power pulse with an overshoot of only 20% above the average power. Nonetheless scheme B provided 10% less acceleration of the beam than method A. This occurred because scheme B introduces a frequency shift of about 30ÊkHz at the output of the LIPS cavities. This has been compensated in scheme C by the negative phase ramp at the beginning of the RF pulse. The energy gain of the beam with scheme C is 5% lower than scheme A for constant klystron power. Because the beam energy was not limited by klystron power but rather RF breakdowns in the 3ÊGHz accelerating section the lower overshoot of scheme C is more important. An energy gain of 87ÊMeV was achieved with scheme C and only 70ÊMeV with scheme A.

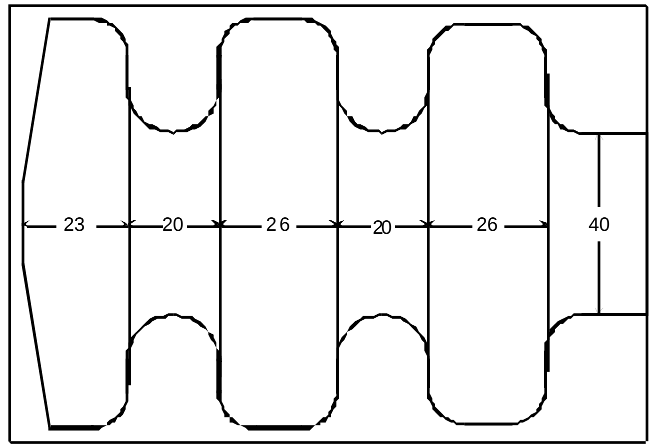
PHOTOCATHODES

Nine photocathodes have been used in the RF gun during the 1994 CTF run. Four Cs_2Te cathodes were used at 100ÊMV/m for a total of 159 days. However, three others worked only at a lower field, 70ÊMV/m, and were used for only a total of 22 days. The typical starting quantum efficiency (QE) was about 5%, measured in a dc gun at 8ÊMV/m. The QE was found to increase with increasing electric field during measurements with the photocathode in the RF gun, see Fig.Ê3.

The QE does not show a strictly exponential degradation with time. During a period of 4 to 5 days after installation in the RF gun, a rather fast decay with a 1/e lifetime of approximately 6Êdays is observed, while afterwards the QE decreases more slowly, with the 1/e decay time varying between 34 and 67 days for the next two months (the beam duty factor is typically 30%). Measurements with closely spaced laser pulses have demonstrated that the relaxation time of electrons in the photocathode material is less than a few picoseconds. Two new photocathode materials which can be transported in air, unlike Cs_2Te which requires a vacuum transfer system and preparation chamber, were tested. CsI with a thin layer of germanium has a QE of 0.19% at 100ÊMV/m. A magnesium layer on a copper substrate has a QE of only 0.027% for the same electric field.



FigureÊ3: Quantum efficiency versus electric field for Cs_2Te and Mg photocathodes.



FigureÊ4: Sketch of the new RF gun (distances in mm)

MODIFICATIONS FOR THE 1995 RUN

In order to reduce the beam-loading and transverse wakefields in the 3ÊGHz accelerating section, the old spare LIL section used until now will be replaced by a high gradient, 1 m long structure borrowed from LAL [5].

A magnetic chicane bunch compressor between the RF gun assembly and the accelerating structure will be used in the 1995 run . An energy/phase correlation in a bunch (introduced by appropriate phasing of the booster cavity) together with the energy/path length dependence in the chicane compresses the bunch. The chicane consists of two 15Êcm long left bending magnets and a 30Êcm long right bending magnet [6]. Two quadrupoles upstream of the chicane and four downstream (not shown in Fig.Ê1) are used to match the beam in the transverse plane.

In order to increase the high charge performance of CTF, a new RF gun is being constructed. A drawing of the RF geometry is shown in Fig.Ê4, and the main parameters are listed in TableÊ2. The design goals were to maximize aperture to allow a large beam radius, maximise acceleration in the first cell to keep the effect of space charge small, and to minimize the r/Q to minimize energy spread in bunch trains. These goals are achieved with a large iris aperture, a 10Ý concave cone around the cathode, and re-optimized cell lengths.

number of cells	3
iris diameter [mm]	40
cone angle	10Ý
frequency [MHz]	2998.55
output energy [MeV]	6.58
input power [MW]	13.6
max. field on photo cath. [MV/m]	100

TableÊ2: Parameters of the new RF gun

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