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Preliminary Design of the CLIC Drive-Beam Transfer Line.

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ABSTRACT

In the drive-beam generation complex of CLIC there is an important beam transfer line between the drive-beam accelerator and the drive-beam decelerators, where the 30 GHz RF power is generated in the decelerator structures. The design proposed for this transport system is based on building blocks or beam optics subsystems, which have been individually studied in detail and can be combined in order to cover specific functions. One function consists of bending the beams wherever required by the geometrical layout, so as to preserve the bunch length and keep the bending arc compact and compatible with acceptable synchrotron radiation. Other functions are to adjust the path length of each drive beam for synchronism with the main-linac beam and to compress or stretch the bunch according to the needs. Furthermore, there are vertical and horizontal beam translations, isochronous or acting as a compressor, and β-function transformers for matching the optics. All these functions are necessary in the drive-beam transfer that precedes injection into the decelerators.

1 MAIN FUNCTION DESCRIPTION

The different parts of the beam transport system between the drive-beam accelerator and the many drive-beam decelerators (making up the CLIC RF power source [1]) must in general terms cover four types of functions:

1. Bending the beams where required in order to follow the geometrical lay-out of the drive beam generation complex, in such a way that the bunch length is preserved and the bending arc is as compact as possible, compatible with tolerable synchrotron radiation effects.
2. Adjusting the path length of each individual drive beam in order to regulate of the synchronism of the beams with the main linac beam, when they are injected into the separated decelerating sections.
3. Compressing and also stretching the bunch length according to the needs at the different stages of the beam acceleration and multiplication.
4. Vertical or horizontal beam translation, isochronous or combined in specific cases with a bunch compression.

Each of the four functions have been studied and are present in various places of the drive beam generation complex. Function 1 appears each time the beam has to be bent, for instance after the pre-acceleration, between the combining rings and mainly in the “turn-around” loop preceding the injection in the decelerator. Function 2 is only required before the injection into the decelerator while Function 3 is essential into the accelerating linac and immediately after the “turn-around” loop in order to satisfy the conditions assumed for the bunch length, considering the drive beam stability. Function 4 serves mainly for the vertical translation needed after the turn-around because of the geometry adopted in the tunnel, but also for the incoming drive beam which has to be lifted up to the level of the “turn-around” loop. The whole complex which requires the four functions is briefly described below.

2 OVERVIEW OF THE TURN AROUND.

The drive beam accelerator and the combiner rings are planned to be in a central position with respect to the two main linacs of the collider, which means that all the drive beams have to be first transported in a direction opposite to the main beams, before being turned around through a 360° loop and injected into the different decelerators [1] where they travel parallel to the main beams. The transport line for the beam going upstream is of course situated in the same tunnel as the decelerators, near the highest point in order to minimise the loss of space in the accessible area (Fig. 1). This position offers the advantage of keeping the “turn-around” loops near the roofs of the tunnel and of the alcoves which will house the loops. This prevents geometrical interference with the main linac and the decelerators which are placed on a common concrete support (Fig. 1), at about 1 m above the level of the tunnel floor. The difference in elevation of the beams going upstream and downstream (1.5 m approximately) imposes the need for vertical bends to bring the drive beams down before their injection in the decelerators. In addition, the up-going beam is not exactly above the down-going beam of the power-linac, since the two have to run anti-parallel over a short distance near the roof (where the path-length chicane is foreseen); they are horizontally separated by 0.75 m. In addition, the transport line carrying the up-going drive-beams must run without interruption all the way to the starting point of the main linac (also the injection-point of the first drive-beam). This transport line must therefore be placed slightly below the level of the turn-around loop (0.25 m) to avoid a crossing at the same level. Each drive-beam entering its specific loop is therefore deflected vertically. The relative vertical positions of the different beam lines are shown in Fig. 1 and in the elevation of Fig. 2. The latter shows the location of the vertical bends bringing the beam from roof-level to decelerator level just above the beam-dump line of the preceding drive-beam.

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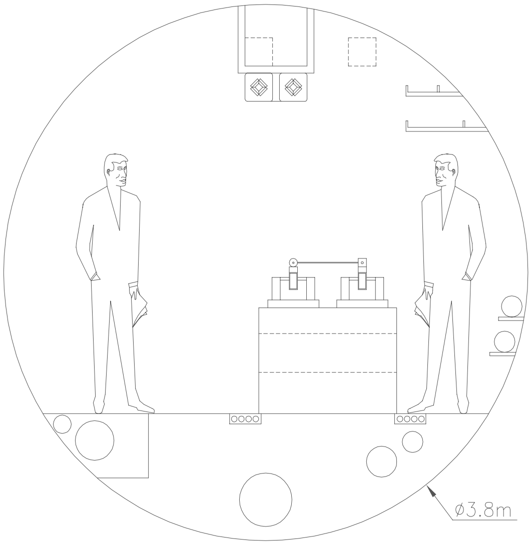

Figure 1 Tunnel cross-section with the transfer lines.

This compact design minimises the space lost for power transfer. The various elements of the turn-around appear in the plan view of Fig. 2. The up-going drive-beam comes from the left through a FODO line. After a vertical deflection, the selected drive-beam pulse enters the 360° loop, consisting of a 90° right-turn followed by three 90° left-turns. Drifts are added to adjust the geometry and separate the axes of the down- and up-going beams.

After the loop, the beam traverses a special kind of chicane or "dipole-snake" that serves to adjust the path length and compress the bunch. It then goes through a dipole that is only turned on in case of emergency to deviate the beam onto a dump. The drive beam pulse is then bent down to reach the decelerator injection-point. A further bunch compression is done in this downward bend. Fig. 2 also shows part of the previous decelerator section (coming from the right) which ends with a dipole and half-quadrupoles to bend the spent beam (with a large energy spread) into the same dump. The various elements or optics-modules of this area are described below.

The size of the alcove containing the turn-around as well as its relative position in the tunnel are shown in Fig.2. There are as many alcoves as there are drive beam pulses; they can also be used to house electronics racks.

3 TURN-AROUND LATTICE.

As seen in Section 2, the turn-around consists of four modules, each with a 90° bend. These modules are designed to be isochronous ($R_{56} = 0$) in order to preserve the bunch length and are based on the design concept elaborated for such applications with compact lattice and acceptable synchrotron radiation effects [2]. A module includes three dipoles of equal length, two quadrupole doublets between them to control dispersion as well as beam focusing and one triplet to join the modules. The dispersion is adjusted such that the integral of $D(s)/\rho(s)$ is zero in the bending magnets (of bending radius ρ) and D vanishes in the triplet. An optimisation of the magnet- and drift-length provides compact modules with reasonable β-amplitudes and magnetic fields. Fig. 3 gives a sketch of one module as well as the β-functions and the

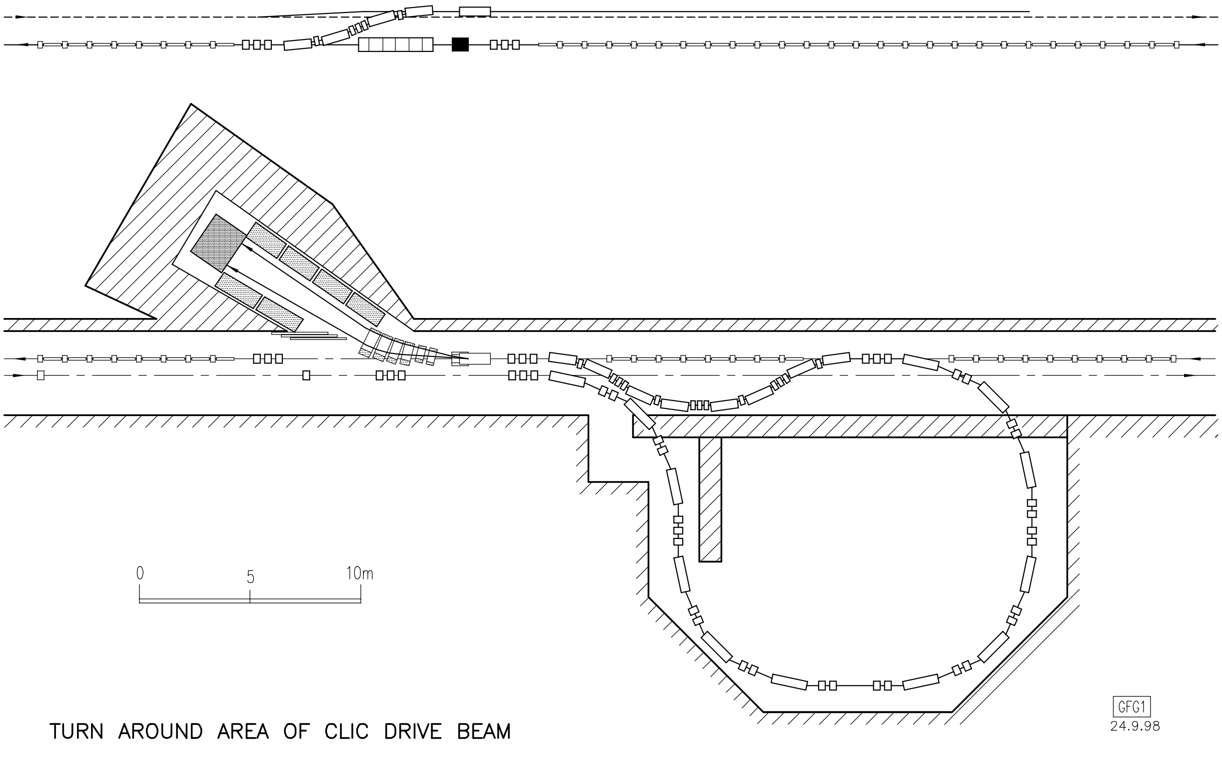

Figure 2 – Sketched Layout of the transfer lines.

dispersion achieved. Table 1 lists the main parameters.

Table 1 - **Isochronous module parameters**.

Bending magnet length	[*m*]	1.6
Bending magnet fields	[*T*]	1.0 / 1.8
Bending angle per dipole	[*deg.*]	23.5 /43
Bending radius	[*m*]	3.9 /2.15
Quadrupole length	[*m*]	0.3
Quadrupole gradient	[*T/m*]	26.0
Module length	[*m*]	11.0
Transfer matrix coefficient R_{56}	[*m*]	0.00

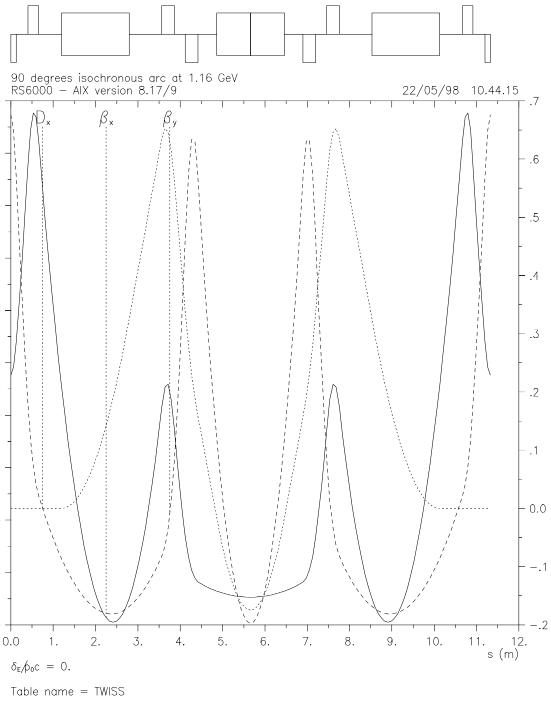

Figure 3 Optical functions of one isochronous module.

The total circumference of the turn-around is near 45 m. The coherent synchrotron radiation effect at 1.24 GeV is tolerable. The path length variation within the bunch, for a momentum spread $\Delta p/p$ of ± 0.025, is strongly reduced with one family of sextupoles placed near the doublets, where the dispersion is relatively large.

4 OTHER BEAM TRANSFER MODULES

To adjust the phasing of each drive beam requires a fine **tuning of the path length** before injection into the decelerator and the addition of a kind of special chicane or "dipole-snake", after the "turn-around" loop. This chicane has to provide a non-zero R_{56} coefficient in order to introduce a correlation between the path-length variation Δl and a change $\Delta\theta$ of the deviation angle in the "snake", around a finite average value θ_0 for the dipoles. The sign of R_{56} is not important since the sign of $\Delta\theta$ is free, but its amplitude must allow an adjustment Δl between ± 2 mm and ± 5 mm (i.e., half the RF period at 30 GHz). R_{56} has therefore been chosen such as to achieve most of the **bunch compression** needed in addition, i.e. R_{56} = 0.13 m, the remaining compression of 0.03 m being provided by the vertical translation that follows. In the drive-beam accelerator, the head of the bunch has an energy above average and the tail below. Such a correlation requires a positive R_{56} for bunch compression and the consequent use of a double-bend with two dipoles deflecting the beam in the same direction, i.e. with ρ and θ_0 of the same sign. To provide the desired R_{56} value, it is necessary to have a succession of four double-bends arranged in a geometry that looks like a long chicane (Fig. 2). A single quadrupole between the two bends controls the dispersion and a triplet of quadrupoles focuses the beam in the two transverse planes. The following parameters were selected to give $R_{56} = 0.13\ m$ and $\Delta l = 0.5\ mm/mrad$:

$\theta_B = 16^o$, $l_B = 1.23\ m$, $B = 0.88\ T$, $l_Q = 0.2\ m$, $G_Q = 20\ T/m$

A path-length adjustment of 2 mm implies a change in the bending angle of 4 mrad with $l_{\text{drift}} = 0.5\ m$.

The elevation difference of 1.5 m between the upstream- and downstream-going beams (Fig. 2) implies a **vertical translation** that can be combined with some compression of the bunch, using double-bends again. This function is achieved by half a "dipole-snake", i.e. two double-bends separated by a drift given by the geometry, and bending the beam into opposite directions. The coefficient R_{56} of this module is equal to 0.03 m in order to give with the path length module the total of 0.16 m that is required. The following parameters have been obtained for these two vertical double-bends :

$\theta_B = 11^o$, $l_B = 1.23\ m$, $B = 0.6\ T$, $l_Q = 0.2\ m$, $G_Q = 38\ T/m$

The drift in the middle of the module, containing a matching quadrupole triplet, has a total length equal to 1.0 m, to satisfy the translation amplitude required.

At various locations of the drive beam transport system, **matching Twiss functions** at zero-dispersion is needed. This happens at the junction between the transport line of the incoming beam and the first 90° isochronous module, between the turn-around and the path-length module, the latter and the vertical translation, and this translation and the drive-beam decelerator. In most cases, it is an adjustment to a FODO type lattice or between two FODO type lattices. This is best achieved by using quadrupole triplets of the type "FODO transformer" (that transforms a β-crossing with equal and opposite derivatives into a different β-crossing with opposite slopes also), the properties of which have been studied elsewhere [3].

5 REFERENCES

[1] H. Braun *and 14 co-authors*, rep. CERN/PS 98-011 (LP) and Proc. EPAC98, Stockholm, 1998.

[2] T.E. d'Amico and G.Guignard, rep. CERN/SL 95-021 (AP) and Proc. PAC95, Dallas, 1995.

[3] T.E. d'Amico and G.Guignard, rep. CERN/SL 980-14 (AP) and Proc. EPAC98, Stockholm, 1998.