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The CERN Linear Collider Test Facility

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ABSTRACT

In the CLIC scheme, the rf power at 30 GHz used for acceleration in the main linac is generated by a drive beam. This beam contains very short (1 mm) high-intensity (10^{12} e⁻) bunches with 10 mm spacing. The generation of such a beam requires the development of electron sources and bunch compressors. For this work a test facility is under construction. This paper describes work on photocathodes, laser systems, the rf gun, beam analysis, and acceleration to 60 MeV. Preliminary results and the current status are reported.

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In the CLIC scheme, the rf power at 30 GHz used for acceleration in the main linac is generated by a drive beam. This beam contains very short (1 mm) high-intensity (10^{12} e⁻) bunches with 10 mm spacing. The generation of such a beam requires the development of electron sources and bunch compressors. For this work a test facility is under construction. This paper describes work on photocathodes, laser systems, the rf gun, beam analysis, and acceleration to 60 MeV. Preliminary results and the current status are reported.

1. Introduction

A study of a two-beam linear collider (CLIC) is in progress in CERN [1,2]. In this scheme, a high-intensity relativistic drive beam running along the whole linac produces the required 30 GHz rf power for the main linac by interaction of the drive beam with TW transfer structures. The drive beam is kept relativistic by periodic acceleration in superconducting cavities operating at 0.35 GHz.

The main objective of the CLIC Test Facility (CTF) is the study of the generation of the drive beam. The best method seems an injector combining an rf gun equipped with a laser-driven photocathode and a couple of magnetic bunch compressors, properly interleaved with accelerating sections. Given the 3 GHz equipment at hand, it was proposed to start with an rf gun at this frequency[3]. This gun operating at 10 cm wavelength is not able to produce the CLIC drive beam which will consist of 4 bunch trains having a spacing in the train of 1 cm corresponding to 30 GHz. However, it allows a study of the basic problems associated with the generation of high-intensity bunches having a typical length of the order of 10 ps. The second objective is to generate 30 GHz rf power for a variety of CLIC structure tests. This is done by accelerating the 4.5 MeV electron bunches from the gun by a spare accelerating section of the LEP Injector Linac (LIL) to more than 50 MeV. A small accelerating section adding 4 MeV and a bunch compressor might eventually precede the LIL section. This beam then interacts with a 26 cm long TW structure of the CLIC main linac used as a transfer structure which converts the energy extracted from the beam into rf power. For 40 nC in the pulse we expect 24 MW at the output. Coupling this power to a second, identical CLIC structure produces there the nominal gradient of 80 MV/m, which can be verified with a probing beam. The CLIC main linac structure is used as transfer structure in this experiment in order to compensate with its high shunt impedance the relatively low intensity of the experimental drive beam. However, this short beam pulse will also serve for testing the real low-impedance CLIC transfer structure and it can be used for tests of the position monitors and other instrumentation of CLIC.

In a first stage, the gun will be operated with an Y or CsI cathode because these materials can be exposed to air without adverse effects on their performance. A Nd:YAG laser providing a long pulse (8 ns), not synchronized with

the rf, will illuminate the cathode. The first part of the beam line with instrumentation after the gun has been designed. It acts as a spectrometer to study and later to monitor the beam parameters. Then the beam line to the LIL accelerating section will be completed probably first without bunch compressor. In the second stage, a preparation chamber will be attached to the gun for in-situ preparation of Cs₃Sb and metallic cathodes. The laser will be replaced by an rf synchronized one producing either single pulses or a train of pulses spaced by a multiple of the rf period (10 cm). At this stage, controlled 30 GHz rf generation will become feasible. The first stage is planned for the end of 1990, the second stage for the middle of 1991. In the following a progress report on the key issues is given.

2. Photocathode development

In order to produce a few tens of nC in the rf gun, the cathode must have a quantum efficiency η of 0.1% and a good lifetime. Initial work [4] has concentrated on Y,Sm[5] and Cs₃Sb[6] after a start-off with CsI. The electron yield is measured with the cathodes inserted in a dc gun providing a gradient between 5 and 8 MV/m. The cathodes were illuminated first by a pulsed Nd:YAG (266 nm, 8 ns) laser; now an excimer laser (308 nm, 15 ns, about 0.1 mJ at cathode) is used. The cathodes can be transferred under vacuum from the preparation chamber to the dc gun by a translator. The beam instrumentation downstream of the gun (luminescent screen, current and charge monitor) completes the dc test stand[4].

Recently, Cs₃Sb cathodes have been produced under improved vacuum conditions, continuously monitoring the electron emission triggered by excimer laser light during the deposition of the materials. Evaporating Sb and then Cs onto the stainless steel substrate in a vacuum in the nTorr range resulted in a cathode with $\eta = 0.5\%$, very similar to the value previously obtained[4]. If the cathode is stored under vacuum at 0.5 nTorr, η slowly decreases, dropping to half the initial value within about 6 days. The cathode illuminated with low energy laser pulses (10 μ J) remained relatively stable; η dropped by 30% over 40 h. However, η decays faster if the laser energy is higher, e.g. to 50% in 7 h with a laser pulse of 350 μ J. All tests were conducted at 2.5 Hz repetition frequency. It appears that Cs₃Sb is a suitable cathode material to start with. Tests with Ar glow-discharge cleaned Y and multi-alkaline cathodes are the next steps envisaged.

3. The laser system

A number of these tests on the dc test stand will be repeated with shorter laser pulses produced by tail-quenching in a dye which is pumped by the excimer laser. A N₂ laser (337 nm, 0.5 ns, 0.1 mJ at cathode) is also in preparation for the dc tests. For the rf gun, a second Q-switched, frequency-quadrupled Nd:YAG laser (266 nm, 8 ns, 15 mJ) will be used in the first stage. Later on, a laser that can be synchronized with the rf will become available. This system produces either single pulses or the energy of

one pulse may be split into a train of sub-pulses produced by a mirror system. The train lasts about 2 filling times (2×11.4 ns) of the CLIC main linac structure, and the spacing of the pulses in the train is a multiple m of the 3 GHz rf period ($m = 1, 2, 4, 8, \dots$). The laser system consists of a mode-locked, diode-pumped Nd:YLF laser oscillator with phase and amplitude stabilization producing a pulse train at the 12th subharmonic of the rf, 250 MHz, and at 1047 nm with 0.4 nJ in these ≤ 20 ps (FWHH) pulses (timing stability ≤ 1 ps relative to rf). After a single-pulse selector, a Nd:YLF regenerative amplifier and two further Nd:YLF single-pass amplifiers raise the pulse energy to > 5 mJ, while a grating pulse compressor reduces the pulse length to 7 ps (FWHH); 10 ps, 30 ps, and 50 ps will also be available. Harmonic generators provide light at 524, 349 and 262 nm with the respective single pulse energy 2 mJ, 0.5 mJ and 0.2 mJ. The repetition rate of the laser, ≤ 10 Hz, defines the repetition rate of the CTF.

4. The rf Gun

The gun consists of a half-cell containing the cathode and a full cell (Fig. 1). The input waveguide is coupled to both cells in such a way that only the π -mode is excited[3,7]. In order to test fabrication techniques and to have a model for comparison between field calculations and low-power rf measurements in air, an OHFC copper model was built without cathode plug. The coupling slot to the waveguide was cut later. The dimensions had been scaled from the BNL design[3] to $f_{LIL} = 2998.55$ MHz, taking into account that the gun would operate at 30° C. The dimensions were adjusted until URMEL [8] gave the correct frequency of the π -mode f_π and the accelerating electric field in both cells was the same. The rf measurements on the model without slot showed that the measured f_π was within 0.16% of the calculated value. After making the eigenfrequencies f_i of the two cells equal by tuning the second ($\lambda/2$) cell, the frequency difference between π and 0 mode was 1.9 MHz, which is a measure for the coupling between the two cells. The unloaded Q was measured to be 10800.

Having demonstrated that the dimensions of the model were correct, "Gun 2" was produced. Its individual parts are brazed together and its main body is equipped with 3 water cooling circuits which are machined into the copper. Each cell is equipped with a radial piston tuner which is, for the moment, set manually. The tuning range is ± 2 MHz. An additional cell 1 tuning offset can be obtained by adjusting the length l of the cathode plug, the sensitivity being $df_1/dl = -26$ MHz/mm, which indicates tight tolerances on the cathode thickness. Each cell is equipped with a small, calibrated coupling loop. According to the calculations, 6.3 MW are sufficient to produce in both cells $E(r=0) = 100$ MV/m provided the theoretical Q (11700) can be achieved. The gun can be baked to 150° C in order to obtain a vacuum in the lower 0.1 nTorr range. The low-power rf measurements are being made and the high-power tests will be performed soon.

Simulations[9] with TBCI-SF[10] up to 75 nC initial pulse charge were carried out assuming in most cases a parabolic distribution $I(t)$ at the cathode having $\Delta t = 30$ ps at the base. The results of TBCI-SF at 1 nC were cross-checked[9] with PARMELA and PRIAM[11]. When an

optimistic cathode performance ($r_c = 7$ mm, $j = 8$ A/mm²) is assumed, a pulse charge up to 32 nC with 6.5 ps rms could be expected provided 15% beam loss in the gun is accepted. However, more realistic parameters $r_c = 5$ mm, $j = 4$ A/mm² were adopted for the nominal case yielding 9.4 nC with the standard initial distribution. The results are summarized in the first line of table I. In this case no beam loss occurred in the gun and emittance as well as energy spread are much smaller. The phase Φ between the zero-crossing of the cathode field E_1 ($dE_1/dt > 0$) and the start of the laser pulse is very important and its choice is a compromise. Small or negative Φ leads to a welcome bunching in the gun but is always associated with particle loss. Table I is for $\Phi = 30^\circ$ providing minimum momentum spread. The left part of the table gives the initial conditions, the right part the gun output parameters: average longitudinal momentum $\langle p \rangle$, rms momentum spread $\delta p/p$, rms bunch length δz and the normalized emittance in the transverse plane using the usual definition[9]. Variation of the initial beam dimensions keeping the charge constant (Table I, 2nd and 3rd line) shows that space charge does not play a major rôle. Trading emittance against bunch length seems to be possible. Cases with $E = 50$ and 25 MV/m were also run showing a degraded performance.

Table I, Beam Simulation Results at Gun Exit for $Q = 9.4$ nC and $E = 100$ MV/m

Dt ps	r_c mm	j A/mm ²	$\langle p \rangle$ MeV/c	$\delta p/p$ %	δz mm	e_n rad.m
30	5	4	4.6	0.4	1.8	1.2×10^{-4}
30	$5/\sqrt{2}$	8	4.6	0.5	1.9	0.8×10^{-4}
15	$5\sqrt{2}$	4	4.5	0.2	0.9	1.5×10^{-4}

The simulations indicate that it might be difficult to get the required 40 nC in a well-behaved bunch from the gun. In this case, a train of bunches with a time structure described under point 3 will be used. It can be shown that the power produced by such a bunch train generates virtually the same gradient in the second CLIC structure as a single bunch, provided that the total charge in the train per filling time and in the single bunch are the same; the bunch length must also be equal. The requirement on the gun can in this way be considerably reduced.

Initially, the laser synchronized with the rf will not be available. An 8 ns long pulse of a Nd:YAG laser will be used. Simulations with TBCI-SF, assuming constant current emission yielding at the cathode 3.2 nC during 166 ps, with $E = 100$ MV/m show 0.3 nC/bunch at the gun exit with 20 ps at the base in the $\pm 0.5\%$ momentum bite at peak energy, consisting of particles having departed around $\Phi = 55^\circ$. The simulations further show that the particles emitted with an unfavorable phase are at first accelerated but then return to the cathode, depositing there almost 0.5 mJ/rf cycle, which is 2.5 times the laser power and which could lead to cathode damage.

5. Other components of CTF

A blockhouse constructed alongside LIL contains the beam line. It has inside dimensions $l \times w \times h = 19.2 \times 4.8 \times 3.2$ m, and the concrete shielding is laterally 2.4 and 1.6 m at the top. The equipment room at the top ($17.5 \times 8.0 \times 3.6$ m) houses the laser, instrumentation, controls and power supplies.

The 35 MW spare klystron of LIL provides the 3 GHz power for the rf gun, for the deflecting cavity foreseen for bunch length measurements, and for the spare LIL accelerating section. Power and phase for the first two items can be controlled independently. The non-load energy is 60 MeV (rf gun + LIL section).

The layout of the beam line based on first-order optics up to the LIL section follows the BNL/ATF solution: three straight sections and two 90° bends (Fig. 2). This solution is attractive because i) the spectrometer can be used permanently and the slits provide the appropriate cuts in longitudinal phase space producing the short pulses during the running-in with the 8 ns Nd:YAG laser; ii) the laser beam is centered on the gun axis. To cope with the large e^- beam divergence after the gun, a solenoid is positioned at the gun outlet followed by a quadrupole triplet. The momentum defining slit is in the horizontal beam waist at $D_{x\max}$ between the two dipoles. The two quadrupoles in this straight section are adjusted to suppress the dispersion after the second dipole magnet. Further triplets focus the beam into the LIL accelerating section. Instrumentation is foreseen to measure beam charge and position with magnetic pick-ups. Beam size is measured with a secondary emission grid, transparent to the laser, in the first straight section and with screens in the rest of the line. Bunch length is measured with a 3 GHz vertically deflecting cavity sweeping the beam over a horizontal slit placed between the two dipoles, and by observing the transition or Cerenkov radiation emitted by a thin foil placed in the beam after the first dipole.

The CTF building including utilities is ready and the rf network is partially installed. Installation of the rf gun, the Nd:YAG laser and the first part of the beam line will be completed by the end of the year.

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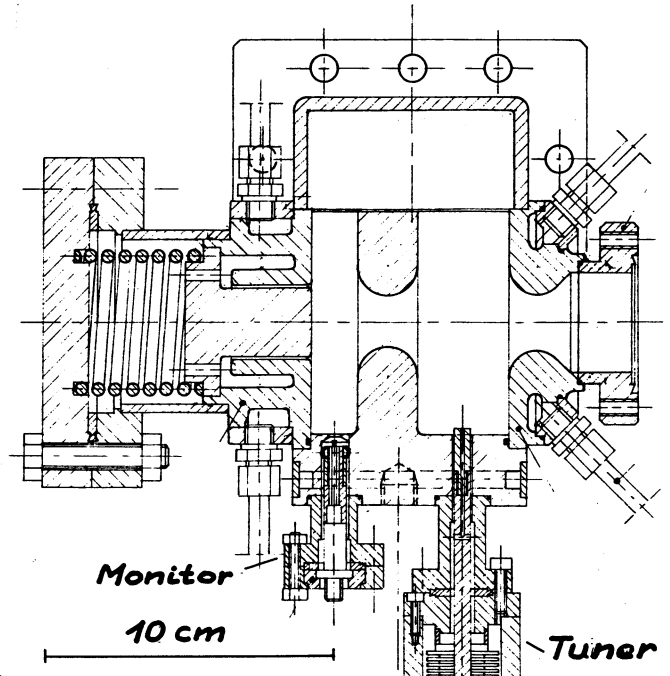


Fig. 1: Cross-section of 3 GHz rf gun (derived from BNL/ATF design [3])

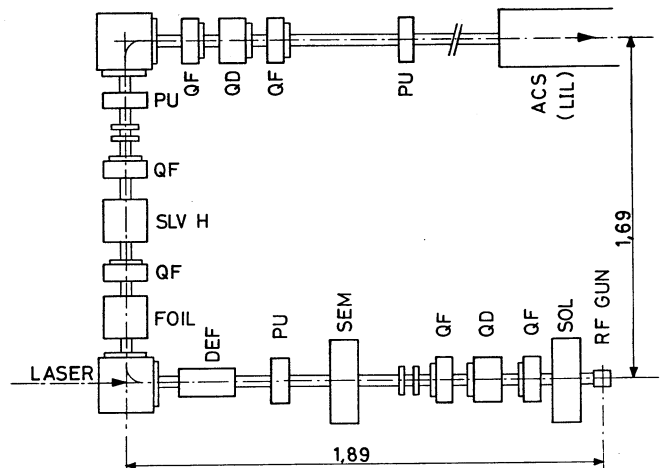


Fig. 2: Layout of beam line after gun; SEM-secondary emission grid; DEF-vertically deflecting cavity; FOIL-foil for streak camera; SLV-H-vertical and horizontal slits; PU-beam position and charge monitor; ACS-LIL accelerating section