PUSH–PULL LINAC PAIRS TO GENERATE TWO DRIVE BEAMS FOR CLIC MULTIBUNCH OPERATION

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Abstract

This note describes an RF power generation scheme for multibunch operation at 1 TeV CM and luminosity of 10^{34} cm^{-2} s^{-1}. The scheme is upgraded to use acceleration with 250 MHz SC cavities (instead of 352 MHz ones) in order to have available the increased stored RF energy necessary to accelerate to 3 GeV the newly required charge of 30 µC/drive beam.

Introduction

The drive beam energy increase (to 90 KJ/drive beam) is a consequence of the recently respecified CLIC main linac acceleration field of 100 MV/m (instead of 80 MV/m, to reduce transverse beam blow-ups) and the introduction of damped acceleration structures [1] for multibunch operation (having degraded R/Q and Q values, see next column).

Independent push–pull linac pairs

These are foreseen, see Fig. 1, mainly for the following 2 reasons:

a) Twice as many drive bunchlets (60 instead of 30) per 250 MHz period halves the required charge per bunchlet (from 100 to 50 nC in our case).

b) Good drive beam to RF efficiencies are obtained through matching of the train energy profile to the decelerating wake pattern in the drive linac. With two trains of 30 bunchlets per period (instead of one) the bunchlet deceleration variation inside one train is reduced (from ±76% to ±23%, see Fig. 2).

As shown by Fig. 3, the reduced wake variation makes it feasible to preshape the train energy profile to the deceleration ramp by simple phase shifting of the 250 MHz voltages in the SC cavities in conjunction with a small H = 4 correction.

One drive beam consists of 11 bunchlet train pairs, obtained with two switch-yards (each combining bunchlets from 10 short parallel S-band linacs [2]) followed by the push–pull (antiphase) accelerations shown in Fig. 1.

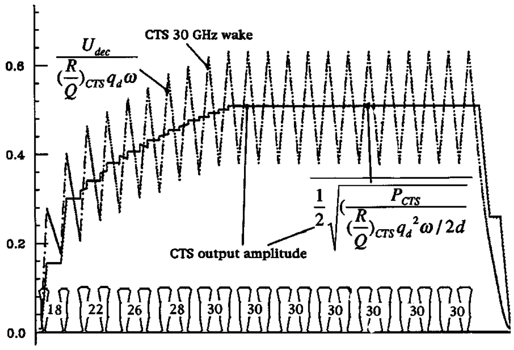

Fig. 2. Computer optimized bunchlet numbers, relative intensities, normalized 30 GHz CTS wake amplitudes (dashed, linear variations of ±23%) and the normalized CTS output amplitude.

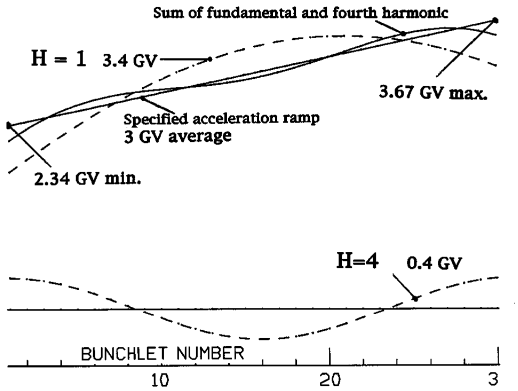

Fig. 3. Acceleration ramp synthesis.

The purpose of each drive beam is to produce, via 7813 Clic Transfer Structures (CTSs), 30 GHz output pulses to power 15626 CLIC Accelerating Sections (CAS) [1] of the main linac with the **provisional** parameters:

R/Q = 3920 Ω/structure,
(circuit convention)
length ℓ = 0.32 m
Q = 2800
v_{gr} = 0.066 c
E_{acc} = 100 MV/m (loaded)
Spacing of multibunches = 1 ns
Multibunch charge = 1.28 nC

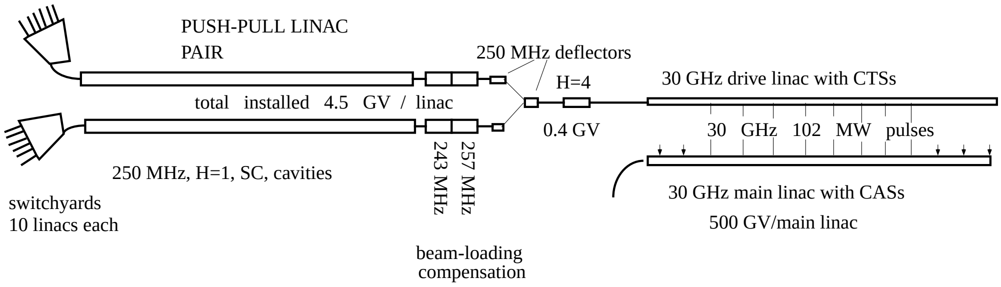

Fig. 1. Generation of one drive beam upstream of one drive linac.

To deliver two flat-top 102 MW CAS input power pulses (2 CASs are fed by one CTS) the main CTS parameters can be chosen as follows:

R/Q = 1.4 Ω/structure,
(circuit convention)
length ℓ = 0.71 cm
drain time d = 4 ns = 1/250 MHz
v_{gr} = 0.37 c
CTS internal power losses = 5%

with CTS to CAS transmission losses of 10% and for a bunchlet length of 0.6 mm rms. The flat-top bunchlet intensity is 50 nC.

Bunchlet trains

Following a suggestion by K.A. Thompson and R.D. Ruth [3], almost constant multibunch energies (±0.2%, necessary to pass the CLIC final focus sections) are obtained by a specially shaped CTS output power pulse: the time shape is such that, prior to the passage of the multibunches, first the steady state of the CAS (with beam-loading) is established (with the first 5 drive train pairs) and then, during the passage of the multibunches, this state is maintained with a constant input power level (102 MW/CAS).

To obtain both the necessary multibunch acceleration precision and drive beam excitation of the fourth harmonic correction structures (explained later), the 5 prefill train pairs have increasing numbers of bunchlets (18, 22, 26, 28 and 30 bunchlets/train) [4], combined with small variations of bunchlet intensities [5].

The energy spread of the accelerated 26 multibunches of the main beam is 0.1% rms.

To guarantee good mains to RF efficiency it is necessary to accelerate the drive beam bunchlets inside each train according to the above decelerating wake curve, such that at the end of the CLIC drive linac, the bunchlets are dumped at an almost equal and low average energy, e.g. 0.3 GeV, but above 0.2 GeV to avoid electron losses.

We focus the acceleration optimization on the flat-top trains (which have the most severe deceleration), in particular on the compensation optimization of the beam-loading they cause in the 250 MHz SC structures.

Figure 3 indicates the specified acceleration ramp (matching the flat-top wake of one train) for any train of the flat-top and the synthesized one obtained with the fundamental and the fourth harmonic.

Beam-loading compensation

The voltage decrease of the fundamental frequency cavities (R/Q = 96.6 Ω/m, circuit convention) has been compensated by two groups of cavities with slightly different frequencies (243 and 257 MHz); they produce a fractional beat during the passage of the drive beam, yielding low deceleration for the first prefill trains and high acceleration for the flat-top ones [5]. During the compensation optimization a beneficial (for drive beam to RF efficiency) voltage increase pattern for the prefilling trains resulted (see Fig. 4, curve D).

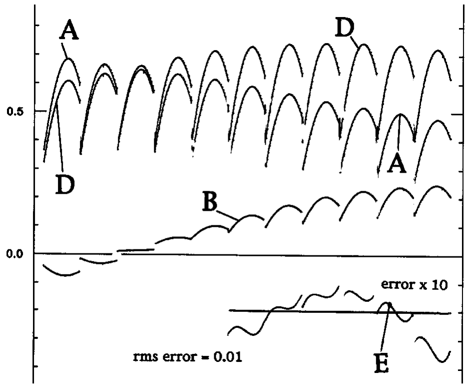

Fig. 4. Decrease of normalized(with respect to the sum of all installed cavity peak voltages) accelerating H = 1 voltage due to beam-loading over 11 trains of bunchlets (upper full trace A). Curve B shows the compensating voltage obtained as a fast beat between the 2 groups of compensating cavities with 29% of the total installed voltage and frequencies of 243 and 257 MHz. Curve D is the sum of A and B. Curve E is the error with respect to constant amplitude during the flat top. Only the successive short phase intervals (of 90°) populated by the bunchlets of each train are shown, whereas the remaining **unpopulated** 270° in each of the 11 periods have been **cut out**. The error with respect to the ideal H = 1 oscillation is 0.01 rms.

Fourth harmonic cavities

Figure 5 shows their energizing by the first 4 prefilling train pairs (excitation occurs when the trains last less than one oscillation period), as calculated using R/Q of 386 Ω/m at 1 GHz. The flat-top trains lasting exactly one period cause no net excitation. The resulting field amplitude is 6.1 MV/m and the total active length 67 m. The geometry is scaled from the H = 1 structures.

Cryogenics

The harmonic synthesis of Fig. 4 shows that 3.5 GV are needed per linac. Beam-loading compensation, as can be seen from Fig. 4, requires an **additional** installed voltage in the fundamental frequency range of 33%. Thus, a total fundamental installed SC voltage of 18.5 GV is needed. We follow investigations by K. Huebner [6] and I. Wilson [7] for LEP2 structures at 6 MV/m, 352 MHz and Q = 4 10^9 with static losses of 29.5 W/m and dynamic losses of 32.3 W/m. For the 250 MHz structures static losses are estimated to be 15% [8] and the Q-value to be 75% [9] higher than for the 352 MHz ones. Taking into account by a factor of 3/4 the yo-yoing stored RF energy level between pulses (the cavities yielding half their energy to the passing drive beam), the dynamic losses are 19.7 W/m. Applying a cryo-factor of 250 the total cryogenics mains power becomes 41.4 MW for the 2 push–pull linac pairs.

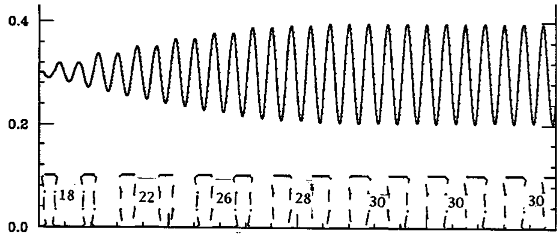

Fig. 5. H = 4 excitation by the prefill train pairs(upper trace). The drive train pairs (bottom trace) are also shown. Only a small fraction (600J, 0.7%) of one drive beam energy (90 kJ) is used for energizing. Furthermore it is taken from the first trains which are underdecelerated in the drive linac. The voltage obtained is 6.1 MV/m.

The most important assumptions, leading to an overall (wall plug to main beam) efficiency of 10.5%, are illustrated in Fig. 6. RF and mains power level indications are for both main beams.

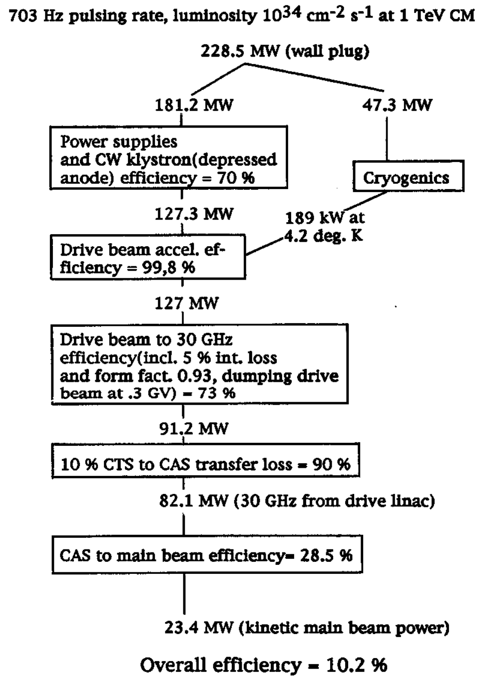

Fig. 6. Wall plug to main beam efficiency.

Figure 7 indicates for a variable number of drive beam train pairs the drive beam to RF and the RF to main beam efficiencies. Unfortunately, because of beam-loading in the 250 MHz SC cavities, it is difficult to accelerate more than 11 drive train pairs corresponding to 26 multibunches.

Conclusions

In this compact double push–pull linac proposal most of the capital investment would be for 250 MHz cavities (with their klystrons and cryostats at 4.2°K) providing usable stored energy for acceleration.

The main disadvantages of the scheme seem to be:

a) a significant amount of RF and cryogenics hardware for the complete drive-beam generation complex, corresponding to about 8 times the LEP2 upgrade [10].

b) a high bunchlet charge of 50 nC.

c) an overall efficiency of only 10.5%, essentially because of the limited stored RF energy in the 250 MHz structures, which limits the number of drive bunchlet trains per pulse.

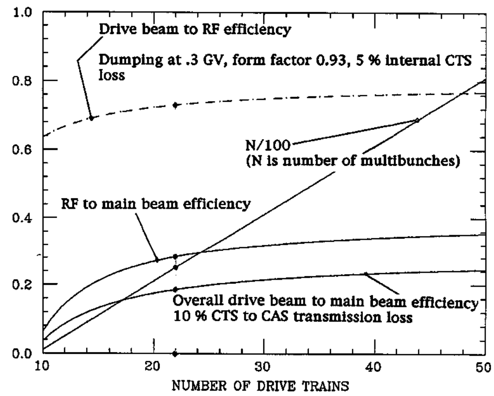

Fig. 7. Efficiencies

The main advantages appear to be:

a) simplicity: no long drive-beam transport lines, no 180° and 90° arcs and no fast kickers as in previous concepts. The drive-beam generation process thus occurs over a limited and almost straight length of about 1.4 km (including SC cavities, magnets and straight sections).

b) acceleration in mainly large-aperture (33 cm) 250 MHz SC structures causing low wakes.

c) only 41 kW/m input power for the SC cavities.

The forty 3-GHz linacs, upstream of the switchyards delivering up to 33 bunchlets of 50 nC per pulse, seem a difficult challenge; the development work can however be attempted within the modest framework of the CTF. Dark currents in the 250 MHz SC cavities should be investigated. Cavity tune changes due to ponderomotive forces, periodic with the 703 Hz pulsing, may be acceptable thanks to the shortness (< 50 ns) of the drive pulse [11].

References

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