CLIC—Developments on 30 GHz Structures and on Vibration Stabilisation

G. Guignard*
CERN

1. Introduction

The CLIC study aiming at a multi-TeV e^+e^- linear collider design [1], the accelerating gradient has to be high in order to reduce the length and, in consequence, the cost of the two main linacs. For achieving this, the CLIC beam acceleration uses high frequency (30 GHz), normal conducting structures and the high RF power needed is provided by the deceleration of a second beam running parallel to the linacs. Reaching accelerating gradients as high as 150 MV/m with tolerable surface fields preventing RF breakdown and with acceptable pulsed surface heating is one of the main challenges of the study. Another important one is related to the high luminosity requested for the physics. This implies small beam sizes which have to be preserved all along the linacs where the damaging transverse wakefields at 30 GHz are very strong. Since any beam misalignments in the cavities blow up the beam, time dependent vibrations of the components, the effects of which cannot be corrected as in the static case, have to be reduced to an amplitude of the order of 1 nm or less. This paper describes the status of the research and development done on these two challenging issues. There are of course other critical issues which are mentioned in a companion paper [2]. The latter also gives a brief description of the whole CLIC complex and of a new test facility under construction in order to test the main parts of the power production scheme (Two-beam Acceleration) mentioned above.

2. Structure development and high-gradient studies

The loaded design gradient of the CLIC accelerating structures is 150 MV/m at a pulse length of 130 ns [1]. These values imply demanding levels of surface fields and pulsed surface heating. Therefore, a program of experiments and developments is under way with the goal to demonstrate the required performance. RF breakdown studies and high-power tests of structures and components are going on. Accelerating structures tested in the year 2000 were a constant impedance structure [3] with single-feed input and output couplers (tested from both ends), and a constant-impedance structure with symmetrical couplers. The ratio of surface to local accelerating gradient was 2.8, with additional factors of 1.4 in the single feed coupler and 1.12 in the symmetrical coupler respectively. Structures were baked out in situ at 120° C for two days before testing and they were typically conditioned for a few 10^5 shots. The maximum gradients achieved after conditioning are given in Table I.

Table I Accelerating gradients and surface fields

Structure	$E_{acc}/E_{surface}$ [MV/m]		
Pulse length [ns]	4	8	16
Single feed right	133/588	90/398	59/260
Single feed left	140/619	100/442	60/265
Symmetrical		95/361	70/266

*e-mail : Gilbert.Guignard@cern.ch

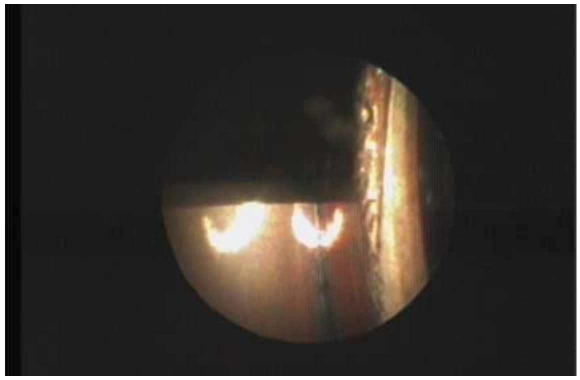

Figure 1: Damaged coupler iris. Looking from the beam axis towards the coupling aperture (section to the right).

The main features noticed during a breakdown are: i) irregular bursts of up to several 100 mA of emitted currents from the structure ends, ii) light pulses lasting many 100 ns, i.e. much longer than the 16 ns RF pulse, iii) missing RF energies of up to 50 % with 16 ns pulses, and iv) some pressure rises and small reflected RF signals. After the conditioning process, the structures were inspected with an optical endoscope. An area of obvious damage, corresponding to a depth of removal of material of about 100 μm was observed in the iris between the input coupler and the first cell. The damage location corresponded very closely to the enhanced field region of the couplers. Surprisingly, the damage region was delimited by a very sharp boundary (Figure 1).

Single-cell standing wave cavities, relatively simple to construct, represent a valid complement to complete structures for many high-gradient tests, since the maximum surface fields obtained after conditioning are very close to those achieved in travelling-wave structures. In an experiment planned to gain insight into breakdown, the optical-quality cavity [4] was powered while heated and cooled over a temperature range from 77° K to over 500° K. The resonant frequency and the surface resistance behaved as expected. Although the surface resistance changed by more than a factor 3, the breakdown threshold did not significantly change over the entire range of temperature.

The planned experiments aim at understanding the physical processes involved in breakdown and what are the important parameters which affect the breakdown level, limits and damage. Technologies are being developed in parallel that may contribute to: i) higher gradients through a geometry decreasing the ratio of the peak surface-field to the accelerating field, ii) arc resistant materials such as Tungsten, and iii) improved surface preparation and cleaning.

3. Vibration and feedbacks

Presently, the uncorrelated motion tolerances for the quadrupoles of the CLIC linac or of the final-focus doublets are estimated to be 1.3 nm (vertical) amplitude above 4 Hz and 4 nm (horizontal) or 0.2 nm (vertical) amplitude above 15 Hz, respectively. For comparison, the natural ground motion was measured in the LEP tunnel. In quiet areas, it is smaller than 0.2 nm above 4 Hz (machine off). The levels approach 20 nm with the equipment switched on. In large, noisy IP detectors, the motion is of the order of a few 100 nm [5]. Given these severe tolerances, launching a stability study was considered essential [6]. It aims at estimating the time-stability of the magnetic quadrupole centre and at predicting the achievable luminosity after application of correction schemes such as feedbacks. It should allow to estimate the spectrum of noise like ground motion, cooling water, or heat-induced errors, the transfer function to the magnet and the magnet supports, the lattice response and the feedback transfer function. It should also investigate the best available technologies, e.g. actively damped magnet supports, and predict the time-dependent effects. The final goal is to establish the feasibility of the design parameters in a realistic environment. A vibration test stand has been set up. It is equipped with a granite table and measurement devices, among which two geo-phones (GSV-310 from GeoSig^{TM}). The latter have a frequency range from 1 to 315 Hz. The first step was to demonstrate vibration measurements with sub-nm resolution and to characterise the ground motion in the test stand.

Figure 2: The left side shows the power spectral density measured in the vertical direction at the test stand and the right side the integrated rms motion above a given frequency with and without rubber feet at the same test stand.

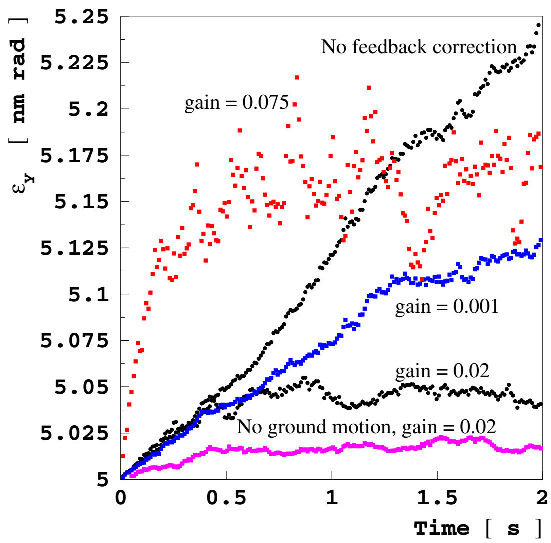

Figure 3: Time evolution of the vertical emittance at 3 TeV, due to ground motion, with 40 independent feedbacks at various gains.

The velocity measurements provide the power spectral density and the integrated rms motion above a given frequency [6]. Examples of these quantities are shown in Figure 2. The measured rms motion of the concrete floor was found to be ≈ 5 nm above 4 Hz and ≈ 4 nm above 15 Hz, which is good but still 5-20 times above the CLIC goals.

As a first stabilisation test, the effect of putting rubber feet on one sensor was measured, while connecting the other sensor directly to the supporting table (right side of Figure 2). This illustrates the benefit of passive damping for higher frequencies, while lower frequency perturbations are enhanced. The tight tolerances needed on the stability of the linac quadrupoles require feedbacks steering the beam back to its original trajectory [7]. A pessimistic model of independent feedbacks (made of two dipoles and three monitors) has been simulated, in which none uses the information provided by the others. Figure 3 shows the emittance growth so obtained, modeling the ground motion by moving the girders that support the linac elements according to the ATL model with A= $5\ 10^{-7}\ \mu\mathrm{m}^2\mathrm{s}^{-1}\mathrm{m}^{-1}$. The various curves correspond to different gains for a correction done by a set of 40 independent feedbacks and the blow-up without correction is also given for comparison.

Vertical position displacements between the beam centres at the IP generate a loss of luminosity. In order to limit this loss, related to beam jitter at the IP, fast position feedback systems have been modelled [8]. They consist of correctors and beam position monitors located very close to each other on the same IP side. The estimated correction is applied to the bunch train moving in the opposite direction, as rapidly as possible. Estimates of the performance of such an intra-pulse IP feedback indicate that the luminosity loss due to small coherent offsets (of about one beam-size sigma) of the bunch trains is reduced by a factor 3. For larger offsets (10 nm at E_{cm} = 1 TeV) 50 % of the nominal peak luminosity is recovered.

References

[1] CLIC Study Team , Ed. G.Guignard, CERN 2000-008, 2000.
[2] CLIC - A 3 TeV Linear Collider Study, this conference.
[3] I.Wilson, W.Wuensch, CLIC Note 145, 1991.
[4] W.Wuensch, 3 co-authors, EPAC2000, Vienna, August 2000.
[5] A.Seryi, HEACC2001, SLAC-PUB-8825, 2001.
[6] M.Aleksa, 12 co-authors,. PAC2001, Chicago, June 2001.
[7] N.Leros, D.Schulte, PAC2001, Chicago, June 2001.
[8] D.Schulte, LINAC2000, CERN/PS 2000-051(AE), 2000.