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The CLIC Test Facilities

The CLIC Study Group

(reported by H. Braun, J.P. Delahaye and I. Wilson),

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The CLIC scheme, based on beam acceleration at high gradient (80 MV/m) and high frequency (30 GHz) with RF power generation by the Two Beam Acceleration (TBA) method, is certainly one of the most promising option for a Linear Collider at high energy. But it is also one of the most challenging by the new technologies it requires which have to be developed. Test facilities were therefore set-up at an early stage of the study to concentrate on the main challenges of the scheme: Alignment techniques in the micron range, Two Beam Acceleration method, high frequency RF power production, drive beam generation by direct bunching in a Free Electron Laser. The present status of these facilities is presented together with the developments foreseen in the future.

1. Introduction

In the multidimensional space of possible parameters, the **CLIC** study of a Compact LInear Collider[1,2] explores the technical feasibility of beam acceleration by travelling wave structures at room temperature and high frequency (30 GHz), powered by a superconducting drive linac, the so-called Two Beam Acceleration scheme[3].

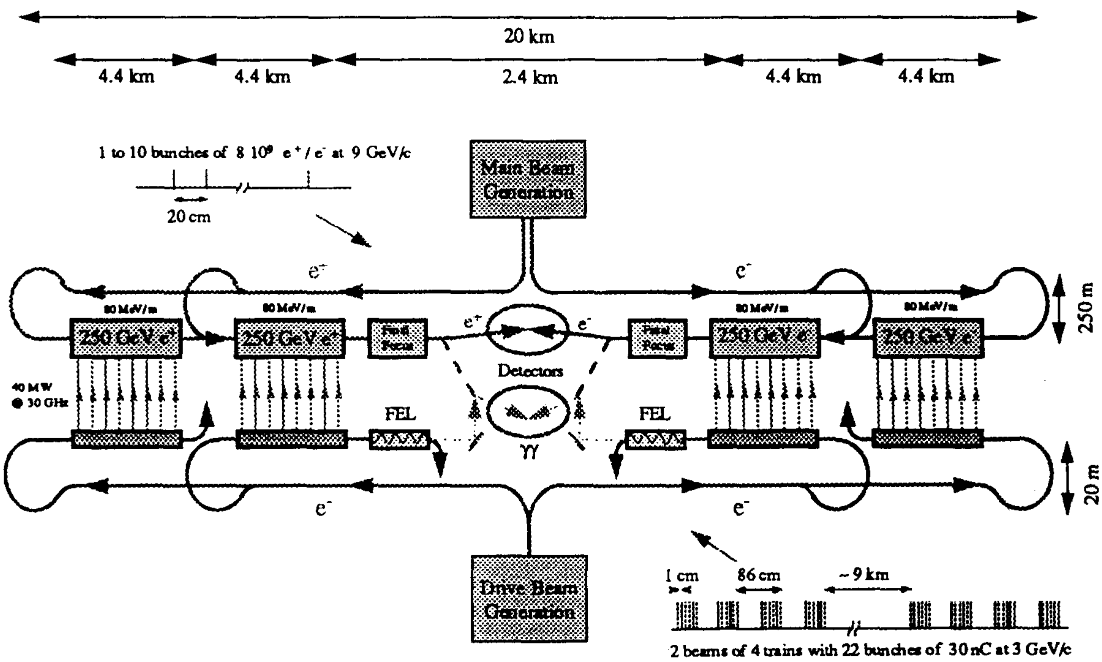
The two main advantages of high frequency accelerating structures are the low RF power requirement for filling because of their small volume and the ability to achieve high accelerating fields with negligible dark currents.

Luminosities of 5.10^{33} cm^{-2} sec^{-1} at an energy of 500 GeV GeV c.m and 1.10^{34} cm^{-2} sec^{-1} at 1 TeV c.m. are obtained by colliding ten bunches at a repetition frequency of 1 - 2 kHz with a reasonable wall-plug power. In both cases, good conditions for Physics are obtained, in particular the average momentum spread induced by beamstrahlung during collisions is limited to a few %. The main beam parameters are summarized in Table 1.

Table 1: CLIC Main Parameters

		500 GeV	1 TeV	
RF Frequency	F_{RF}	30		GHz
Accelerating Field	E_A	80		MeV/m
Effective length per Linac	L_{eff}	3.125	6.25	km
Number of bunches/RF pulse	n	10		-
Distance between bunches	Δ	20		cm
RF Pulse Repetition Frequency	f_{rep}	1.21	1.80	kHz
Total Two-Linac AC Power	P_{AC}	100	275	MW
Beam Power/Beam	P_B	3.92	11.7	MW
AC Beam Power Efficiency	η_B	0.078	0.085	-
Number of Particles per Bunch	N_b	8.10^9		$e^{\pm}$
Norm. Emittances(hor × vert)	$\gamma\varepsilon_{x,y}$	3×0.15	3.9×0.2	10^{-6} rad.m
RMS Bunch Length	σ_z	200		µm
RMS Size at I.P. (hor x vert)	$\sigma^*_{x,y}$	250×7.5	200×6	nm
Beamstrahlung Parameters	Υ	7.5	17.9	%
Relative Energy Loss	δ_B	3.5	7.5	%
Luminosity Enhancement	H_D	1.42	1.31	-
Luminosity with Pinch	L	4.8	10	$10^{33} cm^{-2} sec^{-1}$

Figure 1: Schematic Layout of the CLIC Complex at 1 TeV c.m.



Using accelerating fields of 80 MeV/m, the overall physical length of 20 km for the whole complex at 1 TeV, including 2.4 km for the final focus and detectors, is rather compact as illustrated in the general layout in Fig. 1.

The main drawback of the high frequency option comes from the small accelerator iris aperture which leads to the generation of strong wakefields increasing with the third and second power of the frequency respectively in the transverse and longitudinal planes. In order to prevent the beam emittance being diluted by the adverse effects of the wakefields, sophisticated methods of beam trajectory correction, and structure alignment with a 10 μm r.m.s. precision are applied all along the linac[4]. Such tight tolerances over long distances are achieved with state-of-the art technology on structure fabrication, precise pre-alignment of the elements using a stretched wire system and active beam-based alignment optimising the position of the quadrupoles to minimize beam emittance blow-up.

A major challenge of the CLIC scheme is to generate the RF power at a frequency where high power klystrons are not feasible, using the new concept of the Two-Beam scheme. Accelerating structures are fed, via standard waveguides, with 30 GHz RF power extracted from a relativistic drive beam of high charge (2.6 μC) and an initial energy of 3 GeV. The drive beam is pre-accelerated by a low frequency superconducting linac of modest accelerating field with an excellent power efficiency. It runs all along the linac without any reacceleration and is progressively decelerated in transfer structures before being dumped after conversion of up to 75% of its energy into RF power. An important advantage of the Two-Beam scheme is that only passive RF components are used in the main accelerating section of the linac and these can be housed in one small tunnel.

The three following test facilities have been built to study the specific problems and challenges of the CLIC scheme:

i) The Alignment Test Facility: this is used to test and develop alignment techniques at the micron level

ii) The CLIC Test Facility: this is used to study the generation of the drive beam by photoinjectors, and the generation of 30 GHz RF power. A first phase of this facility (CTF1) has already proved the principle of the scheme and a second phase (CTF2) is in preparation to demonstrate its feasibility.

iii) FEL Test Facilities: an alternative scheme of drive beam generation using the bunching capability of a Free Electron Laser as proposed a few years ago[5] is presently under test using existing installations in two laboratories, CESTA (France) and DUBNA (Russia).

This report describes each of these test facilities and summarizes the major results that have been obtained.

2. Alignment Test Facility

Transverse alignment tolerances of a few microns are required in the CLIC scheme in order to limit the emittance blow-up due to transversely deflecting wakefields to reasonable values. Such tight tolerances over long distances can only be obtained by beam-based active alignment systems using precision micromovers and accurate beam position monitors. Development work includes micron-displacement control systems, micron-resolution beam position monitor studies, active pre-alignment schemes and beam blow-up computer simulations for given overall alignment tolerances using both one-to-one and wakefield-free/dispersion-free correction algorithms[4].

The outer diameters of the accelerating structures and beam position monitors which are machined to ± 1 μm precision and concentricity with the beam aperture, serve as the external references for alignment to the beam. To simplify assembly and reduce costs, it is foreseen to mount and pre-align several of these accelerating sections on a support girder before installation in the tunnel, and to use micro-movers at the ends of these girders to adjust their position.

Each box-section girder which is made from silicon-carbide because of its high stiffness-to-weight ratio and its low thermal expansion, supports four accelerating sections. The sections are clamped to the girder via INVAR V-block supports which are aligned and fixed with a precision of 3 μm in the transverse plane. The ends of two adjacent girders sit on a common platform which assures continuity of position between units. In order to provide independent rotational freedom of each girder, one of the ends is fixed rigidly to the platform whilst the other is connected to it via swivel-joint linking rods. Each platform is activated via similar link rods by three precision jacks. Two in the vertical plane produce vertical displacements and transverse rotations; the third is situated and acts in the horizontal plane. These stepping motor driven micro-movers with a resolution of 0.1 μm and an absolute accuracy of 1 μm over ± 4 mm provide both large displacements for initial alignment and micron movements for correction of slowly varying perturbations (< 1 Hz) during operation.

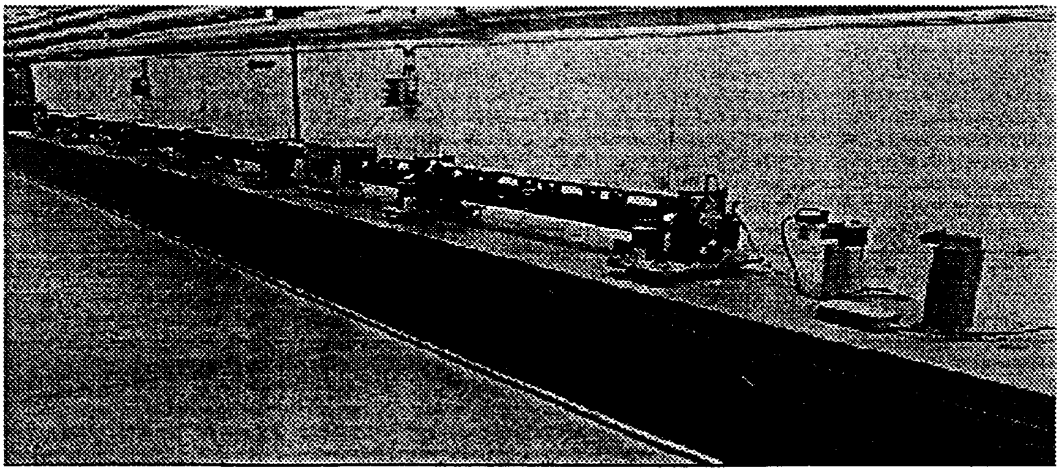
The accelerator has to be pre-aligned with sufficient precision that the beam can be made to pass through the available aperture and produce a signal in a beam position monitor. It is foreseen to do this using signals from a stretched-wire pre-alignment system. The idea is to maintain the relative positions of the far ends of two adjacent support girders to within a few microns in both transverse planes but to allow greater overall excursions from a straight line (say 0.2 mm) over longer distances of about 100 m between reference pillars. By using a set of overlapping stretched-wire systems some degree of redundancy is introduced into the measurement system to enable errors to be minimised.

The quadrupoles are supported and activated independently of the inter-connected string of girders but their positions are referenced with respect to the beam position monitors which sit on the girders by the stretched-wire system. During normal operation the pre-alignment system maintains the positions of the girders within a given "tolerance window" whereas the BPM signals are used to optimise the positions of the quadrupoles to minimise emittance blow-up.

An active alignment test facility[6] has been built in an unused underground tunnel at CERN to study the feasibility of making controlled submicron displacements and to try out alignment systems - the test set-up is shown in Fig. 2.

In the test facility the structures to be aligned, dummy accelerating sections for the moment, are supported by V-blocks on 1.4m long silicon carbide girders. Movements of the set-up are monitored by linear and angular displacement transducers (0.1 micron and 10 micro-rad resolution respectively). A stretched-wire running along the axis of the structures

Figure 2: General View of the Alignment Test Facility



and passing through capacitive position transducers where the BPMs would normally be placed is used to simulate the beam. The set-up is piloted remotely from a small computer. After deliberate misalignments of 1 mm, the system which is programmed for automatic alignment with respect to any of the transducers, settles back to nominal positions within < 1 micron.

The set-up is also being used to test a new optical pre-alignment system, developed by NIKHEF in Amsterdam, for use before injection of the beam. The image of a square-shaped red light source is focused on a light-detecting four-quadrant cell by a thin lens. Displacements of the source, lens or four-quadrant cell out of the optical axis of the instrument produce an imbalance at the detector. This system has been incorporated into the six hollow support girders of the test module and enables the relative positions of the far ends of two adjacent girders to be maintained in position with respect to the ideal straight line to < 2 microns. This pre-alignment system is however unlikely to be used in CLIC because of fears of radiation damage; it will be replaced by a system based on stretched-wires.

3. The First Phase of the CLIC TEST FACILITY (CTF1)

3.1 Objectives and General Description

The construction of a CLIC Test Facility (CTF1) started several years ago[7] in order to:

—study the production of short, high charge electron bunches similar to those required in the CLIC drive beam,

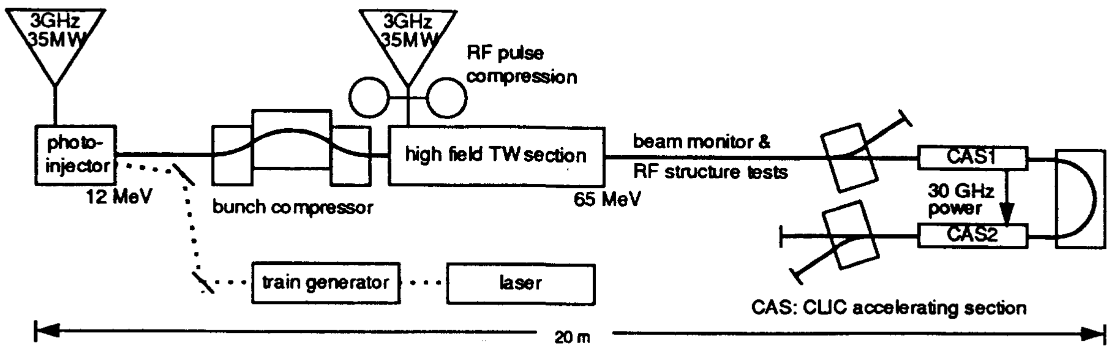
— test the generation of 30 GHz RF power by interaction of bunch trains with transfer structures,

— provide a high power RF source to test CLIC prototype components,

— develop and test specific beam instrumentation such as beam position monitors.

The layout of the present installation[8] is shown in Fig. 3.

Figure 3: Schematic Layout of the first phase of the CLIC Test Facility (CTF1)



The source of particles consists of a laser-driven photoinjector producing single bunches or trains of up to 48 bunches with a minimum spacing of 10 cm and a momentum of 12 MeV/c. A magnetic chicane, together with a correlated longitudinal energy spread introduced by adjusting the RF phase of the photoinjector, is used to get longitudinal bunch compression. Final acceleration to 65 MeV is obtained using a 1 m long S-band Travelling-Wave section (TW) with high accelerating fields and large stored energy to minimize the beam loading induced by the high intensity electron beam. The TW section has been borrowed from LAL/Orsay where it was built and used for high gradient experiments[9]. The photoinjector and the TW structure are each powered by one 35 MW klystron, the one powering the structure is in addition equipped with RF pulse compression. A drift space between the S-band section and a magnetic spectrometer is used to test beam instrumentation and 30 GHz RF structure prototypes with beam.

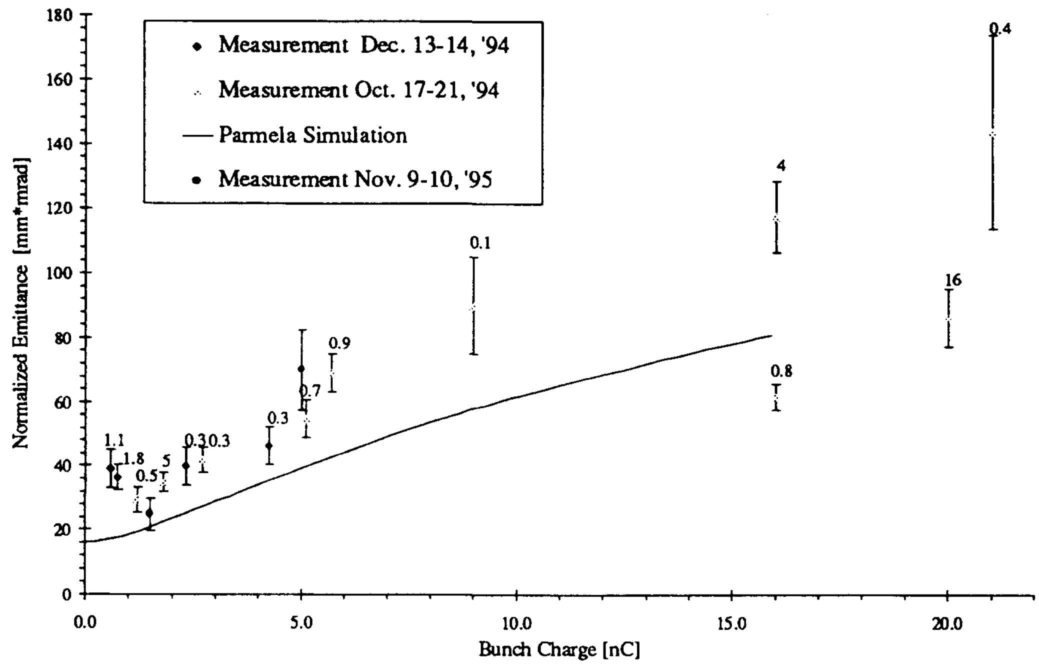
Energy is extracted from the electron beam by interaction with a 30 cm long high impedance travelling wave section, CAS1, acting as a Transfer Structure to provide short high power 30 GHz RF pulses. The RF Power is then used to feed a second identical structure, CAS2 or to supply power to other CLIC prototype components. The sections CAS1 and CAS2 are prototypes of the CLIC 30 GHz accelerating structures. The decelerated beam then either goes through a prototype 33 GHz CLIC Beam Position Monitor system to a dump, or is turned through 180° by bending magnets at the end of the line and re-accelerated by the CAS2 section. The accelerating field in the CAS2 structure is determined from the difference between maximum and minimum energy gain of the re-circulated beam as its phase with respect to the RF accelerating field is varied.

3.2 Beam and RF Power Performances

The facility can be operated in either single bunch or multi-bunch mode at a repetition rate of 10 Hz. A maximum single bunch charge of 35 nC has been obtained from the photoinjector with a laser spot of about 10 mm diameter. The length and the emittances of the electron bunches are measured with a streak camera using the photon beam produced by the interaction of the bunch with a transition radiation monitor or a Cerenkov monitor. At low charge per bunch, transverse normalized emittances of around 30 mm-mrad are observed, these are somewhat larger than predicted by PARMELA simulations (Fig. 4) when bunch length is typically 6 to 8 psec (FWHH) close or even shorter than the standard 8 psec of the laser pulse duration as explained in chapter *3.4*. With high charge per bunch, transverse emittances and bunch length are blown-up by space charge effects at low energy.

Significant amounts of 30 GHz power can only be extracted from the CAS1 section by using bunch trains. 76 MW of 30 GHz RF power has been obtained with trains of 24 and 48 bunches with charges per bunch of 3.3 nC and 3.0 nC respectively.

Figure 4: Variation of the Beam Transverse Emittances with the Charge per Bunch



This power level corresponds to maximum deceleration and acceleration fields of 123 MV/m and 94 MV/m respectively in CAS1 and CAS2. In spite of these very high fields, which are well above the nominal field of 80 MV/m foreseen for the CLIC main accelerating linac, no sign of RF breakdown or the need to condition has been observed. The maximum charges measured at various positions along the beam line in both single and multibunch operation are listed in Table 2. In the photo-injector, the single-bunch charge is limited by space-charge forces when in multi-bunch operation the maximum charge is limited by the available laser energy. In the 3 GHz TW section, the beam loading limits the multibunch charge whereas the single bunch charge is limited again by space charge. Efficiency of beam transportation through the 30 GHz CAS1 section with a 4 mm aperture diameter is reduced at high charges due to emittance growth caused by space-charge forces, transverse wakefields and chromatic errors in focusing quadrupoles due to beamloading.

Table 2: Maximum Measured Charges in CTF1

position in beamline	single bunch [nC]	48 bunches [nC]
Photo-injector exit	35	450
TW section exit	20	160
CAS1 exit	7	81

3.3 A Photo-Injector as the Source of Particles

The present photoinjector consists of a S-band 1½-cell RF Gun similar to the one developed at BNL[10] and a 4-cell standing wave booster cavity [11] (fig. 5). Short electron bunches are emitted by a photocathode inserted under vacuum into the first half cell of the RF gun and illuminated by a YLF Laser system[12] synchronized to the RF wave with a sub-picosecond accuracy. Multiple bunches are made by splitting the laser pulse into a train of pulses each spaced by one 3 GHz wavelength or 10 cm with a train generator consisting of a system of optical components. The laser has been optimised at the fourth harmonic (262 nm) providing a maximum energy of 1.0 mJ per pulse (before splitting) and a pulse length of 8 ps FWHH.

The RF gun runs routinely with a peak cathode field of 110 MV/m. Operation at 120 MV/m is also possible but leads to frequent RF-breakdowns. 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 higher charges. Nevertheless, single-bunch charges of up to 35 nC were measured at the output of the gun. This charge was achieved with an increased laser pulse length of 16 ps.

After extensive comparison of various photocathode materials, Cs_2Te has finally been selected not only because of its good quantum efficiency (QE) but mainly because of its excellent lifetime[13]. The photocathodes are prepared in a separate laboratory, transported under vacuum and installed into the gun using a specially designed transfer system. Fig. 6 shows a typical variation of the photoemission as a function of RF operating hours.

Figure 5: The Photo-Injector of CTF1

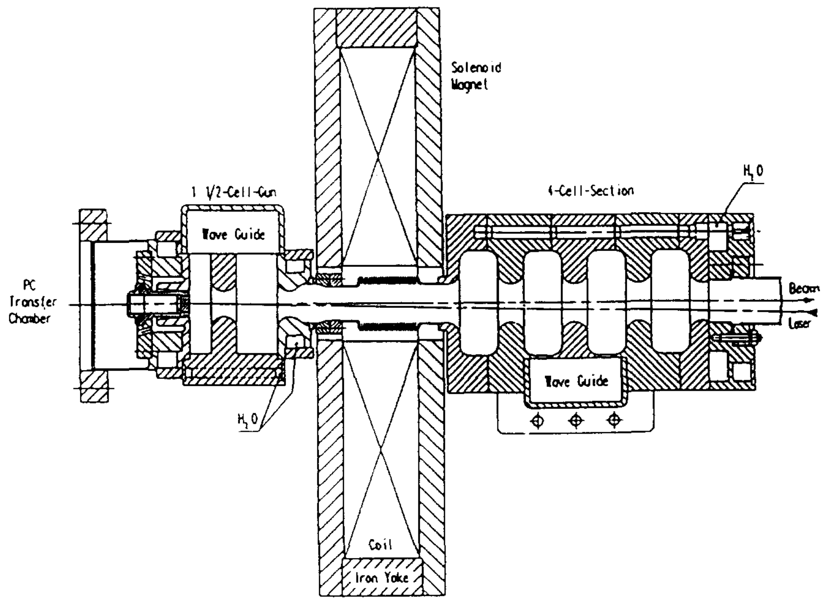
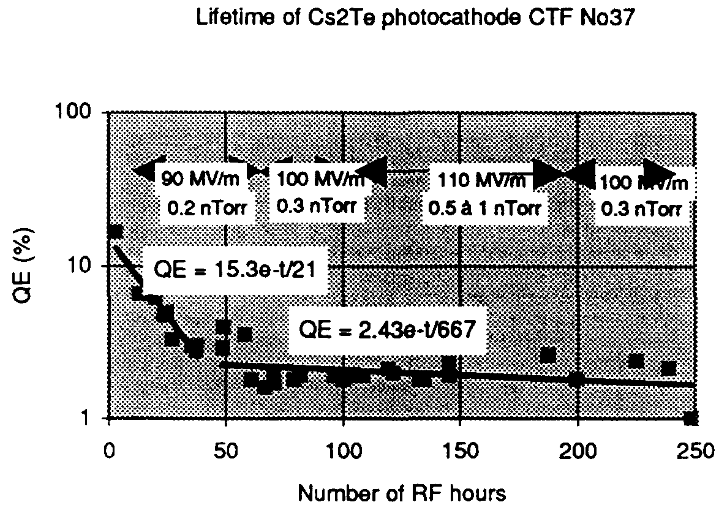
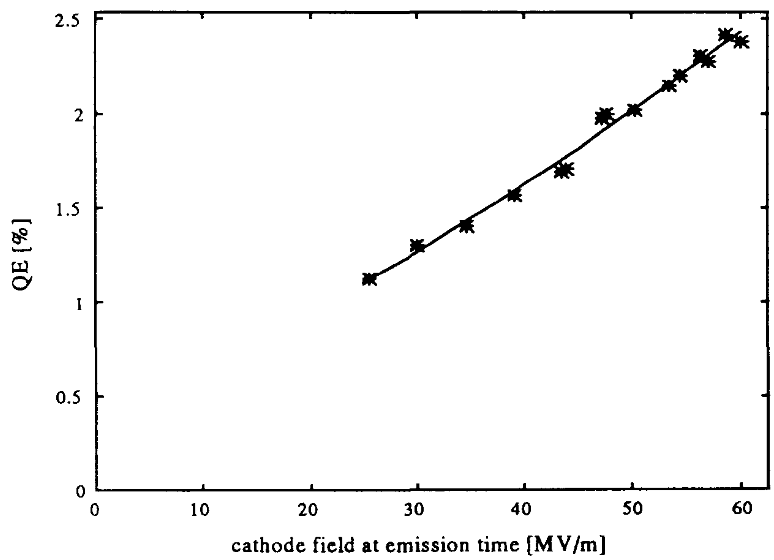


Figure 6: Quantum Efficiency of Cs_2Te Cathodes as a Function of RF Hours



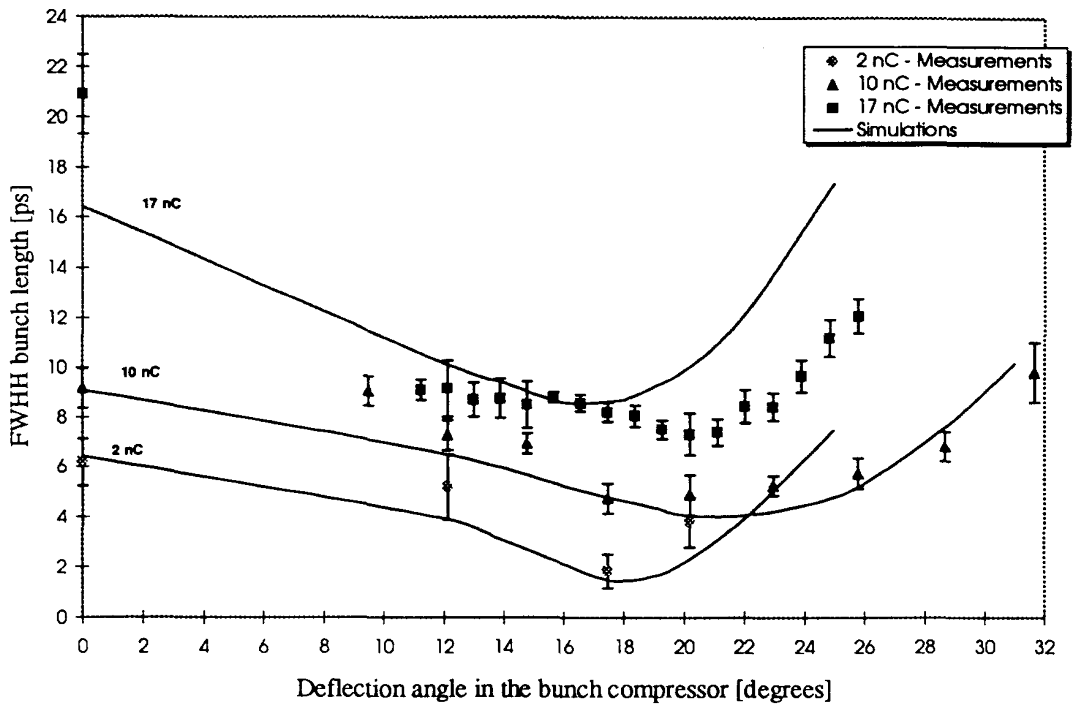
An initial QE of more that 10% is observed which drops rapidly over the first 30 h of operation and then stays at a level of about 2% over several weeks. It was clearly demonstrated that only the time when the RF is applied affects the lifetime of the photocathode. Whether the variation of the photoemission is due to the direct effect of the RF field on the photocathode properties or to the degradation of the quality of the vacuum during RF Gun operation remains to be clarified. QE is not only a function of time but also of the applied field. Figure 7 shows the measured variation of QE as a function of the field on the cathode

Figure 7: Quantum Efficiency of Cs_2Te Cathodes as a Function of RF Field on the Cathode.



When the laser pulse hits the cathode at an RF phase angle of 30°, the peak field on the cathode is a factor 2 higher than shown. Improved photocathode performances have recently been obtained by introducing a molybdenum layer between the tellurium layer and the copper substrate and limiting sparking as much as possible in the RF Gun by appropriate setting of RF interlock thresholds.

Figure 8: Bunch Length Compression by Magnetic Chicane



3.4 Bunch Compressor

For effective production of 30 GHz RF power, bunch lengths much shorter than the 33 psec of the 30 GHz period, typically 5 ps (FWHH), have to be obtained. 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 which are longer than the original laser pulse length of 8 psec. Since in the CLIC scheme as well as in CTF phase II (see Section 4) bunch charges of the order of 20 nC are required, compression of the bunch length compression by a magnetic chicane in combination with off-crest acceleration in the 4-cell cavity of the photoinjector has been studied. Fig. 8 compares the measured variation of the bunch length with deflection angle in the magnetic chicane for various bunch charges to simulations made using the code PARMELA. The bunch length was measured with a streak camera observing the Cerenkov radiation of the electron beam passing through a thin saphire foil[14].

4. The Second Phase of the CLIC Test Facility (CTF2)

4.1 Objectives

The CLIC Test Facility in its present configuration (CTF1) has achieved all its objectives and clearly demonstrated the principle of the Two Beam Acceleration scheme. A second phase for this facility is now planned (the so-called CTF2) with the following main goals:

(1) To study the feasibility of the Two Beam Acceleration scheme on a larger scale with beam parameters as close as possible to those proposed for CLIC. In particular the production of 480 MW of RF power at 30 GHz for beam acceleration up to 320 MeV.

CTF2 target values and CLIC parameters are compared in Tables 3 and 4. The drive beam parameters are very similar, they have the same charge per bunch, the same emittances and bunch length, but only half of the total charge and a much lower energy and repetition rate in order to save power.

Table 3: Main Parameters of the Drive Beam

		CLIC	CTF2	
Beam momentum	E	3000	55	MeV/c
Pulse Repetition Frequency	f_r	2530	10	Hz
Number of trains per pulse	K_t	4	1	-
Trains Repetition Frequency	F_t	350	-	MHz
Number of Bunches per train	K_b	22	48	-
Bunches repetition Frequency	f_b	30	3	GHz
Charge per bunch	q_b	25	21	nC
Total Charge per pulse	N_t	2.2	1.0	μC
Total Beam Power	P_b	$16.7\ 10^6$	550	W
Norm. Transverse Emittances	$\varepsilon_{x,y}$	200	200	μrad-m
Bunch length	σ_z	0.6	0.6	mm

The CTF2 probe beam is accelerated with the nominal CLIC field of 80 MV/m but will be limited to 2 bunches to minimise the length of the drive linac power pulse. The spacing between the two bunches will be variable to enable the second bunch to probe the wakefield created by the first with a nominal charge of 1.3 nC. At its injection energy of 50 MeV the probe beam is expected to be particularly sensitive to the effects of transverse wakefields generated by the 30 GHz structures.

(2) To design and construct a fully-engineered representative test section of the CLIC 30 GHz drive and main linacs *using nominal CLIC components working at nominal RF powers and accelerating fields*. As proposed for CLIC the CTF2 test linac will be built-up from 1.41 m long modules.

The aim here is to make sure that all the necessary equipment and components can be integrated into a string of well-engineered operating units. This means finding realistic design layouts and ensuring functional compatibility between all the RF components (the transfer and accelerating structures, waveguides, couplers, phase shifters and loads), the magnets, the active alignment system, beam instrumentation and beam position monitors, cooling and cabling, and the vacuum components and mechanical supports.

This new 30 GHz two-beam section will serve as a test-bed for the whole RF system, for the few microns precision active alignment system and for the development of beam instrumentation.

Table 4: Main Parameters of the Probe Beam in CTF2

		CLIC	CTF2	
30 Ghz RF power per Structure	P_{rf}	40	40	MW
Overall 30 Ghz RF power	P_t	$5\ 10^5$	480	MW
Beam momentum at injection	E_o	9000	40	MeV/c
Beam momentum increase	E_f	500	0.27	GeV/c
Acceleration gradient	G_a	80	80	MV/m
Repetition Frequency	f_r	1210	10	Hz
Number of Bunches	K_b	10	2	-
Bunches interval	Δ_b	20	20	cm
Charge per bunch	q_b	1.3	1.3 - 0.1	nC
Norm. Transverse Emittances	$\varepsilon_{x,y}$	3	20	µrad-m
Bunch length	σ_z	0.2	1.0	mm

(3) To develop and test the drive beam generation technology:

The generation in CTF2 of a high charge drive beam of 1 µC split into a train of 48 short bunches is very similar to one of the 11 beam lines proposed for the CLIC switchyard scheme. The electron beam is produced by a photo-injector consisting of a laser-illuminated photocathode in a high field RF gun followed by two accelerating structures developed specially to cope with high charge beams and to provide beam loading compensation. The bunches are finally compressed by a magnetic bunch compressor to the specified length for an effective RF power generation.

(4) To make measurements and compare with CLIC beam dynamics simulations:

(i) In particular to investigate the transverse and longitudinal wakefields generated by the high frequency structures in the drive and probe linacs, understanding and limiting the effects of these wakefields is of paramount importance for the CLIC scheme.

As pointed out above, the relatively low energies of both beams will make these measurements particularly sensitive enabling a good accuracy to be obtained using standard instrumentation such as beam line spectrometers, transverse profile and emittance monitors. The delay between the two bunches in the probe beam will be adjustable in steps of one 3 GHz wavelength (10 cm), allowing a scan by the trailing bunch of the wakefield generated by the leading bunch all along the foreseen length of the train of bunches in the CLIC main linac (200 cm). This measurement will be particularly instructive if and when damped accelerating structures become available.

(ii) To study the behaviour of the high intensity drive beam in the generation section as well as during the successive passages in the RF power production modules:

The beam optics (matching and steering) of such a beam is one of the main difficulties of the Two Beam scheme due to the large momentum spread introduced by beam loading first during acceleration then in the successive RF production stages. Again the relatively low energy of the beam will make it specially sensitive. It will in particular allow its behaviour to be explored in a regime close to the one that will occur at the end of the CLIC drive linac.

(5) To help estimate the realistic cost of a representative part of the CLIC complex:

4.2 Brief Description of Overall Layout and Main Components

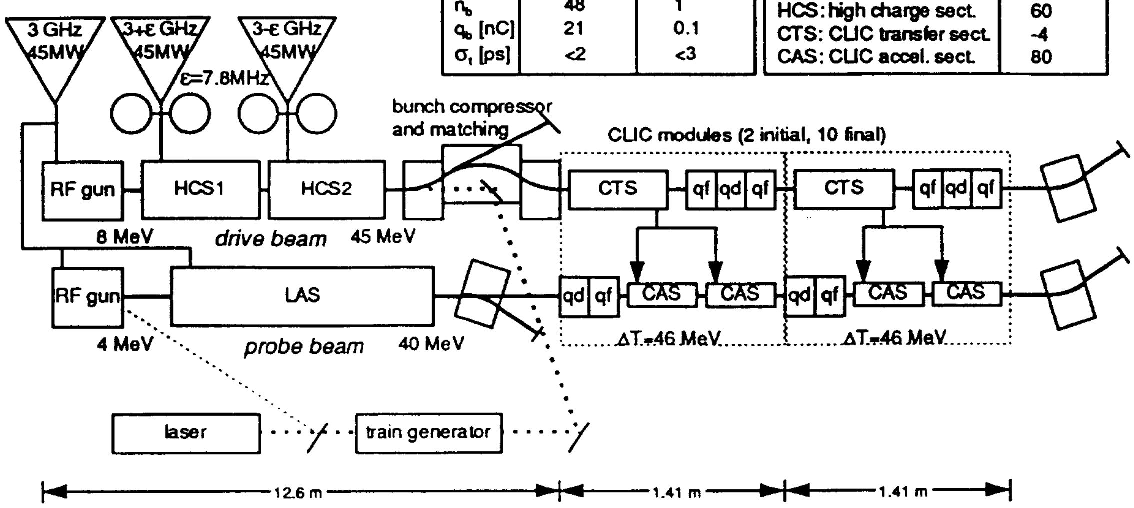
The proposed layout of CTF2 is shown in Fig. 9. The corresponding beam envelopes are shown in Fig. 10. The drive beam train constituted by 44 bunches spaced at 10 cm with a total charge of 1 μC will be generated by a new 2½-cell RF gun driven by the existing laser and will be accelerated to 45 MeV/c by two new 0.65 m long high gradient (60 MV/m) TW structures (HCS). These structures are designed to minimise both beam loading and transverse wakefield effects induced by the high charge of the drive beam. They are working at two slightly different frequencies providing beam loading compensation to reduce the momentum spread along the train of bunches. After passing through a magnetic bunch compressor the bunch train will be used to drive a string of 6 CLIC transfer structures (CTS). The transfer structure consists of a 15 mm diameter circular beam tube coupled through four diametrically-opposite slots to four periodically-loaded rectangular waveguides. Each 70 cm long CTS will produce enough power to drive two CLIC accelerating sections (CAS) with 40 MW, 12 ns long, 30 GHz power pulses.

The probe beam simulating the CLIC main linac will be generated by the existing 1½-cell CTF1 RF gun with its photocathode illuminated by a small fraction of the total available laser power and will be accelerated with the existing LAS section to 50 MeV before entering the string of 30 GHz high gradient (80 MV/m) accelerating sections. In the beginning only one 0.1 nC bunch will be accelerated - this will enable the energy gain and energy stability in the 30 GHz linac to be measured - later on a second bunch will be added and the charge of the first bunch increased up to 1.3 nC to study wakefield and beam loading effects. For initial CTF2 operation the two constant impedance (CI) accelerating sections currently being used in CTF1 will be used - up to six more CI sections including two RF quadrupole sections will be added when they become available. Further sections will be prototypes of CLIC structures adapted for multibunch operation.

Figure 9: Schematic Layout of the CLIC Test Facility Phase II (CTF2)

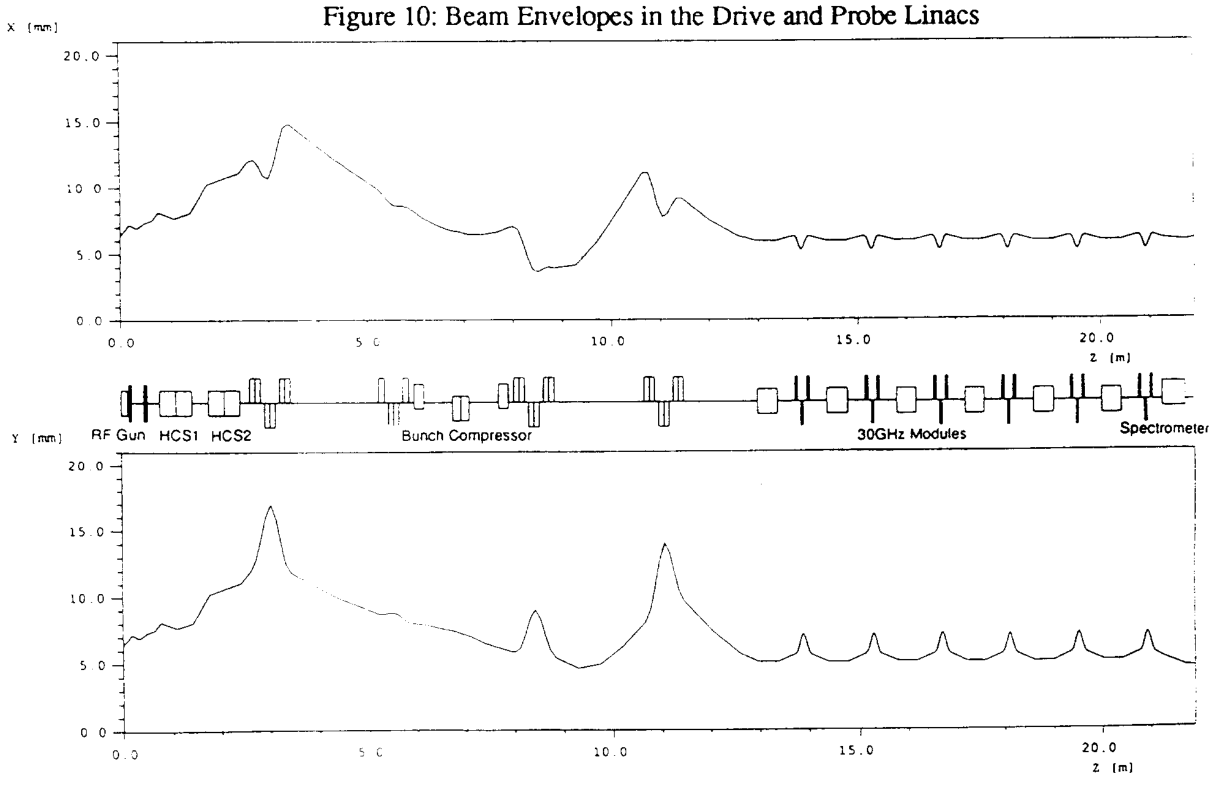
	Drive beam	probe beam
n_b	48	1
q_b [nC]	21	0.1
σ_t [ps]	<2	<3

RF structure	E_a [MV/m]
LAS: LIL section	10
HCS: high charge sect.	60
CTS: CLIC transfer sect.	-4
CAS: CLIC accel. sect.	80



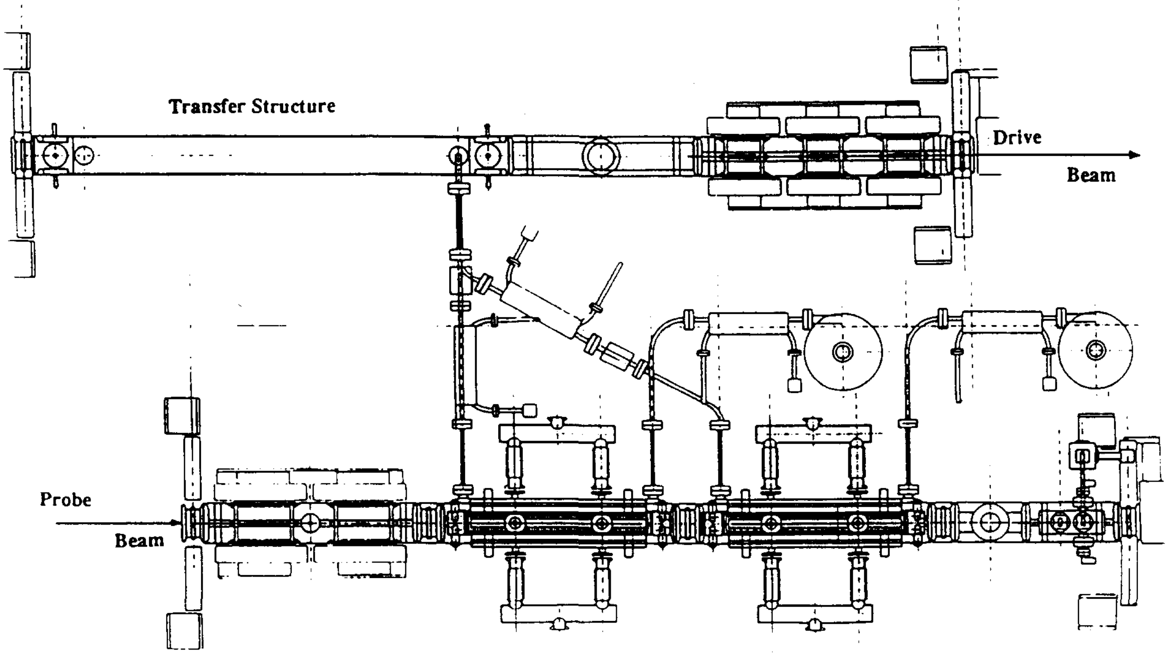
In order to minimise problems due to misalignments and at the same time to simulate the CLIC tunnel configuration as closely as possible, both 30 GHz linacs will sit on a common concrete base and will be equipped with the CLIC support and active pre-alignment system. The structures will be supported by 1.4m long silicon carbide girders. The girders will be moved by precision stepping-motors. The quadrupoles will sit on their own supports and will have their own independent stepping-motor drives. A stretched-wire running along the length of each linac will serve as reference for alignment. All the important linac components will be positioned with respect to this line via capacitive position transducers connected to the control system.

Figure 10: Beam Envelopes in the Drive and Probe Linacs



The probe beam linac will have a 30 GHz Beam Position Monitor (BPM) at the head of each girder, the drive beam will be equipped with button BPMs one at the end of each transfer structure. All the corrector strengths, stepping motor settings and BPM signals will be integrated into the overall control system and will be available to test beam-based steering and alignment (Fig. 11).

Figure 11: Layout of One Module of the Probe and Drive Linacs.

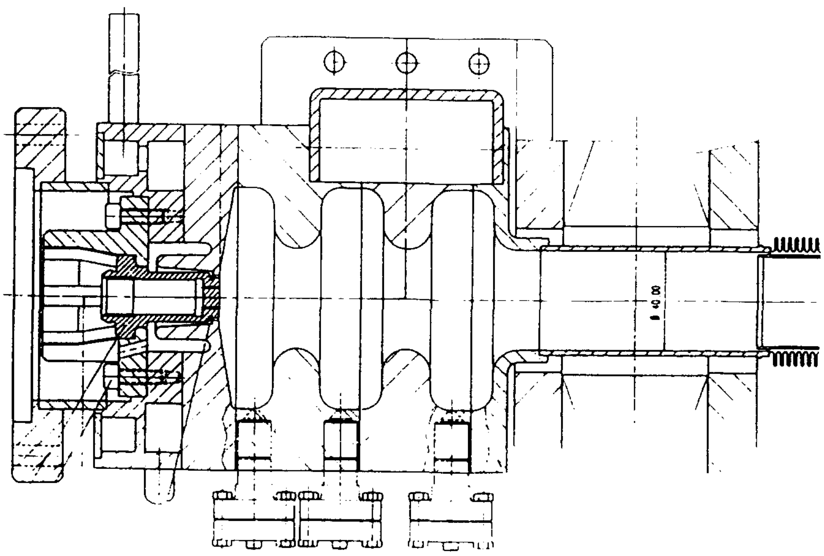


4.2 The 3 GHz RF Gun and Accelerating Sections of the Drive Beam

The 3 GHz RF structures of the drive beam generation are specially designed for high charges:

The RF Gun is shown in Figure 12. It is a 2½ cell gun with the waveguide coupled to the second and third cell. The cell irises have a diameter of 40 mm, twice that of the present CTF1 gun. This large cell diameter allows larger beam diameters and hence reduces the current density of high charge bunches. The large iris also reduces the normalized shunt impedance, r/Q, and thereby the energy spread due to beam loading. However, as a consequence, the S-band RF power required for the gun 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 that this gun should be capable of delivering single-bunch charges of more than 60 nC, three times more than what is needed for CTF phase II.

Figure 12: The RF Gun for the Drive Beam of CTF II



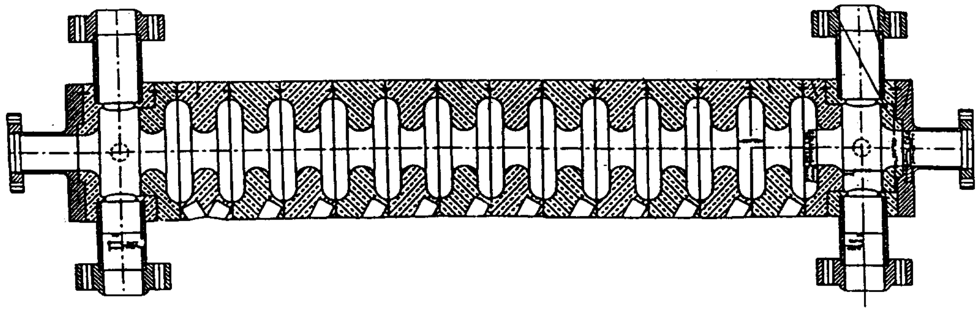
The accelerating sections HCS1 and HCS2 are S-band structures optimized for the acceleration of high charges[15]. Table 5 lists their main parameters and Figure 13 shows a drawing of one of the sections.

Table 5: Parameters of the Accelerating Sections HCS

mechanical length	852 mm
electrical length	653 mm
iris diameter	30.5 mm
phase advance	11/12 p
filling time	0.73 ms
r'	29.1 MΩ/m
Q	13100
gradient	60 MV/m
input power	120 MW
frequency	2998.55±7.81 MHz
v_g profile	const. impedance
v_g/c	0.0031
rel. beamload. for 1mC	35 %

An iris diameter of 30.5 mm has been chosen to obtain a low r/Q so that the energy spread due to beamloading can be minimzed. The large iris also produces a strong reduction of the transverse wake potentials, 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-axisymmetric modes in the coupling cells.

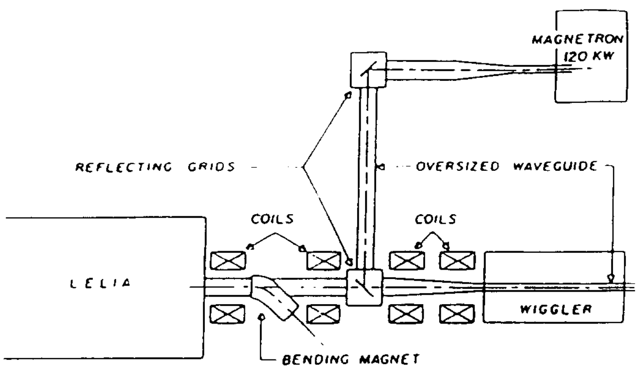
Figure 13: The High Charge Accelerating Structure (HCS)



5. The CESTA and DUBNA Test Facility

Collaborations have been set-up between CERN and the Centre d'Etudes Scientifiques et Techniques d'Aquitaine (CESTA) in Bordeaux (France) as well as with JINR at DUBNA (Russia) to study an alternative scheme[5] of Drive Beam generation by direct bunching at 30 GHz in an Induction Linac driven Free Electron Laser (FEL). In both laboratories, test facilities are being prepared using as much as possible existing installations[16,17], to study and observe the quality of the bunching at a few MeV. In a later phase it is planned to use the bunched beam to generate RF power with a CLIC transfer structure.

Figure 14: Layout of the LELIA Facility for Direct Bunching by FEL (from[16])



In CESTA, the Induction Linac, LELIA, provides a 1 kA, 50 nsec electron beam at 2 MeV which is transported to an helical wiggler specially built for this purpose, where it interacts with a copropagating 35 GHz wave delivered by a 120 kW magnetron[16] (Fig. 14). The beating of the electromagnetic wave and the wiggler magnetostatic field gives rise to an axial ponderomotive force and a consequent bunching of the injected pulse. The bunching however could possibly be affected by longitudinal space charge forces at this particularly low energy.

In DUBNA, a similar experiment is in preparation[17] taking advantage of the 9.5 MeV SILUND 21 Induction Linac made of seven modules of 1.5 MeV each. The detrimental effects of space charge in this case will be significantly reduced.

6. Conclusion

The CLIC scheme, based on beam acceleration at high gradient (80 MV/m) and high frequency (30 GHz) with RF power generation by the Two Beam Acceleration (TBA) method, is certainly one of the most promising option for a Linear Collider at high energy. But it is also the most challenging by the new technologies it requires which have to be developed.

An Alignment Test Facility is already operating to test and develop alignment techniques in the micron regime which is necessary to prevent beam emittance dilution due to the effects of strong wakefields inherent in the high frequency option.

Now that the first phase of the CLIC Test Facility (CTF1) has achieved all its objectives and clearly proved the principle of the Two Beam Acceleration scheme, the second phase of this facility (CTF2) is being prepared to demonstrate the overall technical feasibility by building a fully engineered 30 GHz test section of the CLIC main and drive linacs with nominal components working at their nominal fields. It will be installed in stages from 1996 to 1999.

An alternative scheme of drive beam generation by Induction Linac driven Free Electron Laser is being tested in parallel in the CESTA (France) and JINR (Russia) laboratories taking advantage of existing installations.

A review of the status of the CLIC 30 GHz Two-Beam approach to Linear Collider design is planned at the end of 1999 when the results from all these test facilities will have been obtained.

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