CLIC TWO-BEAM MODULE DESIGN AND INTEGRATION

G. Riddone, CERN, Geneva, Switzerland
A. Samoshkin, D. Gudkov, JINR, Dubna, Russia

Abstract

The Compact LInear Collider (CLIC) is based on two-beam acceleration concept currently developed at CERN. The RF power is generated by a high-current electron-beam, called Drive Beam, (DB) running parallel to the Main Beam (MB). The DB is decelerated in dedicated power extraction structures (PETS) and the generated RF power is transferred via waveguides to the accelerating structures (AS). To facilitate the matching of the beams, components are assembled in 2-m long modules of few different types. Special modules are needed in damping regions or to contain dedicated instrumentation and vacuum equipment. The module design and integration has to cope with challenging requirements from the different technical systems. This paper reports the status of the engineering design and related technical issues.

INTRODUCTION

The CLIC study is currently developing the design of compact modules forming two linacs for the beam collision at two energies of 0.5 TeV at the first stage, and 3 TeV later, with equal luminosity of $2{\cdot}10^{34}$ $\mathrm{cm^{-2}\ s^{-1}}$. [1] The key components being studied and designed are the power extraction and transfer structures (PETS) feeding the accelerating cavities (AS) operating at 11.9942 GHz. Since the linac length is about 21 km, more than 10,000 modules are needed. The required luminosity can be reached with powerful beams (about 14 MW each) colliding with extremely small dimensions (1 nm in the vertical plane) and high beam stability. The main CLIC module parameters [2] are summarised in Table 1.

Table 1: Main CLIC Module Parameters

Parameter	3 TeV	Unit
Module length	2010	mm
Length of PETS (active)	213	mm
PETS tolerance (1σ)	31	μm
Number of AS (in Type 1 Module)	6	
AS length (active)	229	mm
Pre-alignment AS tolerance (1σ)	14	μm
Pre-alignment Quadrupole tolerance (1σ)	17	μm
Pre-alignment "Quadrupole - Beam Positioning Monitor (BPM)" tolerance (1σ)	14	μm
Relative position of AS and BPM (1σ)	5	μm

The precision of the different mechanical part production and assembly must be achieved, which is right on the edge of the current available technologies. On top of that the proper pre- and alignment techniques must be used. Since all the components are periodically repeated, it was decided to place them on the supporting girders, which have a length multiple of two sets of the two PETS and one DB quadrupole (DB Q). As a result the length of the CLIC module was fixed to 2010 mm. Two transversal interconnection planes were defined as a boundary to facilitate the transport, installation and changeability of modules. The MB quadrupoles (MB Q), depending on the module type, replace one or a few pairs of AS. For example the MB of Type 1 Module consists of one quadrupole and six AS. The MB Q is supported independently, which makes the MB girder shorter. In addition to regular modules some special ones are needed in the regions of beam injection and damping. The engineering design of a typical CLIC Module (e.g. Type 1) is described, and it incorporates all the main components, including the MB Q, and technical systems, such as supporting, stabilisation, vacuum, alignment and BPM.

LAYOUT AND MAIN REQUIREMENTS

The scheme of the Type 1 Module is shown in Fig.1.

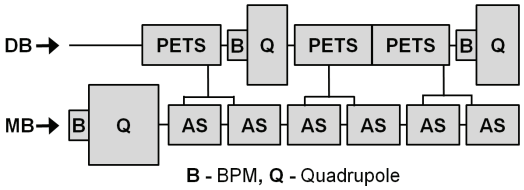

Figure 1: CLIC Module Type 1 schematic layout.

The CLIC two-beam RF network includes the X-band rectangular waveguides providing connection between PETS, AS and other supplementary devices. Firstly it is necessary to join the PETS outgoing waves by one channel. Because of limited longitudinal space a compact coupler is needed. In case of breakdown in a particular AS it is necessary to interrupt the power produced by the corresponding PETS within 20 ms. This is to maintain the overall luminosity. Afterwards the related AS must be slowly put back into operation. The “On-Off” mechanism [3] thus is needed. Another necessity is to guarantee alignment flexibility between the two beams and to allow for the power transmission without electrical contact. Therefore, between inter-beam waveguides, the dynamic performance tolerances (S11< –45 dB) of ± 0.5 mm for the vertical shift, ± 0.25 mm for the one in a horizontal direction and 5° for the twist are required. The next addressed issue is a split of power between two AS without any reflection to the feeding PETS. The newly designed hybrid, linked to the compact damping load is suggested. And finally, the power delivery from PETS to the two fed AS must be perfectly matched in phase. The schematic view of RF network is shown in Fig. 2.

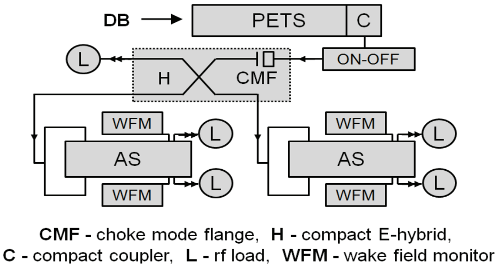

Figure 2: RF distribution principle.

The main components of each beam in the module must be properly aligned to cope with beam and RF requirements. The concept [1] is based on a common girder supporting a number of components of different systems such as AS, vacuum manifolds, RF components, PETS with their compact coupler, "On-Off" mechanism, vacuum connections as well as the DB quadrupoles equipped with BPM.

The girders should provide a sufficient mechanical stability and must assure continuity for the chain of components of one beam. Three degrees of freedom are needed at each end of the girder in order to be able to re-align the components with respect to the beam axis. The AS are the most sensitive components (see Table 1). In addition, for stability reason, the MB quadrupoles must stay independent of other components and such require the self-governing supports, which should combine both, alignment and stabilization functions. The quadrupole support has five degrees of freedom for having the possibility to be adjusted coherently with MB components. Special attention must be paid to the fact that some of MB quadrupoles are almost 2 m long and their weight is about 450 kg each. Also the supporting system must foresee the pre-alignment features to compensate the tunnel profile irregularities and be adapted to transportation. An important requirement is to have an interchangeable module, which means that supports should be linked together and independent at the same time.

The BPM are required for measurement of beam trajectory. The time resolution was set to less than 50 ns and the spatial one to 50 nm for the MB. The corresponding accuracy must be better than 5 µm. A precision of 20 µm and resolution of about 2 µm are necessary for the DB.

The pre-alignment system will be needed for making possible the "first" beams pass through the linac. Then the beam-based alignment will take over this function. Hence to fulfil the requirements the CLIC Module components must be aligned within a transversal and vertical tolerance of 10 µm along a 200-m sliding window [3]. The overlapping wires stretched between two beams are used to form a straight reference line all along the linac. The sensors of Wire Positioning System (WPS) are reading the transversal and vertical distances to the wire.

A high mechanical stability is required for the MB quadrupole to ensure the design luminosity. The magnetic axis must be retained within 1 nm vertically and 5 nm horizontally above 1 Hz. Two options are currently being studied. One is based on idea of active stabilization with nano-alignment between beam pulses and another is a combination of passive and active isolation. The detailed design is under way. For the moment an envelope is used for integration to reserve the needed space.

The residual gases in the vacuum volume of RF structure are ionized by the beam. Therefore, ions (electrons) can accumulate around the electron (positron) beam. A large concentration of them can induce the transverse beam instability. A low pressure level, set to 10^{-9} mbar, is needed for keeping the good beam quality. This requirement together with a high number of components in a very limited space (i.e. with very low vacuum conductance) makes the design of the vacuum system very challenging. The interconnections between main components should sustain the vacuum forces, provide an adequate electrical continuity with low impedance and remain flexible not to restrict the alignment.

A significant part of the RF input power is transferred into heat in the RF structures. The thermal stability of the accelerator tunnel as well as the mechanical stability of components, alignment and vacuum systems require evacuating the heat efficiently by specially designed water circuits. Any vibration induced by coolant flow can result in loss of machine performance. The distribution of the power dissipation by components of one module is shown in Table 2. The total power dissipated to water for all modules in one linac is about 68 MW, which represents 97% of total dissipation.

Table 2: Estimated Power Dissipation in Type 1 Module

Components	**Dissipation (W)**
AS	2500
PETS	340
MB Quadrupole (Type 1)	890
DB Quadrupoles	350
Loads	2250
TOTAL	**6330**

TECHNICAL SYSTEM DESIGN AND INTEGRATION

Different solutions are being studied and tested for the different technical systems. The PETS in the present configuration are composed of eight copper bars [3] milled with 15 µm shape accuracy. Special slots between them are filled with absorbers for damping of the transverse high-order modes. Compact couplers were designed to combine a few functions. Being a part of RF network (see Fig. 3) they also provide an external reference of the DB for the alignment system and play the supporting role. Secondly the "On-Off" mechanism is connected directly to the coupler body. The water cooling channel is machined inside each coupler and conduction cooling is used for the bars. The vacuum “mini-tank”, surrounding the PETS, is centred and fixed by electron beam welding on couplers thanks to specially machined grooves. Two vacuum ports on the “mini-tank” are connected to the main vacuum reservoir, where the ion pump is fixed. The next important component in the RF chain is the choke mode flange (CMF), which permits to move and align two beams independently. Its location is between the “On-Off” mechanism and the Hybrid, distributing the RF power between two adjacent AS. An RF load is attached to one of the hybrid ports to avoid the reflection to the corresponding PETS. The RF splitters are used to equally feed the AS. The micro-precise assembly connections play a significant role for both, vacuum and RF systems. Where possible, joints are implemented by brazing and welding. However in some places, where the assembly cannot be done without RF flanges, the ones recently designed at CERN are adopted.

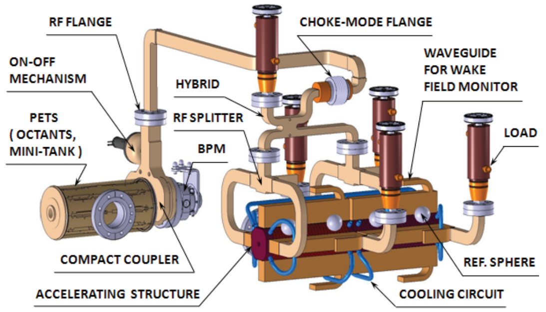

Figure 3: Layout of CLIC Module RF Network.

The AS with damping features is made of disks joined by diffusion bonding at 1040°C. The design [4] is based on experience of an international collaboration between CERN, SLAC and KEK on high gradient X-band AS development. Up to 8 AS can potentially be bonded together to form a single unit. On each AS four vacuum manifolds are brazed as a set of extended damping waveguides equipped with SiC absorbers. One waveguide on each manifold is made longer to house the pick-up antenna for wake field monitoring in both horizontal and vertical planes. Vacuum reservoir is connected to the structure with flexible bellows to the closest manifold. There are four internal channels for flow of water in each AS. Following design optimisation based on thermal dissipation study, the cooling circuits of two structures are connected in series. For alignment purposes, it has been suggested to equip each AS with four reference spheres.

The main components of both beams are supported on rectangular shaped girders linked to one chain all along the linac. The MB focusing magnet is an exception due to stringent position requirements. It has its own support and stabilization unit, which will be integrated in a later phase.

Another accomplished challenging task is the design of interconnections between main components inside the module and between two neighbouring ones. The connections are compact, flexible, provide the electrical contact and sustain ultra-high vacuum.

Figure 4 illustrates the overall layout of the CLIC Module (Type 1) as a result of the current integration.

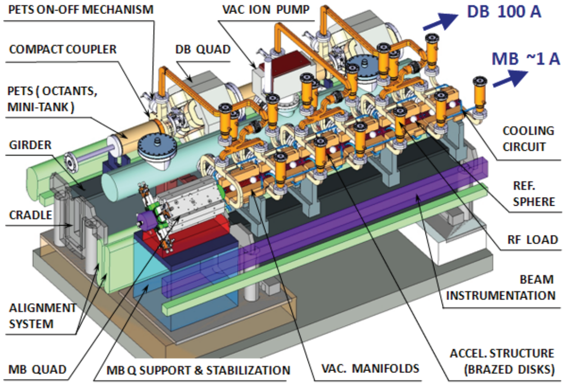

Figure 4: CLIC Module Type 1 integration layout.

CONCLUSION

More than 10,000 modules, housing micro-precision components with stringent requirements, are needed in the CLIC main linac. The module design and integration also aims at maximising the filling factor by optimization of the layout and better functioning of the related technical systems. Possible configurations are being implemented and compared in order to identify critical zones requiring a particular attention for further simulations and design. The manufacturing methods and their influence on the product cost are also addressed in the design phase. The CLIC Conceptual Design Report will be issued by mid of 2011. Therefore the baseline module configuration has been defined. For this, the thermo-mechanical behaviour has been simulated [5], and the necessary changes were introduced into the module design.

ACKNOWLEDGEMENTS

Authors sincerely thank all members of the “CLIC Module Working Group” for their valuable contribution.

REFERENCES

[1] H. Braun et al., "CLIC 2008 Parameters", CERN-OPEN-2008-021; CLIC-Note-764.

[2] G. Riddone et al.: “Technical Specification for the CLIC Two-Beam Module”, MOPP028, EPAC’08, Genoa, Italy, 23-27 June 2008.

[3] I. Syratchev, A. Cappelletti, "A new High-Power RF device to vary the output power of CLIC Power Extraction and Transfer Structure (PETS)", WEPE026, IPAC’10, Kyoto, Japan, May 2010.

[4] A. Grudiev, W. Wuensch, "Design of the CLIC Main Linac Accelerating Structure for CLIC Conceptual Design Report", LINAC’10, Tsukuba, Japan.

[5] R. Nousiainen et al: "Studies on the Thermo-Mechanical behaviour of the CLIC Two-Beam Module", LINAC’10, Tsukuba, Japan.