RF Hardware Development Work for the CLIC Drive Beam.

G. Carron & L.Thorndahl

CERN, 1211 Geneva 23, Switzerland

ABSTRACT

It is foreseen that the transfer structures (CTS) of the drive linac will produce 40 MW, 11.4 ns, 30 GHz RF power pulses for acceleration purposes in the CLIC main linac. Extensive model work, using the beam simulating wire method, has been undertaken in order to study the properties of the CTS with oversize models working at 8.6 GHz. At present a real size Cu 30 GHz CTS is under construction for beam tests in the CLIC Test Facility. A second Cu structure is in preparation for power testing with an MIT 33 GHz FEL power source. Further work is the development of power phase shifters and, inspired by the SLAC SLED-II studies [1], investigation into the use of longer RF pulses (than 11.4 ns) from the CTS (by a factor 3-4) combined with pulse compression. With longer RF pulses the drive beam bunchlet generation should become easier since the total drive beam charge of 7.04 μ C would be distributed over more bunchlets.

DESCRIPTION OF A PERIODICALLY LOADED CLIC TRANSFER STRUCTURE (CTS)

In the CLIC design the drive linac uses four trains spaced by 2.84 ns of 43 bunchlets (1 cm bunchlet spacing, 40 nC each) to produce via the transfer structures 30 GHz power pulses of 40 MW for the main linac [2]. With the 2.84 ns train spacing all 4 trains can be preaccelerated at 352 MHz.

The structure shown in Fig. 1 consists of a smooth round beam chamber containing two coupling slits into two periodically loaded (with "teeth") rectangular waveguides. The TEM wave accompanying the bunchlets has radial electrical fields and azimuthal magnetic ones at the slits causing constructive excitation of a hybrid forward mode in the waveguides (useful power) 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 hybrid mode is that the it has a phase velocity equal to c at the operating frequency; this is obtained by loading the waveguide with the periodic "teeth" structure.



Fig. 1: Upper half of the vertically symmetric CTS showing the round beam chamber and the upper periodically loaded ("teeth") waveguide with $\lambda/3$ cells.Units: millimeters.

A further requirement is that the structure should work as a "pulse stretcher" by extracting from each train of 43 bunchlets (lasting 1.4 ns) a 40 MW RF pulse lasting 2.84 ns is met by using a forward wave in the waveguide as shown in Fig. 2 where a single bunchlet is followed as it crosses the structure.

There is constructive superposition in the waveguide of 43 successive RF wave packages (from the 43 bunchlets) spaced in time by one RF period (33.3 ps) to create a rising flank (1.4 ns), a flat top (1.4 ns) and a falling flank (1.4 ns) for the output pulse. Four successive bunchlet trains (43 bunchlets each) create a global pulse approximately 11.4 ns long (flat top) to fill a module of the CLIC main linac.



Fig. 2:

a) Arrival of a bunchlet at the structure. The waveguide extremity is immediately energised (no output power yet).

b) The bunchlet exits the structure g/c later leaving the waveguide energised over the length $g(1-\beta_{gr})$.

Total RF pulse duration: $g(1/\beta_{gr}-1)/c$

 β_{gr} : normalised group velocity in the waveguide.

SCALE MODEL MEASUREMENTS

The TEM fields of the bunchlets have been simulated by a $Z_0=300 \Omega$ transmission line situated at the centre of the beam chamber. At each extremity of the oversize model (scale factor=3.5, 8.6 GHz instead of 30 GHz) conical matching transitions from 300 to 50 Ω have been installed adjacent to damping sections against TEM, TE and TM modes of the chamber. There is adiabatic matching of the hybrid mode to the terminated TE₁₀ output waveguide by gradual "teeth size" reduction at the extremities(see figs. 3 and 4).

The longitudinal beam coupling impedance $Z_L(\omega)$ of the model is obtained from a calibrated (the coupling slits are closed for calibration) measurement of the transmission

 $S_{21}(\omega)$ along the wire in the frequency range 0-40 GHz (This includes the three first harmonics of the scaled bunchlet frequency 8.6 GHz):

 $Z_{L}(\omega) = 2 Z_{0} (1 - S_{21}(\omega)) / S_{21}(\omega)$

Multiplying the beam current spectrum $i(\omega)$ with $Z_L(\omega)$ and applying an inverse Fourier transform, we obtain the beam wake. In a similar way $i(\omega)$ S'21(ω) and inverse Fourier transformation yields the output power pulse(S'21: transmission from wire input to structure waveguide output port).



Fig. 3: Scaled CTS wire model for 8.6 GHz. The periodic waveguide has been cut into 2 pieces; the piece to the left is upside down to visualise the coupling slit and the periodic loading. The wire is too thin to be seen.

Both wake and output pulse obtained are in good agreement with recent results from MAFIA calculations [3]. Furthermore the MAFIA and the wire method indicate that HOMs cause insignificant loss factors compared with the fundamental. RF leakage through the coupling slits may be the mechanism that prevents HOM confinement in the waveguide.

30 GHZ COPPER CTS PROTOTYPE

Recently a real-size prototype design was undertaken to investigate manufacturing possibilities as well as precision and RF breakdown problems. The design should be suited for mass production, since the 2 drive linacs of the project would require about 12 000 units distributed over 6 Km of active length. The design proposed, see figs. 5 and 6, consists of 2 side pieces forming the central beam chamber and the coupling slits held together by 2 comb like precision spacers. The necessary tolerances (~5 μ) were evaluated with MAFIA [3] and it turned out that mainly the teeth parameters mattered for the beam/wave synchronism; the most important being the distance between teeth. One prototype for 33 GHz power testing at an MIT 40 MW FEL power source as well as two 30 GHz structures are under construction by industry.



Fig. 4: Vertical cross sections through the Cu CTS prototype showing the central beam chamber and the periodic waveguides and a top view with flanges for WR28 waveguide.

One of the 30 GHz structures is intended for studies with beam in the CLIC TEST FACILITY. The delivery of the first unbrazed unit is imminent and the beam/wave synchronism will be checked with the wire method. The feasibility of an electrolytic method for "teeth tuning", if necessary prior to brazing, is being considered.



Fig. 5: One end of the 30 GHz CTS prototype made from 2 sidepieces (only one is shown in a horizontal position) and the 2 precision spacers forming the waveguide ceiling with periodic loading (courtesy KM -Kabelmetall AG).

30 GHZ POWER PULSE COMPRESSOR

The purpose of the pulse compressor is to ease the drive bunchlet production by distributing the total drive beam charge of 7.04 μ C over, say, 12-16 trains of 43 bunchlets rather than 4 trains as in the original CLIC design. An experimental compressor for 11.5 GHz using SLAC SLED-II

components was built and measured at low level to gain general experience and to check that sufficient bandwidth is available for the CLIC drive pulse (360 oscillations instead of 860-1720 at SLAC). Transmission measurements $S_{21}(\omega)$ and inverse Fourier transformation of $S_{21}(\omega) * I(\omega)$ show that the compressed pulse, even in the case of only 240 oscillations, suffers little from the limited device bandwidth.(see fig. 6, $I(\omega)$: Fourier transform of compressor input pulse). Furthermore the compressed output pulse contained 78% of the input pulse energy. One of the device inventors, A.Fiebig, had previously estimated that efficiency to be 82%.



Fig. 6: Relative amplitudes of compressor input and output pulses (time compression factor = 3). Horizontal: 120 osc./div

Since twice as many compressors ($\approx 24\,000$, one per output channel) would be required as transfer structures it is important to simplify their construction. Fig. 7 gives a sketch of a concept for mass production based on 10 machined Cu pieces assembled by brazing (this design has neither been measured nor built). To the left is the input mode converter from the rectangular TE₁₀ waveguide to the circular (low loss) TE₀₁ mode through 4 slits (flower petals) followed by a hybrid 3 dB coupler (coupling slit between the 2 TE₀₁ waveguides).



Fig. 7: Sketch of a 30 GHz pulse compressor concept for mass production. Only the lower part of the resonator is visible.

A reflecting iris is situated between the coupler and a round shorted TE_{01} resonator with an el. length of half the output pulse length. The right half of the device is symmetrical to the left one and contains a second mode converter with a rectangular output flange. Since the mode converter is considered the component with the highest field strengths (in the flower petals) a version for 33 GHz is under construction for power testing at the MIT FEL power source.

POWER PHASE SHIFTER

RF quadrupoles in the main linac will be powered by CTS units in the drive linac. In order to adjust the focusing/defocusing strength one method could be to arrange quadrupoles in pairs with phases ϕ and $-\phi$ such that for $\phi=90$ deg. the strength is zero and maximum for 0 deg. This requires power phase shifters for 30 GHz as shown in fig. 8. The component is based on a TE₁₀ waveguide (WR28) with variable width. The ceiling and the floor of the guide contain in the middle (where there are no transverse currents) a rounded slit of variable width (slotted line). The waveguide halves are brazed to a thin-walled vacuum tube and the slit width is changed by squeezing. Slit width and rounding radius have been chosen to keep local field increases below 50% and the shifter range is +- 90 deg.. A 33 GHz prototype is in preparation for power tests.



Fig. 8: Cross sections of power phase shifter .

ACKNOWLEDGEMENTS

The authors to are indebted to A.Fiebig and S.Luetgert for discussions as well as to P.Wilson (SLAC) for helpful information and advice. The flower petal mode converter is a SLAC design. The hybrid 3 dB coupler was optimised by C. Nantista also at SLAC.

REFERENCES

- [1] P. B. Wilson et al., 1992 HEACC proceedings, p. 824-827.
- [2] G.Carron and L. Thorndahl, "Impedance and loss factor measurements on a CLIC transfer structure", paper presented at the 1992 European Particle Accelerator Conference, Berlin, 24-28 March 1992, in CERN-SL/92-15 (DI).
- [3] A. Millich, Clic Transfer Structure Simulations using MAFIA. These proceedings.