Focussing the $e^-$ bunches for the 30 GHz power generation in the CLIC Test Facility

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Abstract

In the CLIC Test Facility (CTF), short bunches of photo-electrons produced on the cathode of a 4.5 MeV RF gun are thereafter accelerated up to about 50 MeV by an accelerating structure of the LIL type (LAS). Then, they are focussed through the CTF Transfer Structure (TRS), in which their energy is converted into RF power for feeding the CLIC Accelerating Structure (CAS), which is the accelerating cavity for the CLIC Main Linac. The energy gain provided by CAS to a test beam should be 80 MeV/m. K.Hübner [1] has proposed to share the charge loading TRS between 16 bunches, each containing 7 nC; this reduces the laser beam intensity per shot, reduces the spread in energy and also reduces the space charge in the gun and in the transport line up to TRS.

Even with this scheme, a large spread in energy results from the wake fields and beam loading in LAS and TRS. This is analyzed in [1] and in the first part of this paper. The spread in energy may prevent the correct focussing of the bunches through TRS, therefore limiting the power which can be transferred to CAS. In the second part, the optical transmission through TRS has been systematically studied for charges per bunch from 1 to 7 nC. The limit values of the charge per bunch and of the energy gain available in CAS have been evaluated for the present installation and for the modifications which are foreseen.

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1 Introduction.

1.1 CTF layout.

As the bunches are used for loading TRS, their characteristics have strict limitations: bunch length should be less than 1mm rms. By placing LAS just after the gun, we would avoid most of the problems of space charge and of interactions with the tubes. But for measuring the characteristics of the bunches, we have to provide a drift between the gun and the accelerating structure, where the instrumentation is installed. Intermediate focussing is also required. For CTF, the total interval is 8m long. References [2, 3] describe the low energy part of the CTF layout fig. (1)

![Schematic layout of CTF](image_url)

Figure 1: Schematic layout of CTF

It is summarised below:

Spectrometry is made with a 90º bending magnet. Permanent use of the magnet permits axial illumination of the cathode. Two quadrupoles and a second bend restore the zero dispersion further. Measurement of bunch length is made with a streak camera observing the Cerenkov radiation of a retractable foil, or by the method of the transverse RF kick. Bunch charge and bunch transverse position are measured by magnetic sensors (UMA) and Sem-Grid. Focussing is provided by a solenoid at the RF gun exit, then by a series of quadrupoles. LAS is 4.6 m long and has an iris of about 20 mm diameter. The active part of TRS which follows is 0.2866 m long with an iris of 4 mm diameter. Between LAS and TRS, a triplet is used for transverse focussing through the 4 mm aperture of TRS. A 30 GHz waveguide, by which energy will be transferred to the test beam, links TRS and CLIC CAS.

1.2 Operation with a train of bunches: scheme proposed by K.Hübner.

We refer to [1] for the analysis of the 30 GHz RF power in the CTF operating with bunch train. In [1] a sequence of 16 bunches separated by 5 RF periods of 3 GHz (1.67 ns)
is proposed. The first seven bunches of the train fill TRS (filling time 11.7 ns). Then, the maximum field at TRS output port is reached, but not yet in the CLIC Accelerating Structure (CAS). CAS filling time is also 11.7 ns. Then 7 other bunches are needed to reach the maximum voltage in CAS, because it is only after bunch number 7 that the maximum power begins to flow into CAS.

2 Calculations of the energy spread from beam loading and wake.

2.1 Beam loading and energy flow.

Consider a very short bunch of charge \( q \) passing through a structure of constant impedance, and exciting the longitudinal mode \( n \). Averaged over all the particles of the bunch, the energy lost by the bunch is:

\[ w = k_{\delta n} q^2 \]  
(1)

\( k_{\delta n} \) is the loss factor for the \( \delta \) charge distribution function. It depends on \( n \), on the impedance \( R \) and the quality factor \( Q \) of the structure of length \( l \).

The bunch excites a field on itself. The field seen by the particles of the bunch is, on average over all the particles:

\[ E_{zn} = -\frac{k_{\delta n}}{l} q \]  
(2)

The theorem of the beam loading gives the field \( E_{zn}(t=0) \) on the axis just after a bunch of charge \( q \) has crossed the structure.

\[ E_{\delta n} = 2E_{zn} = -2\frac{k_{\delta n}}{l} q \]  
(3)

The loss factor \( k_n \) for a bunch with a gaussian distribution of rms value \( \sigma \) can be derived from the loss factor \( k_{\delta n} \) for a \( \delta \) function distribution:

\[ k_n = k_{\delta n} e^{-\omega_0^2 \sigma^2} \]  
(4)

In the following, we consider only the fundamental mode \( n=0 \), and write \( \omega \) for \( \omega_0 \). Just after the crossing of a gaussian bunch of charge \( q \), the mean field in the structure is:

\[ E_0(t = 0) = -2\frac{k_0}{l} q \]  
(5)

and the energy deposited is:

\[ w = k_0 q^2 \]  
(6)

This energy is dissipated with the time constant \( Q/\omega \).

Simultaneously, the energy flows through the structure to the output port at a speed \( v_g \) related to the filling time \( T_f \).
\( v_g = \frac{l}{T_f} \)  

so the power at the output port is

\[ P(t) = k_0 q^2 \frac{v_g^2}{l} e^{-2(\omega/\Omega)t} \]  

\[ (8) \]

From

\[ E_z(t) = \left( \frac{R}{dP/dz} \right)^{1/2} \]  

and using

\[ \frac{dP}{dz} = \frac{1}{v_g} \frac{dP}{dt} \]

\[ k_{50} = \frac{\omega R}{4 Q} \]  

the variation with time of \( E_z \) may be written as in [1]:

\[ E_z(t) = 2q \left( \frac{k_{50} k_0}{l} \right)^{1/2} e^{-\omega t/2Q} \]  

\[ (12) \]

The parameters for LAS and CAS structures are given in tab.(1) Primed quantities of the table are relative to unit length, such as \( k' = k/l \). The load voltage is \( U \). The interval between bunches is 1.667 ns (5 periods of 3 GHz), the bunch length \( \sigma_l \) is 3 ps. LAS is a nearly constant gradient structure. The impedance given here is an averaged value.

<table>
<thead>
<tr>
<th>Units</th>
<th>LIL structure (LAS) constant gradient</th>
<th>CLIC structures (CAS and TRS) constant impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>f</td>
<td>(GHz)</td>
<td>3.0</td>
</tr>
<tr>
<td>l</td>
<td>(m)</td>
<td>4.5</td>
</tr>
<tr>
<td>Q</td>
<td></td>
<td>14600</td>
</tr>
<tr>
<td>( R' )</td>
<td>(MΩ/m)</td>
<td>64.9</td>
</tr>
<tr>
<td>( R' /Q )</td>
<td>(MΩ/m)</td>
<td>0.0044</td>
</tr>
<tr>
<td>( k'_{50} )</td>
<td>(MV/nC m)</td>
<td>0.0209</td>
</tr>
<tr>
<td>( k'<em>0 / k'</em>{50} )</td>
<td></td>
<td>0.997</td>
</tr>
<tr>
<td>( k_0' )</td>
<td>(MV/(nC m))</td>
<td>0.0209</td>
</tr>
<tr>
<td>( dU/dq = 2lk'_0 )</td>
<td>(MV/nC)</td>
<td>0.188</td>
</tr>
<tr>
<td>( T_f )</td>
<td>(ns)</td>
<td>1350</td>
</tr>
<tr>
<td>( v_g ) /c</td>
<td></td>
<td>0.024 / 0.0072</td>
</tr>
</tbody>
</table>
2.2 Beam loading and energy flow: application to TRS and LAS

TRS.

$q_1, q_2, ..., q_n$ are the charges of the successive bunches. The total field in the cavity is the superposition of the fields deposited by each bunch. The length $l$ of TRS, the time $\Delta t$ between 2 bunches and the group velocity, limits to $n$ the number of these elementary fields simultaneously present.

$$n = \frac{l}{v_g \Delta t} \quad (13)$$

$\Delta t$ is fixed by the frequency and by the number of periods between bunches, $v_g$ by the design of the structure. By choosing the number of cells, $l$ has been defined such that $n$ is integer. At the exit port of TRS, and just after the crossing of the $i$th bunch, the field is:

$$E_0 = 2k_0' (q_{i-n+1} e^{-\frac{\omega}{2} \frac{n-1}{n} T_f} + q_{i-n+2} e^{-\frac{\omega}{2} \frac{n-2}{n} T_f} + ... + q_i e^{-\frac{\omega}{2} \frac{1}{n} T_f} + q_i) \quad (14)$$

The fields components decrease with time constant $2Q/\omega$. The first term of the sum corresponds to the field due to bunch $i-n+1$, crossing $\frac{n-1}{n} T_f$ seconds before the crossing of the $i$th bunch.

The last term of the sum corresponds to the field due to bunch $i$. If $i \leq n$, the number of terms of the sum is $i$, the first term is the contribution of charge $q_i$. In a simple scheme, the charges in the successive bunches are identical. Inside TRS, the field distribution is as follows: Because of the flow at the group velocity, the space extents of the field contributions of the successive bunches, measured from the output port are shown in tab.(2).

<table>
<thead>
<tr>
<th>bunch</th>
<th>space extent (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$i-n+1$</td>
<td>$l / n$</td>
</tr>
<tr>
<td>$i-n+2$</td>
<td>$2l / n$</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>$i$</td>
<td>$l$</td>
</tr>
</tbody>
</table>

Table 2: Space extent for the fields created by the successive bunches

Superposition gives a staircase distribution in $z$. The periodic regime is reached after arrival of bunch $n$. Then, before bunch $n+1$ arrives, all the distribution slips by $l/n$ towards the output port, and decays according to the different bunch times. Just before bunch $n+1$ arrives, the first $l / n$ part of the structure becomes empty. The crossing of the last bunch causes a sudden step of the field at the output port, with the amplitude:

$$\frac{\Delta E}{q} = 2k_0' \sim 1.8MV/(nC \ m) \quad (15)$$

Summation of the field at TRS end gives, if the $n$ charges are identical, and if $n=7$:

$$E_0 = 2k_0'q (1 + \sum_{j=1}^{n-1} e^{-(\omega/2Q) T_f (j/n)}) \quad (16)$$
\[ E_0 \sim 2k_0' 6.26 \, MV/m \]  

Voltages: The total voltage in TRS, just after the crossing of the \( i \) th bunch corresponds to the staircase distribution of the fields along the structure:

\[ U = 2k_0'(q_{i-n+1}e^{-\frac{\pi}{2}\frac{n-1}{n}T_f l} + q_{i-n+2}e^{-\frac{\pi}{2}\frac{n-2}{n}T_f l} + \ldots + q_{i-1}e^{-\frac{\pi}{2}\frac{n-1}{n}T_f l} + q_ilf) \]  

with \( f=1 \). With \( f=1/2 \), the formula represents the average voltage seen by the bunch which has just crossed through.

The duration of 26.7 ns, for a train of 16 bunches, is short compared to the filling time of 1.35 \( \mu s \). The decay of the induced load and the effect of the energy flow can be neglected. The load voltage experienced by the \( i \) th bunch of a train of identical bunches is therefore:

\[ U \sim 2k_0 (0.5 + i - 1) q \]  

where \( q \) is the charge per bunch, \( k_0 \) is the loss factor for LAS. In the parenthesis, 0.5 accounts for the average action of the field created by the \( i \) th bunch itself. The load experienced by a particle at \( z/c \) from the centre of the bunch will be modulated by

\[ \cos(\omega z/c) \]

For bunch number 16, with \( k_0 \sim 0.1 MV/nC \), the load is:

\[ \frac{U}{q} \sim 3 \, MV/nC \]  

### 2.3 Wake fields: Cancellation of the linear part by RF phasing

We use of the values of the wake potentials as they are given in [1] for 1 mm RMS bunch length. In tab.(3), the maximum values are recalled.

<table>
<thead>
<tr>
<th>Unit: MV/nC</th>
<th>LAS (LIL)</th>
<th>TRS (CLIC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>at ( z/\sigma = -1 )</td>
<td>-0.45</td>
<td>-0.37</td>
</tr>
<tr>
<td>at ( z/\sigma = 1 )</td>
<td>-0.15</td>
<td>-0.15</td>
</tr>
<tr>
<td>at maximum</td>
<td>-0.45</td>
<td>-0.4</td>
</tr>
</tbody>
</table>

The maximum occurs at \( z/\sigma = -0.85 \) for LIL and -0.5 for CLIC.

For a bunch, the differences between the values of the wake fields at \( z=\sigma \) and \( z=-\sigma \) may be cancelled by choosing the RF phase \( \phi_0 \) according to the charge per bunch [1]. This is included in our calculation.
2.4 Energy gain in CAS

At a given time, the field in TRS varies with z as a staircase distribution. It flows to the output port at velocity \( v_g \) and decays with time constant \( (2Q)/\omega \). The field at the output port has been calculated in section 2.2, just after the crossing of the \( i \)th bunch \( (t=0) \). At this time, the field is maximum in the last \( l/n \) part of TRS, the last step of the staircase. With the constants given above, and with \( n=7 \), value selected for the CTF, 

\[
E_0 = 2k_0^' 6.26 \text{ MV/m}
\]  

with 

\[
2k_0^' \sim 1.8 \text{ MV/(nC m)}
\]

In the time interval \( T_f/7 \) between 2 bunches, this field flows by the output port and decays by the time constant \( 2Q/\omega \) such that the relative value after \( T_f/7 \) is:

\[
\epsilon^{-(\omega/2Q)T_f/7} \sim 0.96
\]

We recall that the structure CAS into which the energy flows is identical to TRS. Therefore the field which appears at CAS input port is equal to the field at TRS output port, if the loss in the waveguide is neglected. The field in CAS flows at speed \( v_g \) and decays with the same time constant as in TRS. Again, the form of the field has a staircase pattern, but the height of the steps decreases with \( z \), because the power source is the input port. When CAS is filled, the field distribution along \( z \) is in staircase form

\[
E_i = E_0 \epsilon^{-(\omega/2Q)T_f(i/7)}
\]

\( i \) varies from 1 to 7. The total voltage available is:

\[
U = E_0 \sum_{i=1}^{7} \frac{l}{i} \epsilon^{-(\omega/2Q)T_f(i/7)} \sim 6.9 \ E_0 \ l
\]

\[
U \sim 2k_0^' \ q \ 5.4 \ l
\]

2.5 Comparison with a single bunch process

Consider the field in TRS in the single bunch process:

\[
E_s = 2k_0^'Q
\]

The voltage available in CAS is:

\[
U_s = 2k_0^'Q \ \epsilon^{-(\omega/2Q)T_f \ l}
\]

\[
U_s = 2k_0^'Q \ 0.765 \ l
\]

Suppose that we have the same bunch length for only one bunch as for the individual bunches of the train, then the loss factors in eq: (24) and eq: (27) are equal, and, for the same total voltage available in CAS \( (U = U_s) \), \( Q = 7 \ q \).
Comparing eq: (21) and eq: (25), the maximum field due to the beam loading in TRS, with the multibunch process, is only reduced by 0.9, when compared to the maximum field with the single bunch. When considering the wake potential only, and with the same hypothesis on bunch length, the multibunch procedure divides the values of the wake potentials by \( n = 7 \).

2.6 Possibility to balance the beam loading by a phase shift when filling LAS

The first and the last bunch are separated by \( \Delta t \). In this scheme, at first bunch crossing time, the structure is filled with \( +E_{RF} \) along length \( (l - v_y \Delta t) \), and with \( -E_{RF} \) along the remaining length \( v_y \Delta t \). This field distribution is obtained by a 180 deg phase shift at filling time. The last bunch crosses when all the structure is filled with \( +E_{RF} \). Considering only the driving RF field, and supposing that the phase shift is a step function of time, the difference in energy gain experienced by the bunches 1 and 16 is:

\[
\frac{\Delta W}{W'} = 2 \frac{v_y \Delta t}{l} = 0.026
\]

(28)

where \( \Delta t \), length of the train = 26.5 ns, \( v_y/c = 0.0072 \), and \( l = 4.5 \) m.

The factor 2 comes from the inversion of the field. But the beam loading is 10 times this effect. Moreover, the phase shift is not instantaneous, and its duration, measured at the LAS structure input coupler, is of the order of the duration of the train. The expected effect of the phase shift is reduced by a factor 2 at least. Therefore, the method is inappropriate to achieve the necessary correction.

3 Limits related to the momentum spread and the optics

3.1 Model used to evaluate the maximum charge

Characteristics of the 4.5 MeV bunches at the RF gun exit have been calculated for given operating conditions of the gun and of the laser [4]. They are used to calculate at that point the elements of the beam matrix \( S \), which are the 21 second moments of the projections in phase space: \( \langle xx \rangle, \langle xdx/ds \rangle, \langle xy \rangle, \langle xdy/ds \rangle, \langle xl \rangle, \langle xdp/p \rangle, \ldots \)

An electron trajectory at longitudinal position \( s \) is represented by the vector of its coordinates \( \mathbf{V} = (x, dx/ds, y, dy/ds, l, dp/p) \). \( x \) and \( y \) are the transverse coordinates, \( l \) the longitudinal one, \( l \) the distance to the centre of the bunch. This vector transforms along \( s \) according to the matrix \( \mathbf{R} \), representing the beam line: \( V_1 = R_{o,1}V_0 \). According to [7], the 'beam matrix' \( S \) is transformed as:

\[
S = R \; S_0 \; R^t
\]

(29)

This gives in particular the envelopes of the projected transverse motion \( \langle xx \rangle^{1/2}, \langle yy \rangle^{1/2} \). Space charge is here neglected. The forces of the triplets in front of LAS and of TRS are optimized for focusing into TRS. The difficulty comes from the large energy spread. For a given no-load energy gain in LAS (nominally 57.5 MeV), as in [1], the effective energy gain for a bunch depends on the charge per bunch, and on the number of bunches ahead because of the beam loading. It is represented on fig. (2). The offset \( \phi_0 \) of the phase of the driving
field is chosen to cancel the linear part of the wake field by the RF slope. The wake field and the beam loading effects are calculated at the centre of the bunch.

Fig. (3) represents the energy loss for TRS, also for the successive bunches and different charges per bunch.

Figure 2: Energy gain in LAS $\Delta E$ (MeV) as function of the bunch number for different bunch charges. (no load energy gain is 57.5 MeV)

Figure 3: Energy loss in TRS in MeV, as a function of the bunch number for different bunch charges
3.2 Results of focussing in TRS aperture by triplets: optics I

The focussing currents in the triplets are the same for all the bunches. The calculations are made for 1 to 7 nC per bunch. For each charge per bunch, the focussing forces are optimized for producing a beam waist at the centre of TRS, the triplets being set for the average energy of the whole train. Dynamics in TRS is calculated according to the energy available at the time of the passage of the bunch. TRS is only a decelerating section, with a field which varies from bunch to bunch and also depends on the bunch charge.

The focussing forces in the triplet which is in front of LAS may also be trimmed for better focussing, but their main purpose is to keep the clearance between the envelopes and the iris along LAS. Fig. (4) represents the beam envelope at the end of LAS, up to TRS, for 4 nC per bunch.

![Figure 4: Envelopes of transverse RMS beam size at end of LAS and in TRS](image)

(no load energy gain in LAS is 57.5 MeV, bunch number 9, 4 nC/bunch)

The clearance of the beam with the iris of TRS is represented by the ratios:

\[ f_x = \frac{r_{TRS}}{\sigma_x}, \quad f_y = \frac{r_{TRS}}{\sigma_y} \]

where \( r_{TRS} \) is the inner radius of TRS (2 mm), and \( \sigma_x, \sigma_y \) are the projections of the beam envelope on the transverse planes (RMS values).

\( f_x \) and \( f_y \) measure the quality of the focussing. They are calculated at the entrance, centre and exit of TRS, the lower number being kept. For gaussian distribution, 86.5\% of the \( e^- \) are contained in the envelopes at \( \pm 2\sigma \). We try to calculate focussing forces such that these envelopes are within the full aperture of TRS (2 mm radius, 0.286 mm length), for the first and the last bunches of the train. If this can be achieved, the clearance for the bunch with the average energy is several \( \sigma \) (typically 5).

Bunch 1 (maximum energy) has its beam waist beyond the centre of TRS, bunch 16
(minimum energy), in front of TRS. Increasing the charge per bunch increases the difference in energy between the bunches and it may be impossible to provide the required focussing for all the bunches. With 4 nC per bunch we just hit this limit: $2\sigma \leq 2\text{mm}$, with bunch 1 or 16. For comparison, the charge necessary to produce 80 MV/m in CAS is 7 nC per bunch, when successive bunches are separated by 5 periods of 3 GHz, as shown fig. (10).

Fig. (5), fig. (6), fig. (7) show the envelopes at 1 $\sigma$, for bunches number 1, 9 and 16, and for 4 nC per bunch (at 2 $\sigma$, the size is just doubled).

On fig. (8), $f_x$ and $f_y$ are plotted as a function of the bunch number (1 to 16). The horizontal scale corresponds to the total momentum at each bunch centre, at the exit of LAS. All the effects on the energy, from the gun to this point have been taken into account.

### 3.3 Avoiding direct beam impacts on TRS wall (optics II)

Suppose the focussing optimized for bunch 9. Bunch 1 is focussed behind TRS. The limiting envelope for the part of bunch 1 which goes through TRS is defined by the aperture $r_{TRS}$ of TRS at entry: only the fraction $p_1\sigma$ of the first bunch goes through. The rest of the bunch hits the entry face of TRS, as represented on fig. (9).

The limiting envelope for the part of bunch 16 which goes through TRS is defined by the aperture of TRS at exit. Fraction $p_2\sigma$ of the bunch 16 goes through. But the rest hits the inner wall of TRS, or the TRS entry face.

On the contrary, if we optimize the focussing for bunch 16, with a waist at TRS centre, as on fig. (9), then $p_2\sigma$ of bunch 16 goes through TRS, and the rest, as represented on fig. (9), is lost on TRS entry face. The limiting envelopes for all the other bunches are also defined by the TRS aperture at entry only. Then, a screen of Tungsten placed in front of TRS will prevent beam loss on the TRS inner walls.

But by focussing bunch 16 at the centre of TRS, we have less transmission and the limit passes from 4 nC to 3 nC per bunch when we keep our condition $p\sigma \geq 2\sigma$ for all bunches.

The following table resumes the results obtained in these conditions.

<table>
<thead>
<tr>
<th>bunch 16</th>
<th>Horiz.</th>
<th>Vertic.</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRS</td>
<td>entry</td>
<td>exit</td>
</tr>
<tr>
<td>$\sigma$ (mm)</td>
<td>.391</td>
<td>.398</td>
</tr>
<tr>
<td>$r_{TRS}/\sigma$</td>
<td>5.11</td>
<td>5.02</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>bunch 1</th>
<th>Horiz.</th>
<th>Vertic.</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRS</td>
<td>entry</td>
<td>exit</td>
</tr>
<tr>
<td>$\sigma$ (mm)</td>
<td>1.17</td>
<td>.911</td>
</tr>
<tr>
<td>$r_{TRS}/\sigma$</td>
<td>1.71</td>
<td>2.20</td>
</tr>
</tbody>
</table>

All bunches go through TRS with $r_{TRS} \geq 2\sigma$, except bunch 1, for which the limit is
Figure 5: Envelopes of the transverse rms beam size for bunch number 1 near TRS. Beam focusing optimized for bunch number 9, charge 4 nC per bunch. The distances $z$ are counted from the photocathode.

Figure 6: for bunch number 9

Figure 7: for bunch number 16
Figure 8: Ratio aperture / rms beam size, in both planes for the different bunches and 57.5 MeV non load energy gain in LAS. The bunch charge is 4 nC. Horizontal scale gives the total energy of each bunch at entrance of TRS. Rf gun contribution is 4.5 MeV.

Figure 9: Envelopes for bunches 1 and 16 at TRS. The optimization is made for bunch 9 (intermediate energy) at centre of TRS: particles are hitting TRS inner wall (a). If the optimization is made for bunch 16 (lower energy) at centre of TRS, an iris at TRS entry avoids particle impacts on inner walls (b).
1.71 at the TRS entry face, and for horizontal motion only. With the approximations of the calculation, we do not try to have more precision, and consider that 3 nC per bunch is the limit.

3.4 Increasing the energy gain for the test beam

Fig. (10) shows that for 3 nC per bunch in the CTF beam, the energy gain in CAS is 7.5 MeV, compared to the 18 MeV required.

![Figure 10: Energy gain in CLIC accelerating structure (CAS) as a function of bunch charge in TRS](image)

The accelerating section we use is a spare of LIL section 25. Therefore, a solenoid is installed on LAS. Calculations of the envelopes of the trajectories have shown that using the solenoid instead of the triplet does not give better results considering the adverse effects of the energy spread. However, we could try using both solenoid and triplet if necessary.

Higher power is required on LAS in order to reduce the relative effect of the beam loading. Hence, the smaller relative energy spread will enable the required 7 nC per bunch to be focussed into TRS. For a first step, J.H.B. Madsen [5] had proposed to reorganize the distribution of the rf power, providing enough power in LAS for reaching 75 MeV energy gain (non-load) in the structure.

Fig. (11) represents the gain of energy we have for the different bunches with different charges per bunch, for 75 MeV no-load energy gain in LAS. The calculations for the focussing by the triplets are made again, as for the case of the 57.5 MeV energy gain.

Fig. (12) shows that up to 7 nC per bunch, the beam can be focussed through TRS. Beam loss in TRS is avoided if the charge per bunch is reduced to 6 nC per bunch, by focusing the 16 bunch at TRS centre. This gives 15 MeV energy gain in CAS.

In this case, a different optimization of the optics (optics III) is required. The gradients of the quadrupoles in front of LAS and in front of TRS are given in the table (5), for the 3
Figure 11: Energy gain in LIL structure (LAS) for different charges per bunch and for the 16 bunches. The no-load energy gain is 75 MeV.

Figure 12: Ratio aperture/rms beam size in both planes at the TRS for the different bunches. Bunch charge is 7 nC, LAS no load energy gain 75 MeV. Horizontal scale gives the total energy of each bunch at entrance of TRS. (bunch centre)
optics solutions successively calculated. The parameters at the exit of the gun are those of [4], i.e. for the Gun:

- electric field: 100 MV/m (4.5 MeV)
- charge: 9 nC
- cathode: r=5 mm
- laser pulse: parabolic, centre at 30° Rf phase.

Table 5: Gradients for the triplets in front of LAS and of TRS

<table>
<thead>
<tr>
<th></th>
<th>opt.I</th>
<th>opt.II</th>
<th>opt.III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy gain (no load)</td>
<td>MeV</td>
<td>57.5</td>
<td>57.5</td>
</tr>
<tr>
<td>Charge / bunch</td>
<td>nC</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Total energy LAS exit</td>
<td>MeV</td>
<td>bunch 1</td>
<td>47.1</td>
</tr>
<tr>
<td></td>
<td>MeV</td>
<td>bunch 16</td>
<td>59.1</td>
</tr>
<tr>
<td>Gradients of triplet in front</td>
<td>T/m</td>
<td>f 360</td>
<td>.487</td>
</tr>
<tr>
<td>of LAS</td>
<td></td>
<td>d 370</td>
<td>-.359</td>
</tr>
<tr>
<td></td>
<td></td>
<td>f 380</td>
<td>.393</td>
</tr>
<tr>
<td>Gradients of triplet in front</td>
<td>T/m</td>
<td>d 410</td>
<td>-.955</td>
</tr>
<tr>
<td>of TRS</td>
<td></td>
<td>f 415</td>
<td>-.879</td>
</tr>
<tr>
<td></td>
<td></td>
<td>d 420</td>
<td>-1.2</td>
</tr>
<tr>
<td>Voltage available in CAS</td>
<td>MV</td>
<td>10</td>
<td>7.5</td>
</tr>
</tbody>
</table>

3.5 Conclusion

The multibunch beam loading process of the transfer structure of CTF, as presented in [1], gives a solution for the space charge problems and reduces also the part of the spread in energy which is due to the wake fields. The spread is reduced even further as the linear part of the wake field is partially compensated by a suitable choice of the phase of the driving field. However, with the present layout of the CTF, there are severe limitations to the amount of energy which could be transferred from the beam to the TRS structure and then to the test beam.

One limitation certainly comes from the length of the transfer line between the gun and LAS: the bunch is modified by space charge and wakes, a problem which is not treated here. However, increasing the energy of the gun [6] will help considerably. Another limitation comes the energy spread created by the beam loading in LAS, because it will not allow more than 3 nC per bunch with the voltage available at present in LAS. This limitation could be raised to 6 nC per bunch by a modification of the network.
4 Acknowledgments

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References

[1] K. Hübner CERN/PS/91-06 (LP) and CLIC Note 134
Generation of 30 GHZ RF power in the CLIC Test Facility

1990 Linac Conference, Cern Divisional Report, PS 90-55 LP
The CERN Linear Collider Test Facility

The proposed beam optics for the CTF

EPAC- Nice 1990, CLIC Note 117
Beam dynamics simulations of the RF gun

More RF power for the gun and LAS

[6] R. Bossart Communication at the CTF meeting PS, 22-02-91
Adding more cells to the 3 GHZ gun

Transport. A Computer program for designing charged particle transport systems.