TECHNOLOGY DEVELOPMENTS FOR CLIC

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Abstract

Just after the publication of its Conceptual Design Report (CDR) the CLIC study has made detailed plans for necessary technology developments in the coming years. This program includes the development of fully working prototypes of several technical subsystems as well as first pre-series or industrialization concepts of components needed in large identical quantities. The presentation will explain the development program and show in particular fields for potential collaboration.

INTRODUCTION

CERN's latest and foremost accelerator, the LHC, will probe the "terascale" energy region and provide a rich program of physics at a new high-energy frontier over the coming years. In this energy domain, it will study the validity of the standard model and explore the possibilities for physics beyond the Standard Model, such as super-symmetry, extra dimensions and new gauge bosons. The discovery potential is huge and will set the direction for future high-energy colliders. Particle physicists worldwide supported by ICFA [1] have reached a consensus that the results of the LHC will need to be complemented by experiments at a lepton collider in the Tera-Electron-Volt (TeV) energy range. The required beam collision energy range will be better defined following Physics requirements based on LHC results when substantial integrated luminosity will have been accumulated, tentatively by 2013-15.

The highest energy of lepton collisions so far, 209 GeV, was reached with electron–positron colliding in LEP at CERN. In spite of the 27 km diameter of LEP, beam energy was limited by synchrotron radiation losses just compensated by the most powerful super-conducting RF system built so far and providing up to 3640 MV per revolution. Since synchrotron radiation is inversely proportional to the bending radius and proportional to the fourth power of the particle mass, two alternatives are being explored to overcome this limitation and build a terascale lepton collider:

- use muons with a mass 207 times larger than electrons. The feasibility of Muon Colliders is being studied [2] addressing critical challenges specially the limited muon lifetime and their production in large emittances requiring developments of novel cooling methods,
- mitigate bends of particle trajectories in e+/- linear colliders where two opposing linear accelerators accelerate the particles to their final energy in one pass before focusing and collision in a central interaction point inside a detector.

Following preliminary Physics studies based on an electron-positron collider in the multi-TeV energy range [2,3], the CLIC study is focused on the design of a linear collider with a colliding beam energy of 3 TeV and a luminosity of 2.10^{34} cm-2 s-1 at the extreme of the considered parameter space. A scaled-down design is deduced at a lower energy, arbitrarily set at 500 GeV with the same luminosity for comparison with the alternative ILC technology.

The layouts of a 3 TeV linear collider using the CLIC technology is displayed in Fig 1.

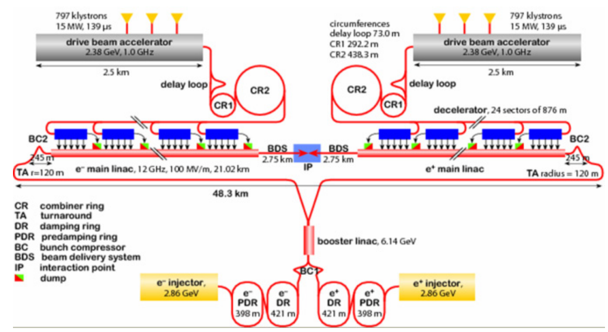

Figure 1: Layout of a 3 TeV cms energy linear collider based on the CLIC specific two-beam acceleration scheme.

WHY TWO-BEAM ACCELERATION?

In order not to confuse the arguments, no explicit references are given in this section. All important Details including further references can be found in the CLIC Conceptual Design Report [4].

– The main objective is to build at reasonable cost and at a reasonable size a linear collider for the Multi-TeV range. This requires a very high acceleration gradient (100 MV/m), which cannot be achieved with super-conducting technology.

– For a given breakdown rate there is a very steep scaling between gradient and RF pulse length, hence the beam pulse has to be limited to about 150 ns. This short beam pulse is the fundamental design parameter, which has major consequences for the physics analysis of the events, for beam parameters to achieve the required luminosity, and for the RF power generation.

– In a circular accelerator the counter-rotating beams collide with a high repetition frequency, typically in the tens of kHz range. The repetition frequency of a linear collider by contrast is typically only 5–100 Hz. The luminosity necessary for the particle physics experiments has then to be reached with challenging parameters for bunch charge, beam emittance, and strength of the final focusing magnets. In the case of CLIC about 300 bunches

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at high bunch charge spaced by only 0.5 ns have to be accelerated.

- For the generation of very high RF power only klystrons are currently available as power sources. There are, however, no klystrons on the market which can generate the required power for the short RF pulses (some 200 ns, which accounts for the 150 ns beam pulse plus some filling time of the accelerating cavities). The available klystrons can only deliver power into pulses which are about one order of magnitude longer. Hence klystrons with subsequent pulse compression networks would have to be used. A klystron powered linear collider with 100MV/m accelerating cavities would need about 35 000 high power klystrons (about 50MW each) with each klystron having a factor of five pulse compression.

– The numbers presented for klystron powering are not feasible in terms of cost and maintenance; they might be reconsidered as an option in case of a collider with a very low center-of-mass energy.

– The so-called CLIC scheme foresees the generation of the necessary RF power through the production of a second low-energy Drive Beam over a very long pulse (high-power klystrons are readily available) followed by a sophisticated compression scheme, in which the RF pulse is not time compressed, but the generated electron ‘Drive Beam’ itself is. The time-compressed Drive Beam then travels along with the Main Beam and generates the necessary RF power for acceleration by losing its energy in the ‘decelerator’ in special RF structures (PETS).

TECHNOLOGY DEVELOPMENTS

After publication of the CDR the mandate of the CLIC study for the next five years will be the development of all technologies needed for the construction of the accelerator. The present publication is restricted to a selected number of technology items, for which the CLIC study is actively looking for collaboration partners.

These developments cover the following domains:

- Industrial production of x-band (12 GHz) RF structures for beam acceleration, power extraction or interconnectivity.
- Test stands for long term high power testing of these x-band structures. This will need the procurement of the corresponding power source.
- Development of high efficiency 1 GHZ high power klystrons. Most likely this will be done in collaboration with industry.
- Continuation of the present CTF3 experimental program at CERN.
- Complete engineering integration of all components for the main beam acceleration and drive beam power extraction into so called “Two beam acceleration” modules. (TBM modules)

These (2m long) TBM modules integrate also a number of other technology development items, such as:

- active quadrupole stabilization against mechanical vibrations
- precision alignment system with remote controlled actuators
- vacuum manifolds
- the x-band RF system

In the following text more details are given.

TWO-BEAM ACCELERATION MODULES

Overview

The CLIC two-beam acceleration configuration consists of repeated 'modules' [5]. Each main linac contains more than 10000 “repeated “modules. The drive-beam, running parallel to the main linac, regularly powers two Accelerating Structures (AS) from one Power Extraction and Transfer Structures (PETS). Each module contains up to four PETS (see Figure 2), feeding two AS each, and two drive-beam quadrupoles, as a very dense lattice is required for the low-energy drive beam. Space for quadrupoles in the main linac is made by leaving out two, four six or eight accelerating structures and suppressing the corresponding PETS.

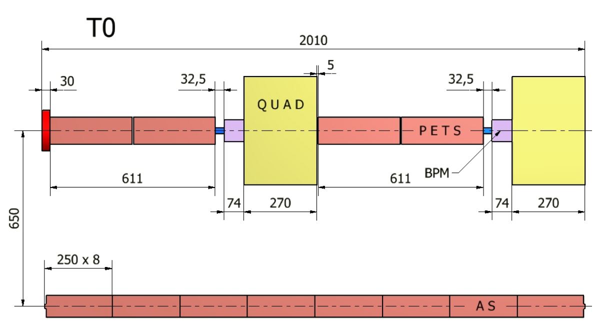

Figure 2: Schematic layout of CLIC type 0 module.

The module components are mounted on alignment girder. The stagger between the two linacs is made to give the correct relative RF to beam timing. The module length (2010 mm) is determined mainly by the length of accelerating structures (230 mm) and the fact that a PETS feeds two structures (a number which depends on the high-power capability of the PETS). Drive linac beam dynamics simulations show that the drive beam quadrupole spacing must be about 1 m with a quadrupole length of about 270 mm for sufficient strength. The remaining space is then available for two PETS and the BPM which is just sufficient. A 30 mm length has been reserved for inter-girder connections. A few modules with main beam and drive beam quadrupoles only are required in the end sector regions (about 10 m) where each drive beam is fed into and out of a drive beam linac sector. The two-beam module design has to take into consideration the requirements for the different technical systems. The main components are designed and integrated to optimize the filling factor and gain in compactness. Figure 3, shows the 3-D view of a typical two-beam module, with the main components, such as AS, PETS and quadrupoles. In this chapter the

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main technical systems are reviewed and the main technical requirements recalled.

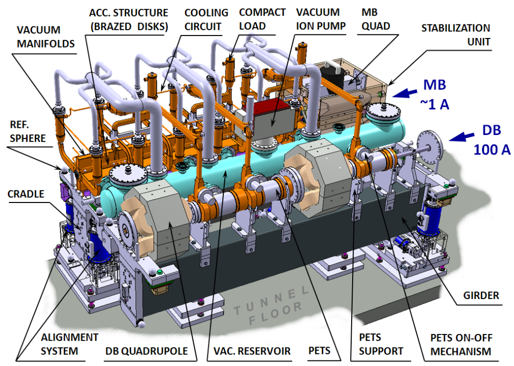

Figure 3: 3-D view of the CLIC two-beam module.

Quadrupole Stabilization System

One of the required actions to preserve the ultra-low transverse emittances during the beam transport is the mechanical stabilization of all 3992 main beam quadrupoles (MBQ) The integrated Root Mean Square (RMS) [17] of the vertical absolute displacements of the magnetic field centre of each quadrupole shall stay below 1.5 nm above 1 Hz. Similarly, it shall stay below 5 nm in the lateral direction.

To reach such a mechanical stability for the CLIC MBQ, ground vibration measurements in operating particle accelerators [6] have shown that a mechanical stabilization system is needed under each quadrupole. At each MBQ, the interconnected girders and supports with accelerating structures will be interrupted by the independent MBQ support. The MBQ will be supported by the stabilization system that is supported inside a magnet girder placed on the eccentric cams of the alignment system. The MBQ stabilization strategy is based on a stiff actuating support with stiff piezoelectric actuators, the measurement of the relative displacement between the quadrupole and an inertial reference mass (seismometer) and an active reduction of the transmissibility of the magnet support at low frequencies [7]. The main reason for the choice of this strategy is the robustness against external disturbance forces. The actuators are mounted in pairs in a parallel structure with flexural hinges, inclined and in the same plane. Each actuator pair is mounted inside an x-y guidance that will allow vertical and lateral motion but will block motion along and around (roll) the longitudinal axis of the magnet. A conceptual drawing of the quadrupole stabilization system is shown in Figure 4.

The displacement range and the stiffness of the actuators also allows to reposition the quadrupole in vertical and lateral direction between beam pulses with steps up to 50 nm in a range of ± 5 µm.

Beam Instrumentation

The linac module beam instrumentation mainly consists of Beam Position Monitors (BPM) and Beam Loss Monitors (BLM).

The present design of the BLM system is not advanced enough to be integrated in the mechanical layout of the module at this stage.

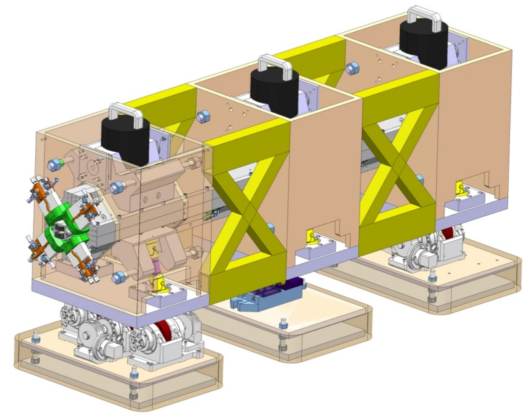

Figure 4: Conceptual drawing of the quadrupole stabilization system for MBQ type 4 placed on the alignment stage.

CLIC modules will be produced in large quantities and the BPM system is extensive. The main beam contains about 7500 BPMs while the drive beams require about 42000. There will be two drive beam BPMs per module. In the main beam, there will be a BPM for each quadrupole.

The main beam BPM consists of two cavities, a position cavity measuring both X and Y directions, and a reference cavity measuring beam charge and phase. Both cavities are resonant at 14 GHz. The reference cavity has two monopole mode coupling ports which allows for redundancy of the readout electronic in order to ensure optimal reliability, as required for the orbit feedback controller. The main BPM will be connected rigidly to the quadrupole with no possibility to adjust its position. Alignment targets are mounted on the top, in order to measure its relative position with respect to the quadrupole. The BPM is not connected to the Wire position system, (WPS). A 3D image of the main beam BPM is depicted in Figure 5.

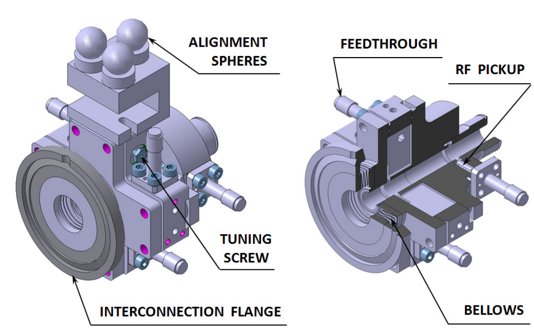

Figure 5: Main beam cavity BPM.

For the drive beam BPM, the current plan is to use short stripline BPMs, only 25mm long, with position signals processed at baseband in a bandwidth of 4-40

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MHz. The strip lines are built into the quadrupole vacuum chamber, as shown in Figure 6.

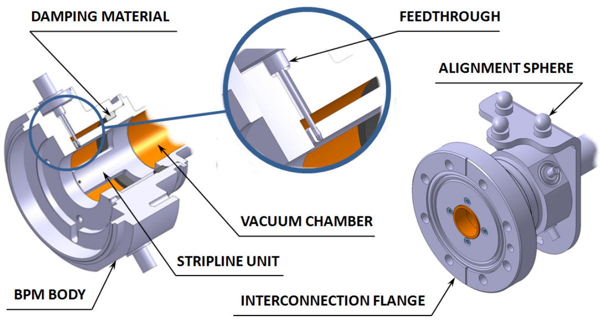

Figure 6: Drive Beam BPM.

Alignment System

Pre-alignment of two beam module will take place when beam is off. It will consist of two steps: a mechanical pre-alignment, which will pre-align all the components within +/- 0.1 mm with respect to the Metrological Reference Network (MRN), and an active pre-alignment fulfilling the requirements here after. For a sliding window of 200 m, the standard deviations of the transverse position of each component with respect to the straight fitting line must be inferior to a few microns. The total error budget in the determination of the position of components has been calculated. It corresponds to 14 µm for the RF accelerating structures and 17 µm for the main beam quadrupoles [8].

The determination of the position of the components will be performed thanks to a combination of two measurement networks:

1) A Metrological Reference Network (MRN) providing an accuracy and precision of a few microns over at least 200 m, and consisting of overlapping stretched wires

2) A Support Pre-alignment Network (SPN), associating to each support proximity sensors (capacitive based Wire Positioning Sensors (cWPS)) measuring with respect to a stretched wire, providing a precision and accuracy of a few microns over 10-15 m. Both networks will perform measurements with respect to the same stretched wire alignment reference. Overlapping stretched wires will be located between the two beams, as illustrated in Figure 7.

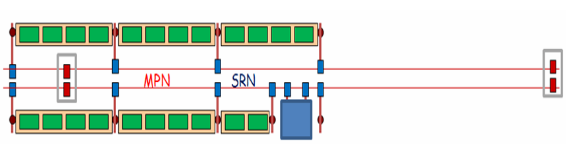

Figure 7: Module and measurements networks.

Several issues must be taken into account concerning the pre-alignment solution. First, the integration of the alignment systems must be considered. As a matter of fact, hydraulic network linking HLS sensors follows the equipotential surface of the Earth's gravity field; this will not be the case of the tunnel which will be straight. So every few hundred meters along the tunnel, superposed sensors will compensate the slope (see Figure 8).

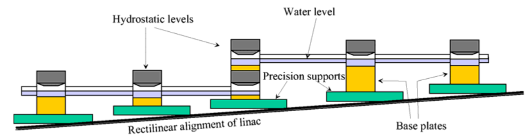

Figure 8: Configuration of HLS network in a laser straight tunnel.

A second issue is the constraints on the re-adjustment system from the other systems, which will apply additional transversal loads on the actuators and on the associated mechanics. Some simulations concerning their impact is under way; these constraints will be studied on the two beam module prototypes.

Third issue is the difference of temperature foreseen concerning the components between installation and operation. Fiducialisation and pre-alignment of the components on their supports will be performed at a standard temperature of 20°C, which will be modified during operation, generating dilatation of the components on the girders (mainly in the longitudinal direction) and misalignments. Simulations concerning misalignments are under way and will be validated on the two beam module prototypes. Temperature variation in the tunnel will also imply dilatation of the supports on which the position of the sensors have been determined. Temperature probes will be added on each support to correct dilatation effects. This means that the distance between sensors on their support and the stretched wire should be minimized. The sag of the wire could be limited (shorter length of wires, develop wires with small linear mass and high resistance to traction). Then, materials with low expansion coefficient should be used for the sensors supports.

SUMMARY

Using the example of the two beam acceleration module the complexity of the technologies needed for the future 3 TeV CLIC linear collider has been demonstrated. Starting from the published CDR in the year 2012 a technology development phase of about 5 years has been launched in order to define all components ready for construction. This large task is well suited to integrate international collaboration with institutes and industrial partners, which are cordially invited to contact the CLIC study team in order to establish such collaborations.

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