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THE CERN LINEAR COLLIDER TEST FACILITY (CTF)

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Abstract

The CTF was brought into service last year. The 3 GHz gun produced a beam of 3 MeV/c which was accelerated to 40 MeV/c. This beam passing a prototype CLIC structure generated a sizeable amount of 30 GHz power. This paper describes the results and experience with: the gun driven by a 8 ns long laser pulse and its CsI photo cathode, the beam behaviour, the beam diagnostics in particular with the bunch measurements by Cerenkov or transition radiation light and streak camera, the photo cathode research, and the beam dynamics studies on space charge effects.

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Introduction

The CLIC Test Facility (CTF) is part of the study in progress at CERN of a two-beam linear Collider (CLIC). The objectives of the CTF are to study the generation of high intensity, short e$^-$ bunches. These bunches will also be used to generate 30 GHz rf power for testing CLIC structures and beam monitors. An rf gun equipped with a laser driven photo cathode operates at 3 GHz. The gun produces e$^-$ bunches of a momentum of 4.5 MeV/c at the nominal field of 100 MV/m. These bunches are then accelerated to 45 MeV/c in a 4.5 m long TW structure. A general description of the CTF was presented at the LINAC 90 Conference [1]. The present layout of the beam line is shown on Fig . 1.

Last year the experiments in the CTF were made with a long laser pulse, 8 ns. The train of micro bunches created by each laser pulse was accelerated and transported through a CLIC prototype structure. Although the characteristics of the micro bunches were not optimal, 30 GHz rf power was generated by the CLIC prototype accelerating structure. The photocathodes are introduced into the gun in air. Therefore, the choice of photo emissive material is limited to some metals and CsI. We used the latter one as we need a quantum efficiency of a few percent. This choice implies the use of an UV laser beam, at about 210 nm. A Nd:YLF laser providing short pulses - approximately 13 ps FWHH - and synchronised with the rf is being commissioned at 209 nm.

Operation of the CTF

The rf gun used during the experiments since last year has 1 1/2 cells, at 2998.55 MHz. The nominal accelerating field is 100 MV/m in both cells with an rf input power of 6 MW, pulse length 2.5 µs and 10 Hz. With the CsI photo cathode frequent rf breakdowns occur in the gun above a level of 70 MV/m and most of the time the gun is operated at 66 MV/m[2]. The gun with its photocathode was baked out at 150°C during 24 hours. The beam line downstream of the gun is baked out over approx. 6 m together with the gun on a number of occasions. The vacuum pressure in the pumping

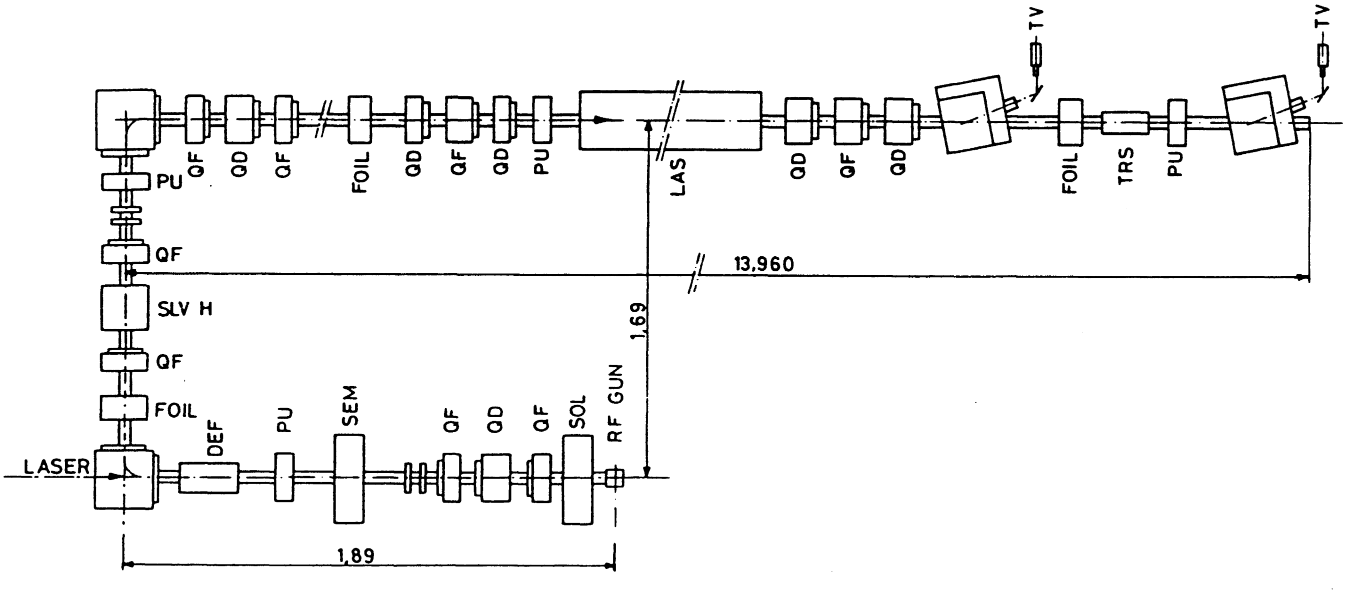

Fig. 1 Layout of beam line; SOL-solenoïd; QF, QD-quadrupoles; SEM-secondary emission grid; DEF-vertically deflecting cavity; FOIL-foil for streak camera; SLV-H-vertical and horizontal slits; PU-Beam position and charge monitor; TV screen in air viewed by camera. LAS LIL acceleration section; TRS the CLIC prototype structure.

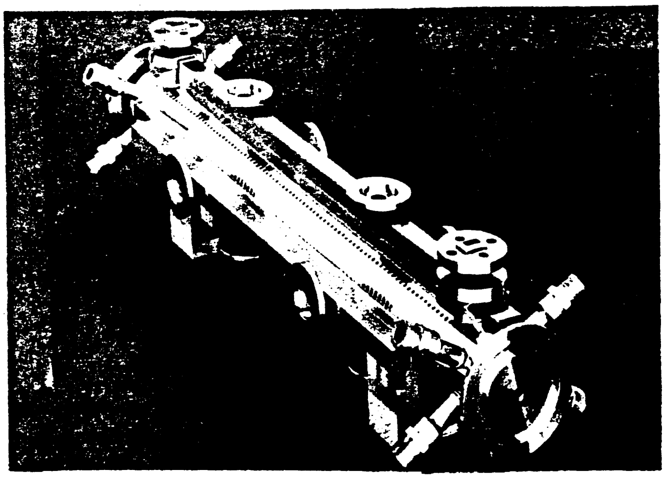

Fig. 2 The 30 GHz prototype CLIC accelerating section

manifold next to the gun is about 1.10^{-10} Torr with rf on, and we estimate that the pressure in the gun is higher by a factor 10. The quantum efficiency (QE) of CsI is approx. 2% at 213 nm; it drops to 1% over 100 hrs with rf and laser on, if breakdowns are avoided. The fifth harmonic of the Nd:YAG laser was used. The energy on the cathode was typically 25 µJ, spot size on the photo cathode diameter 3 - 4 mm.

The energy dispersion in the bunch leaving the gun was high and approx. 20% of the charge measured behind the gun arrived after acceleration to 40 MeV/c at the CLIC structure. Best results were 46 nC from the gun and 9.8 nC/8.2 nC at input/output of the CLIC structure. The charges were distributed over about 22 micro bunches. Typical length of a micro bunch was 37 ps (FWHH). The amplitude of the micro bunches was varying from pulse to pulse due to poor stability of the laser beam.

30 GHz power generation

One of the aims of the CTF is to generate 11 ns long rf pulses at a frequency of 30 GHz and a power level of 40 MW to be able to test the behaviour of our accelerating sections at fields of 80 MV/m. For the moment we do not have a suitable source to generate the very intense tightly bunched drive beam required to generate these levels of RF power with the low-impedance transfer structure as foreseen in the CLIC two-beam scheme, so a high impedance structure (in fact the first prototype accelerating section) is being used in its place. This section is shown in Fig. 2 It is an 84 cell iris-loaded travelling-wave structure made by the machine-and-braze technique. Individual cells having an aperture diameter of 4 mm and a diameter of 8.7 mm are pumped through four radial pumping holes by vacuum manifolds brazed on the sides. The $v_g = 0.082$ structure operates in the $2\pi/3$ mode, has a fill time of 11 ns, and has been tuned to have a phase velocity $v_p = c$ at 29.985 GHz.

Using this structure in the CTF we have generated a 20 ns 80 kW power pulse (shown in Fig. 3) with a 8 ns long train of 22 drive bunches spaced at 10 cm intervals and having a total charge of 4.8 nC. The estimated bunch length was 30-40 ps (FWHH).

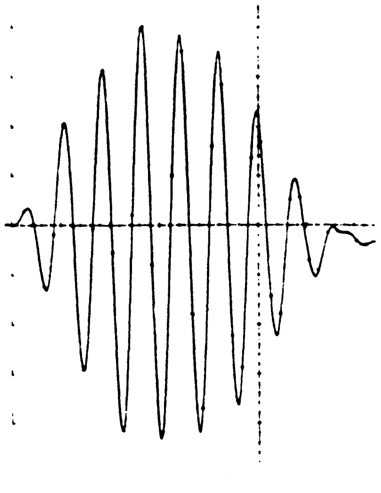

Fig. 3 The 20 ns long 30 GHz RF power pulse mixed down for measurement purposes to 500 MHz.

Measurement of the length of the electron bunch and of the laser pulse

The e^- bunch produces a photon beam in a transition radiation or a Cerenkov monitor. The first consists of a sheet of Al, 1 mm thick, and the second of a sheet of sapphire, 0.3 mm thick. Both sheets are mounted in a chamber and can be moved remotely into the beam. Three chambers are installed, two for measuring the beam from the gun, and one in front of the CLIC structure. An optical system composed of lenses and mirrors provides an image of the photon emission at the input of the streak camera.

Main characteristics of the measurement system

	electron beam				laser beam
energy, MeV	4		50		
	Tr.	Cer.	Tr.	Cer.	
photon energy	visible				180 - 750 nm
intensity resolution*	5.10^5	5.10^3	1.10^5	1.10^4	10^3 at 560 nm
time response (ps. FWHH)	4	4.5	2.	3.4	2.

Tr.= Transition radiation Cer.= Cerenkov radiation

* in e^- or photon per ps.mm equivalent to noise

Photocathode development

In order to provide the most suitable photo cathode for the CTF rf gun different kinds of cathodes are developed and studied in a photo emission lab [3]. The electron yield is measured with the cathodes inserted in a DC gun providing a gradient between 5 and 8 MV/m. The cathodes are illuminated by different pulsed lasers: excimer laser (193 and 308 nm, 15 ns) and Nd:YAG laser (213 and 266 nm, 6 ns). The cathodes can be transferred under vacuum from the preparation chamber to the DC gun by a translator.

Both alkaline and metallic cathodes are produced and tested. Different sorts of antimonide alkaline cathodes have been produced under improved vacuum conditions, continuously monitoring the electron emission triggered by laser light during the deposit of the materials. For K_3Sb cathodes we have obtained QE from 4 to 10% but their life time is

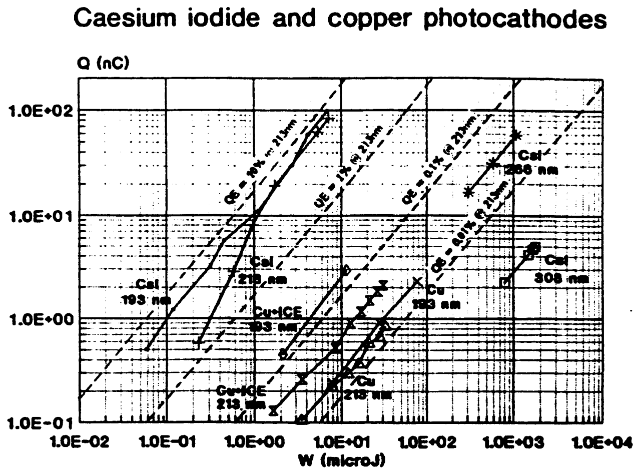

Fig. 4 Charge as function of the laser energy of the photocathode - ICE: Ion Controlled Etching

rather short (5 hrs for 1/e QE_{max}) at 308 nm and a current density of 72 A/cm^2. For a longer life time and installation in ambient air we have produced halide alkaline cathodes: 350 nm of caesium iodide (CsI) deposited on a copper substrate [4]. Due to its high work function ($\emptyset_S$ = 6.4 eV), this cathode is only usable at short wave lengths. We have obtained close to 10% at 193 and 213 nm during some days (fig. 4). On this graph the yield is computed by

$$QE[\%] = 125 \times \frac{Q\ (nC)}{W(\mu J) \times \lambda(nm)}$$

For metals as Cu, a technique has been developed to clean surfaces by argon glow discharge with an ICE equipment.

Commissioning of Synchro Laser

The laser system used to produce the picosecond pulses comprises 5 sub-groups: oscillator, regenerative amplifier, 2 power amplifiers, the harmonic generators and the control electronics.

The oscillator is a diode pumped Nd:YLF laser, mode locked at the twelfth sub harmonic of the 2.99855 GHz klystron frequency, i.e. at 249.879 MHz and emits 6.6 ps long pulses. The particularity of this Lightwave Electronics Corp. model 130 laser is its built-in timing stabiliser, which guarantees operation to less than 1 ps timing jitter.

The laser pulse train from the oscillator enters and leaves the regenerative amplifier continuously until Pockels Cell PC1 is activated. This traps one pulse, which stays inside the regenerative amplifier for about 50 round trips, i.e. 500 ns, until it has obtained a maximum energy gain of about 10^6. Activation of PC2 switches it out of the cavity. Further amplification is provided by two single pass amplifiers. A grating pulse compressor allows compensation of the pulse duration broadening due to the chirp in the regenerative amplifier.

The particular configuration of a mode-locked regenerative amplifier has been chosen to cut down the satellite pulses, which accompany the main pulse at ± 4 ns within the 10 ns round trip time of the regenerative amplifier. These satellites would otherwise extract substantial amplification from the active medium.

A chain of three non linear crystals (KD*P, BBO) permits the generation of the second, fourth and fifth harmonic of the fundamental 1047 nm laser light.

Timing and electronics are controlled by the built-in 250 MHz generator of the Lightwave laser.

Increase of the 30 GHz Power Generation

It is not possible to generate 40 MW rf power with the installed prototype CLIC accelerating section using a single bunch. Space charge forces are limiting the charge per bunch. With a charge of 9.5 nC, bunch length 12 ps FWHH, about 1 MW at 30 GHz can be expected. It has therefore been proposed to excite the CLIC structure with a train of bunches[5]. One scheme has two trains of eight e^- bunches with the bunches in the train separated by one 3 GHz wavelength, the trains separated by one CLIC structure filling time [6]. The trains are produced by splitting one laser pulse into the pattern required. The optimised bunch parameters for a train of 2 x 8 bunches are: 12.3 nC per bunch, 20 ps at FWHH resulting in a peak current of 615 A. It is difficult to achieve such a bunch train.

In the drift between the rf gun and the accelerating section the bunch is defocused longitudinally and radially by the space charge forces. In order to reduce these adverse effects we will put in the near future the rf gun in front and at a small distance, approx. 1 m, from the accelerating section. With a single solenoid placed at the gun exit, the beam can be focused into the accelerating section. In the long run we are preparing a 5 1/2 cells gun providing 8.5 MeV/c also to be installed just upstream of the accelerating section. This will substantially reduce the space charge effects.

Acknowledgements

The timing of the Synchro laser was designed and constructed by I. Kamber. F. Caspers participated in the design of the synchronising system of the laser and in the pulse jitter measurements. Thanks are due to D.J. Warner for useful comments and improvement of presentation.

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