Impedance and Loss Factor Measurements on a CLIC Transfer Structure (CTS)

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Abstract

Previous measurements were done by creating with low-impedance transmission lines TEM fields around coupling holes such as those accompanying real bunchlets. This first approach made it possible to simulate the output power pulse from the CTS. Similarly, in the second approach (wire measurement), TEM waves are created but with a high impedance line in the middle of the chamber. Simulations are made not only of the power output signals but also of the beam wakes. A comparison of the wire input and output signals yields the CTS chamber beam impedance and k-factors (loss factors).

1. INTRODUCTION

The structure is needed to produce for acceleration in the CLIC (CERN Linear Collider) main linac [1] 12 ns, 30 GHz and 40 MW RF pulses. The structure input is four trains (spaced by 2.84 ns) of 43 drive bunchlets (40.9 nC, $\sigma < 1$ mm) separated by 33.3 ps.

The non-availability of 30 GHz power tubes with appropriate power levels (~ 100 MW) for achieving acceleration in colliding linacs has prompted the use of two-beam accelerators (TBA). In a TBA a primary (or drive) beam of relatively high current and relatively low energy is used to produce the necessary high-frequency power for accelerating the secondary (or driven) high-energy, low-current beam. The high-frequency radiation is generated during the interaction of the primary beam with some "extraction" structure. The properties of the CLIC drive beam have been discussed in detail elsewhere [2] and so this paper will be concerned primarily with the results of studies of the extraction cavity, or CLIC transfer structure (CTS).

It is intended that the CLIC drive beam will be fully relativistic (~ 5 GeV) and accelerated at 350 MHz using superconducting cavities such as those planned for LEP. Generation of the desired 30 GHz power for the secondary beam will be by direct deceleration of the tightly bunched ($\sigma_z < 1$ mm) primary beam in the CTS. A fundamental requirement of the CTS is that it should exhibit a very low shunt impedance [2].

A first version [3] [4] with an aperture of 4 mm was studied both with MAFIA codes and model measurements but had to be abandoned because of its high transverse and longitudinal resistive wall impedances. For acceptable impedances to be reached, it was considered necessary to increase the aperture to at least 12 mm with the unavoidable disadvantage of an overmoded beam chamber.

A second concept based on a smooth beam chamber with **coupling holes** into waveguides and the TEM wave associated with the drive beam bunchlets has been analysed

theoretically and in scale models [5][6]. The TEM wave was simulated with 50 Ω transmission lines. The structure output response was measured in the frequency domain and then multiplied with the bunchlet spectrum, yielding via a subsequent inverse Fourier Transform, the amplitude and phase versus time of the resulting 30 GHz power pulse.

Wideband investigations (using a centred wire to simulate the beam) however, have recently revealed that the concept based on periodic coupling holes between chamber and waveguides suffers from important beam wake problems. The wakes are mainly caused by backscattering of image currents at the coupling holes.

The most recent configuration is an attempt to overcome the scattering by using **continuous coupling slits**.

## 2. DESCRIPTION OF A NEW CTS

The structure shown in Fig. 2 consists of a smooth round beam chamber containing a coupling slit into a rectangular waveguide. The TEM wave accompanying the bunchlets has radial electrical fields and azimuthal magnetic ones at the slit causing constructive excitation of the TM_{11} forward mode in the waveguide (useful output) and non constructive excitation of the backward mode (not useful, terminated). The forward output is intended for acceleration in a module of the main linac. The condition for constructive interference between the beam and the TM_{11} mode is that this mode has a phase velocity equal to c at the operating frequency which can be obtained by loading the waveguide with periodic structures or with a dielectric. For simplicity this second approach was chosen for the model work.

3. PRINCIPLE

The requirement that the structure should work as a "pulse stretcher" by extracting from a train of 43 bunchlets (lasting 1.42 ns) a 40 MW RF pulse lasting 2.84 ns is met by using a forward wave in the waveguide as shown in Fig. 1 where a **single bunchlet** is followed as it crosses the structure.

There is constructive superposition of 43 successive RF waves in the waveguide spaced in time by one RF period (33.3 ps) to create a rising flank (1.42 ns) and a falling flank (1.42 ns) for the output pulse. Four successive pulses create a global pulse approximately 11 ns long to fill a module of the CLIC main linac.

Figure 1c gives a simplified qualitative phase diagram of the CTS.
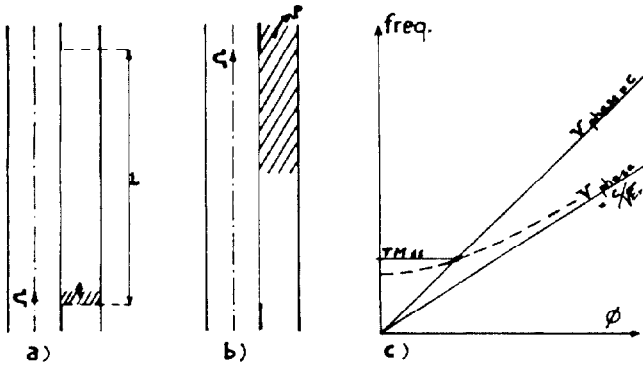
Figure 1:
a) Arrival of a bunchlet at the structure. The waveguide is immediately energized but yields no output power yet.
b) The bunchlet exits the structure ℓ/c later leaving the waveguide energized over the length: $\ell(1-\beta_{gr})$.
Total RF pulse duration: $\ell/c(1/\beta_{gr}-1)$
β_{gr}: normalized group velocity in the waveguide.
c) simplified phase diagram for a coupling slit.

4. MEASUREMENTS

The TEM fields of the bunchlets are simulated by a 300 Ω transmission line situated at the centre of the beam chamber (see Fig. 2). The waveguide is loaded with polyethylene ($\varepsilon_r = 2.26$) to obtain a phase velocity = c at 11 GHz for the TM_{11} mode. The chimney at the side is a waveguide in cut-off for TM_{11} but allows propagation into free space (damping) of higher modes (unwanted) also created through constructive interference with the beam. Furthermore at each extremity of the model conical matching transitions from 300 to 50Ω have been installed adjacent to damping sections against TEM, TE and TM modes of the chamber. The TM_{11} waveguide is terminated.
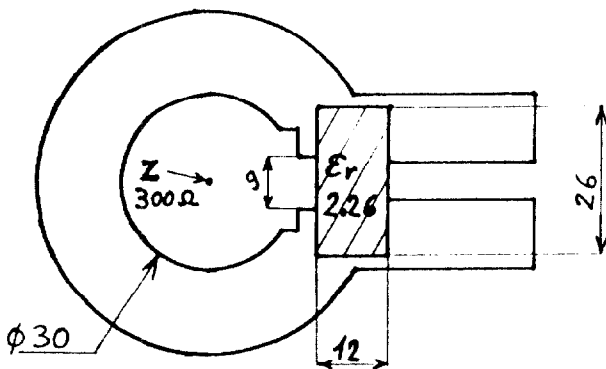
Figure 2 Simplified scaled CTS analogue model with only one waveguide. TEM waves are excited with a $Z_0 = 300 \Omega$ transmission line. Dimensions are larger by a factor 2.73. The operating frequency is thus 11 GHz.

The longitudinal beam coupling impedance $Z_L(w)$ of the model is obtained from a calibrated (the coupling slits are closed for calibration) transmission measurement along the wire in the frequency range 0-40 GHz. (This includes the three first harmonics of the bunchlet frequency 11 GHz — see Fig. 3.)

$$Z_L(\omega) = 2Z_0 \frac{1-S_{21}(\omega)}{S_{21}(\omega)} \tag{1}$$
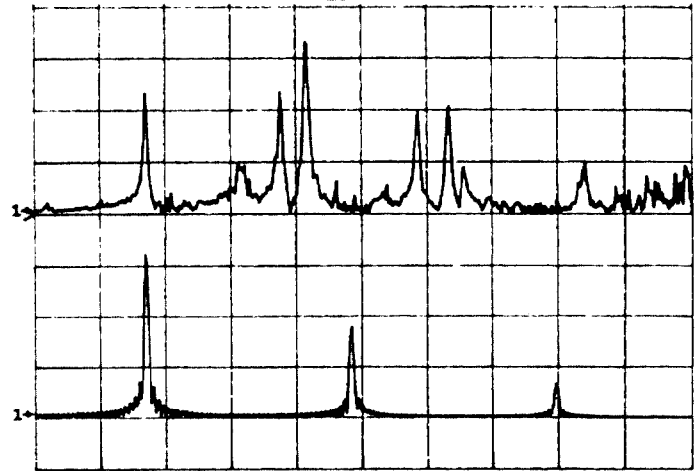
Figure. 3. CTS beam coupling impedance (40 Ω/div., absolute value) and beam excitation spectrum. Note that the first harmonic of the spectrum coincides with the first peak of $Z_L(\omega)$ corresponding to constructive interference between bunchlets and the TM_{11} waveguide mode. (5-40 GHz horizontally)

Multiplying the beam spectrum with $Z_L(\omega)$ and applying an inverse Fourier transform, we can now obtain the beam wake, essentially an increasing 11 GHz oscillation with a phase varying slightly with respect to an ideal 11 GHz source. There being 43 bunchlets per train we simplify and show with two curves only the values of the wake at the centre and at $+\sigma$ for each bunchlet. (For $-\sigma$ almost the same curve is calculated as for $+\sigma$.)
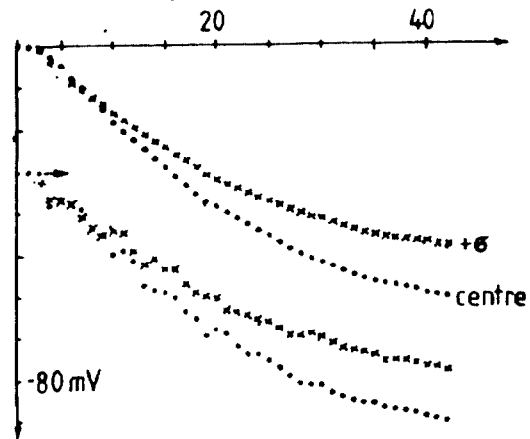

Figure 4. Bunchlets' wake per pC total charge at bunchlets' centres and $+\sigma$ versus bunchlet number. The two upper curves are obtained with the integration interval 10.5-

11.5 GHz and the two lower ones (offset by -30 mV) with the integration interval 5-40 GHz. A comparison of the two sets of curves indicates only a small contribution from higher waveguide modes than TM_{11}.

Scaling from 11 GHz to 30 GHz operating frequency the average wake experienced by the particles in the 43 bunchlets was found to be 139 kV for a total charge of 1.76 μC. For an output pulse length of 2.84 ns the average power level is 86 MW. The coupling slit is too wide!

This model also allows a network analyser measurement of the frequency response of the CTS, the output signal being the forward wave from the waveguide. (See Fig. 5.)
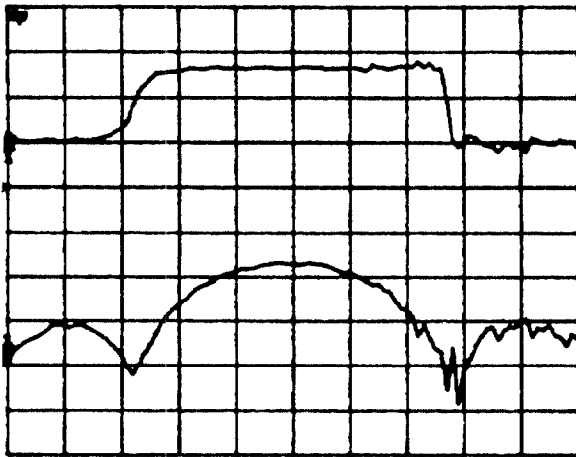
Figure 5 Frequency response of CTS output waveguide. Amplitude 10 dB/div. and phase 100°/div. Centre frequency 11 GHz, 0.2 GHz/div.

Again frequency scaling the measured CTS model response (11→30 GHz) and multiplying with the Fourier transform of 43 gaussian pulses spaced by $t_0 = 33.3$ ps, charge $g = 40.9$ nC and $\sigma = 3.33$ ps, the CTS output spectrum can be calculated with an online desktop calculator.

By applying a subsequent inverse Fourier transform to the output spectrum we obtain the output pulse as a function of time. (See Fig. 6.)

The peak power was found to be ~200 MW (average value ~100 MW, in reasonable agreement with the 86 MW found with the wire transmission method described above).

5. CONCLUSIONS

The model work shows that the specified power level of 40 MW can be achieved with a simple CTS based on a smooth round chamber with coupling slits into parallel adjacent waveguides.

The longitudinal wake deformation caused by the bunchlet spectrum above 30 GHz (30-120 GHz) seems acceptable.

UHV TM_{11} waveguides with coupling slits, capable of supporting 40 MW, with periodic or ceramic (alumina) loading remain to be designed to obtain a phase velocity of c at 30 GHz.
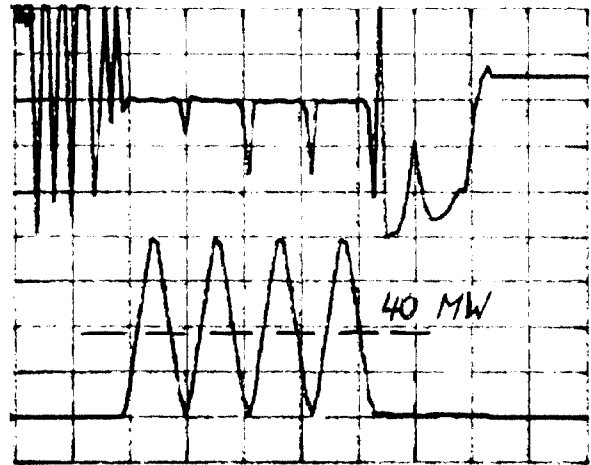
Figure 6 RF phase (50°/div) and amplitude (r.m.s. Amps into 50Ω, 500 A/div) of a CTS pulse caused by four trains of 43 bunchlets. The integration bandwidth for the inverse Fourier transformation is 1 GHz, corresponding approximately to the bandwidth of the driven main linac structure. The amplitude corresponding to the nominal 40 MW is indicated. Time scale 3.2 ns/div. The model being only two-fifths of the nominal length, the four successive pulses do not join into a long continuous pulse.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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