CLIC Transfer Structure (CTS) Simulations Using "MAFIA".

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Abstract

In the two-beam accelerator scheme of CLIC the Transfer Structure serves the purpose of extracting 30 GHz power from the drive beam. The purpose of the 3D simulations of the 30 GHz CTS using the MAFIA set of codes has been to assist the designers in the choice of the final dimensions by appreciating the sensitivity of the RF characteristics to the mechanical parameters. The results of the frequency domain analysis have allowed plotting of the dispersion curves of the waveguides and appreciation the relative importance of higher modes. The time domain investigations have produced results on the shape and magnitude of the beam-induced longitudinal and transverse wake fields and of the loss factors.

1. INTRODUCTION

The CLIC Tramsfer Structure serves the purpose of extracting 30 GHz power from the drive beam in the two-beam accelerator scheme of CLIC [1]. Initial design of the CTS was based on model work using the wire method of beam simulation [2]. This provided the designers with approximate CTS dimensions and wake field magnitudes.

A complementary method, described here, makes use of simulations of the 30 GHz structure by computer codes. The CTS geometry not being axes-symmetric, a three dimensional simulation using the code MAFIA [3] was performed on a SUN-IPX workstation. In spite of the restrictions on the number of mesh points imposed by the limited memory space (32 Mbytes of main memory) the results obtained confirmed and completed the ones obtained by model measurements.

2. CTS GEOMETRY AND FUNCTION

The CTS essentially consists of a smooth cylindrical beam chamber of 12 mm diameter, which is coupled by means of diametrically opposite slots to two periodically loaded rectangular (8 x 4 mm) waveguides (Fig. 1). The periodicity of the waveguide 'teeth' is such that the phase velocity of the $2\pi/3$ mode at 30 GHz is equal to the speed of light in vacuum.

The ultra relativistic drive beam creates in the waveguides a field that propagates in phase with the exciting bunch, so that constructive transfer of energy to the waveguide mode is possible all along the structure. The drive beam is made up of a train of bunches spaced by one wavelength of the 30 GHz mode, which is 10 mm, so that each bunch contributes to the coherent excitation of the mode, the energy of which increases until the last bunch has left the structure. At that moment the waveguides are filled with energy which propagates at the group velocity of about one third the speed of light and which is transferred to the main linac disc-loaded structure.

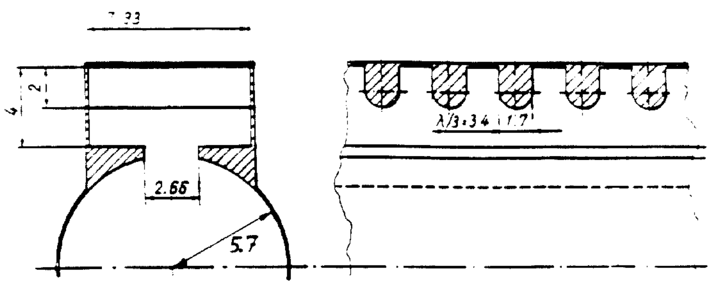

Fig. 1 CLIC Transfer Structure Geometry (upper half) Courtery of L. Thorndahl and G. Carron.

The length of the CTS is such that the duration of the energy discharge pulse fills the gap between two successive bunch trains spaced 2.84 nsec or one 352 MHz period. Taking into account the bunch train transit time and its time span, one CTS is about 0.50 m long and presents 144 rounded teeth in the waveguides. Four bunch trains are therefore necessary to provide a pulse of duration longer than 11.1 nsec, which is the main linac disc-loaded waveguide filling time. The energy stored in the CTS waveguides by one train of bunches must supply a power level of 80 MW during 2.84 nsec.

3. MESH GENERATION AND FREQUENCY DOMAIN ANALYSIS

By means of the MAFIA module M310 the CTS geometry was simulated as shown in Fig. 2.

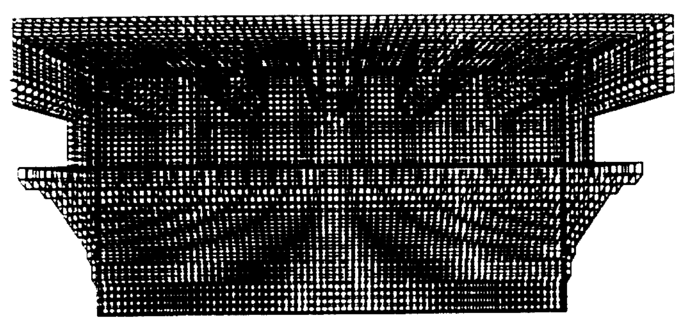

Fig. 2 Mesh of a six cells section of CTS (only one quarter shown).

Thanks to symmetry, only one fourth of the structure needs to be retained in the simulation. The memory space available in the workstation being limited, only six cells were used in the frequency domain computations with 64000 mesh points, whereas 12 cells with 128000 mesh points were used in the time domain computation of wake fields. The average resolution in the three dimensions is 0.3 mm. The beam trajectory is the z axis which coincides with the axis of the cylindrical chamber.

By means of modules R310 and E310 the resonant modes of the CTS were computed. The solutions found varying the boundary conditions of the z end planes present a phase shift per cell from 0 to π in steps of $\pi/6$. They are shown in Table 1, while the dispersion characteristic is plotted in Fig. 3.

Table 1. Normal modes found by MAFIA for the first CTS pass band.

Mode number	Frequency (GHz)	Phase shift/Cell
1	19.729	0
2	20.759	$\pi/6$
3	23.430	$\pi/3$
4	26.858	$\pi/2$
5	30.000	$2\pi/3$
6	32.027	$5\pi/6$
7	32.690	π

The dimensions of the CTS were chosen such that the intersection of the line representing a phase velocity equal to the speed of light with the dispersion curve occurs at the frequency of the $2\pi/3$ mode, which is 30.00 GHz. The group velocity of the $2\pi/3$ mode is 32% of the speed of light.

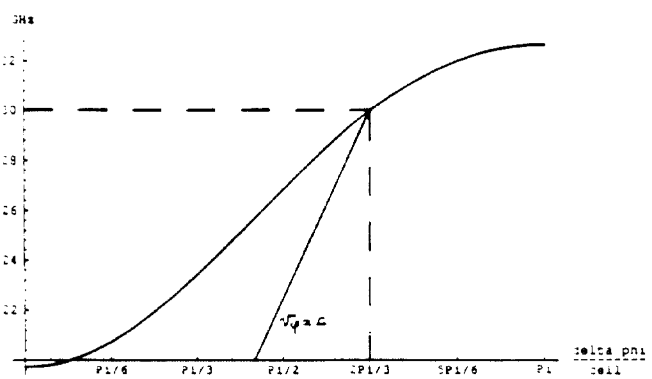

Fig. 3 Dispersion characteristic of the CTS

By means of the post processor P310, the Q of the structure was computed together with the shunt impedance per unit length R' and the r'=R'/Q parameter. Table 2 gives the numerical values including those of the longitudinal loss factor per unit length and per structure for the $2\pi/3$ mode.

Table 2. CTS RF parameters

Synchronous mode frequency	=	30.00	GHZ
Q factor	=	3808	
Shunt impedance R' (true ohms)	=	12.6	KΩ/m
r' = R'/Q	=	3.30	Ω/m
Loss factor k'	=	0.156	V/pCm

4. WAKE FIELDS COMPUTATION IN TIME DOMAIN

4.1 *Longitudinal wake fields*

For this analysis the 12 cells geometry was used in module T3310. The boundary conditions were chosen as perfect magnetic conductors for the x = 0 and y = 0 symmetry planes, while for the z end planes the waveguide condition was imposed. For the computation of the longitudinal wake field, a bunch of σ_z = 1 mm and charge normalised to 1 pC was placed in the centre of the beam chamber. The longitudinal wake is shown in Fig. 4. It is a damped sinusoid with zero crossings distant exactly one 30 GHz wavelength or 10 mm.

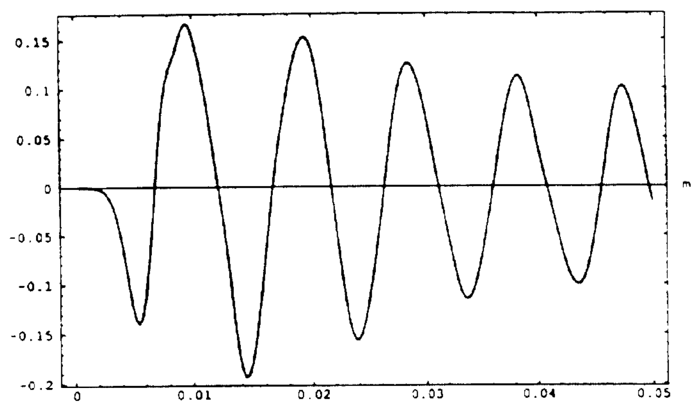

Fig. 4 Longitudinal wake field of a bunch of σ_z = 1 mm charge 1pC traversing one CTS structure. Vertical scale V/pC, horizontal scale: m)

The peak field seen by the second bunch in the train is found to be 1.5 10^{-2} V/pC for the 12 cells length, or 0.375 V/pCm. A bunch of 160 nC generates a peak wake field of 60 KV/m at the second bunch position. The last bunch in the train, say the 11th, experiences ten times this peak field plus its own wake, that is about 630 KV/m, so that on average the bunch train sees a decelerating voltage of 330 KV/m with a loss of 0.58 J/m, which is the energy that gets transferred to the waveguide modes.

4.2 *Transverse wake fields*

The knowledge of the amplitude and shape of these wake fields is of paramount importance for the studies of the transverse drive beam stability by means of tracking programs. [4]

Setting the y = 0 symmetry plane as perfectly conducting, only the deflecting modes are excited by the bunch placed one mm off centre in the y direction. The bunch exciting the wake experiences its own deflecting action which reaches a maximum at its tail. Since the transverse wake is offset by $\pi/2$ with respect to the longitudinal one, the subsequent bunches arrive at the nodes of the wake field and therefore no cumulative deflecting effect occurs for particles near the bunch centre. The peak transverse wake field is found to be $2.9\ 10^{-3}$ V/pC for 1 mm beam displacement and 12 cells length, which corresponds to 32 V/pCm for one CTS structure. Fig 5 shows the computed transverse wake field.

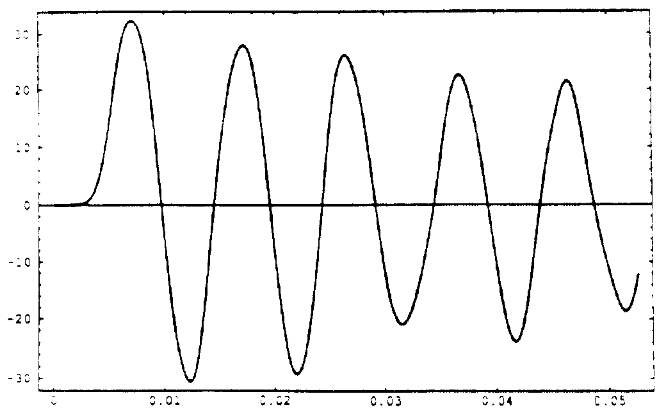

Fig. 5 Transverse wake field of a bunch with σ_z = 1 mm, charge 1 pC, traversing one CTS structure. (Vertical scale V/pCm, horizontal scale: m)

5. HIGHER ORDER MODES

The present version of the MAFIA program does not allow to explore the resonant modes of a structure in a user defined frequency interval, but it finds all the modes starting with the lowest one. This feature sets a limitation on the number of higher bands one can explore given a fixed amount of computer memory available. Using the six cells geometry of the rectangular waveguide without the cylindrical beam chamber, it was possible to find some forty modes in the frequency band from 18 GHz to 72 GHz. Fig 6 shows the resulting dispersion diagram. The intersections of the straight line representing a phase velocity equal to the speed of light with the dispersion curves indicates the synchronous modes that may be harmful to the beam. The relative importance of the shunt impedance of these modes with respect to the fundamental one, the synchronous $2\pi/3$ at 30 GHz, has been computed and the results have shown that only the TE_{30} mode has an appreciable effect, of the order of 5%.

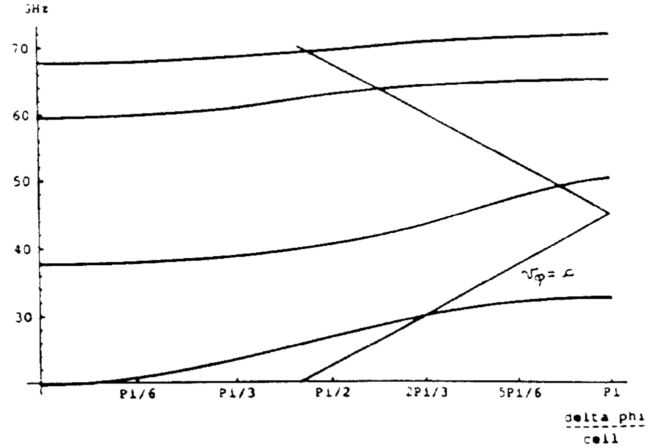

Fig. 6 Pass bands of the periodically loaded CTS waveguide in the range 18 GHz to 72 GHz

6. MECHANICAL TOLERANCES

MAFIA has proved to be a very helpful tool in the determination of the sensitivity of the CTS RF properties to the mechanical parameters of the structure [5]. To this end small variations have been applied to the four main parameters of the waveguides, namely their width and height as well as to the teeth height and length in the z direction, and the resulting variation in the $2\pi/3$ mode frequency computed by means of the E310 module.

Table 3. Sensitivity of the $2\pi/3$ mode frequency to the mechanical parameters : Wh, Ww, Th, Tl, respectively height and width of the waveguide and height and length of teeth.

Wh	= 4.0 mm	$\Delta f/\Delta Wh$	= 0.44 MHz/µm
Ww	= 8.0 mm	$\Delta f/\Delta Ww$	= 1.67 MHz/µm
Th	= 2.0 mm	$\Delta f/\Delta Th$	= 4.30 MHz/µm
Tl	= 1.666 mm	$\Delta f/\Delta Tl$	= 2.45 MHz/µm

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