THE CLIC MAIN LINAC MODULE UPDATED DESIGN

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Abstract

In 2016, CLIC implementation working groups have started their reflection on how to finalize the CLIC design work in the different areas of the project, aiming for a technical design and an overall implementation plan for CLIC being available for the next European Strategy Update around 2019. One of the working groups has focused its attention on the Main Linac hardware, which has brought together the different competences of the study with the aim of producing an advanced set of specifications for the design, installation and operation of the CLIC module. As the fundamental unit for the construction of the Main Beam linac, the CLIC module needs to move from the existing prototypes exploring its performance into an advanced and functional unit where the full life cycle of the module is considered. The progress of the working group activity is summarized in this paper, with considerations on the requirements for the design of the next-phase CLIC module.

INTRODUCTION

Since the last decade of the 20th century a large international collaboration coordinated by CERN has been working on the concept of an electron-positron linear collider capable to deliver multi-TeV collisions with very high luminosity (~10^{34}cm^{-2}s^{-1}) [1]. The accelerator is based on the two-beam concept where a high intensity beam travels on a parallel line to the main beam linac and feeds its high-gradient accelerating cavities with the RF field produced by the wakes developing inside specialized power transfer structures called PETS. The Main Beam (MB) and the Drive Beam (DB) linacs run side by side at few tens of centimetres distance. The main linac needs to actively maintain very tight transverse alignment tolerances over several kilometres, in order to guarantee the efficient production of the high luminosity colliding beams.

A rather detailed description of this complex machine, made up of several different accelerators was provided in the CDR that was published in 2012 and the updated baseline of the study was published in 2016 [2]. Following the results obtained in the CLEX test area and the developments performed since then, it became clear that a more advanced concept for the realization of the so-called Two-Beam Module (TBM) [3] was needed. It is being elaborated, taking into account all aspects from fabrication to installation and operation of the modules. An energy staging strategy has been elaborated which maximizes the integrated luminosity for the physics at each energy stage.

The initial stage is at 380 GeV hence our investigation has put a particular emphasis on the case.

TWO-BEAM MODULE DEVELOPMENTS

The efforts of the working group have been focused on the review of the design specifications; in particular, we investigated how a first stage at 380 GeV could affect fabrication tolerances and operational parameters with respect to the designed peak luminosity. We have also tried to introduce a life-cycle perspective into our analysis, by looking how different stages in the machine realization and operation could influence design choices.

Beam Dynamics

The optimization for the 380 GeV stage aims at providing a consistent comparison of requirements for the Drive Beam (DB) and the Klystron-based (K) configurations, which are the powering options for the MB linac being considered for this stage. Table 1 shows how the beam parameters change in the MB linac to assure the same luminosity for the two cases

Table 1: Beam Parameters for DB and K Scenario

Parameters	units	DB	K
N particles	10^9	5.2	3.87
N bunches		352	485
Rep rate	Hz	50	50
ε_x / ε_y	μm / nm	0.95/30	0.66/30
β_x / β_y	mm / mm	8.2/0.1	8.2/0.1
σ_x / σ_y	nm / nm	149/2.9	120/2.9
L_{total}	10^{34}cm^{-2}s^{-1}	1.5	1.5
$L_{0.1}$	10^{34}cm^{-2}s^{-1}	0.9	0.9

A cost optimization performed on the basis of these parameters has allowed to identify the characteristics of the accelerating structures that could match the performance in each of the two cases, which are summarized in Table 2.

Taking assumptions on the klystron and modulator efficiencies from recent studies [4], the analysis seems to indicate that this option could be compared to the DB baseline in terms of cost. This will be the task of the Main Linac HW Baseline and of the Cost and Energy working groups to evaluate and compare the two options.

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Table 2: Optimized RF Structure Design

Parameters	units	DB	K
Frequency	GHz	12	12
Gradient	MV/m	72	75
Cells/structure		33	28
Particles/bunch	10^9	5.2	3.87
Bunches/train		352	485
Pulse length	ns	244	325
RF Power (peak)	MW	59.5	42.5

Two distinct machine optics have been elaborated at 380 GeV and some optimization is still expected for the DB options. Table 3 summarizes the component quantities on the Main Beam side for the two options.

Table 3: Main Beam Linac components (380 GeV)

Components	DB	K
AS (33 cells)	20592	0
AS (28 cells)	0	23296
Short Quadrupoles	712	724
Long Quadrupoles	432	452

RF and Accelerating Structures

RF accelerating structures are certainly the key element of the whole CLIC concept. The Power Extraction and Transfer Structures (PETS), used to produce the RF pulse required by the main beam in the DB scheme, have been produced and tested in the CLEX facility, delivering the designed performance. As regards the MB linac accelerating structures (AS) a significant production statistics would be required to prove that they can condition at the required breakdown rate of $7{\cdot}10^{-5}$ breakdowns/pulse, providing the nominal gradient of 100 MV/m and 250 ns pulse length, with the requested margin.

An intense program of production of around 40 AS and for their testing is under way, with the operation of three multi-klystron testing stations, called Xboxes, which will be completed by the end of 2019.

At the initial stage of 380 GeV collisions, more than 23000 AS will be required in the MB linac and the relevant point of their qualification tests and of their commissioning is being addressed to produce a realistic strategy.

The current conditioning scheme requires about $3{\cdot}10^8$ RF pulses/structure, i.e. 40 days/structure when pulsing the klystron at 100 Hz. Such an extensive test would be conceivable only after installation in the tunnel and, for the DB option, when the DB would be available.

It is however being considered to which extent a shorter test could allow to validate the production quality of the AS and enable their acceptance, also in the case that the DB option is chosen.

In Figure 1, it is shown how the conditioning trend after 10^8 RF pulses with 80 nS pulse length could already provide a reasonable assessment of how well an AS is following the expected conditioning track. For this acceptance test, when using a klystron operating at 1 kHz repetition rate, one day would be sufficient [5]. We expect to validate this scheme by using the Xbox3 RF test bench working at 400 Hz.

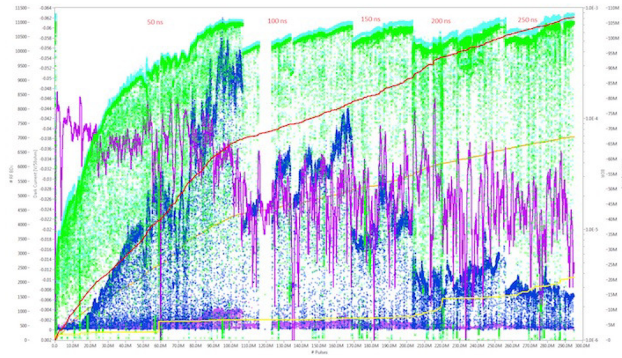

Figure 1: Typical conditioning curve for the CLIC AS.

RF Considerations In the CLIC K-based option, the RF power production is accomplished by a 2-pack modulator unit, equipped with two klystrons delivering 68 MW RF peak power each, during 1.625 µsec at 50 Hz. Each unit would feed one accelerating module made of 8 AS. The studies being performed on klystrons by the HEIKA collaboration give concrete hope to upgrade present figures of efficiency from about 50% up to 70%. This, together with the implementation of high efficiency modulators and focusing channels made of permanent magnets, could rise the overall efficiency to above 30%. The impact that such an efficiency improvement could have on the project cost is currently being evaluated and will be included in the cost review that will take into account both the DB and the K options for the 380 GeV case.

Alignment Requirements

The alignment strategy as presented in the CLIC CDR is based on the transverse alignment of the linac on distance scales of 200 m, which is achieved by means of overlapping stretched wires and wire position sensors; the accurate alignment of the accelerator elements on girders is assured by fixed supports, relying on the accuracy of machining and assembly of the individual components and V-shaped supports.

Recent results achieved in the frame of the PACMAN project [6] and the experience gained during the operation of the CLEX facility have encouraged us to slightly change the CDR approach. V-shaped supports can be replaced by a simple adjustment system and the fiducialization and pre-alignment steps can be performed at once with an important reduction of complexity and time consuming measurements. The development of portable solutions, like CuBe wire and micro triangulation, for the fiducialization and pre-alignment now would allow to perform these operations in the tunnel or at least to cross check the correct alignment of components once they are installed in the tunnel. The alignment requirements on the major accelerator components, i.e. accelerating structures (AS), beam position monitors (BPM) and quadrupoles (MBQ and DBQ), have been achieved.

The thermal stability will be a crucial element in the alignment strategy and the evolution of the accelerator components during operation, with respect to the initial conditions at which the alignment procedure is applied.

In Table 4 we show a summary of the results achieved so far; they confirm that the goals set by the CLIC CDR can be achieved with the present techniques.

Table 3: Validated steps in the alignment process

Steps	AS µm	BPM µm	MBQ µm
Zero of components to fiducials	5	5	10
Fiducials to sensor interface on support	5	5	5
Sensor interface on support	5	5	5
Sensor measurement wrt straight reference	5	5	5
Stability knowledge of the straight reference	10	10	10
Total error budget	14	14	17

The accelerator components will be supported by a combination of active movers, which will guarantee the possibility to dynamically correct the machine alignment during operation, and of adjustable supports for the initial alignment of the machine.

Thermal Management

The thermal load produced by such a machine is going to be a critical parameter in the evaluation of the stable operational conditions of the accelerator. In particular, the thermal exchange to air is going to heavily influence the environmental conditions in the main tunnel and have a major impact on the overall project cost.

A survey of the power dissipation to water and to air have been performed and the preliminary results are summarized in Table 4. The figures of power dissipation to air are given in W/m, since the local dissipation is the relevant parameter influencing the design and the cost of the tunnel ventilation system.

Table 4: Power Dissipation in the Main tunnel according to the different options, AS loaded values are provided.

Component		3 TeV DB	380 GeV DB	380 GeV K
Alignment	W/m	1.9	1.8	0.8
BPM	W/m	13.9	13.0	2.3
Vacuum	W/m	51.1	43.9	31.7
Magnets (air)	W/m	49.9	34.8	17.5
Magnets (water)	MW	19.9	3.4	1.4
MBQ stab	W/m	8.7	14.3	15.7
RF System (air)	W/m	137	98	181
RF System (water)	MW	79	9	19

CONCLUSION

The work of the Main Linac Hardware Baseline working group has made significant progress with the identification of the aspects of the CLIC Module design that leave margin to improvement, however this process is not complete yet.

One important outcome of the discussions has been that no compromise will be made on cost or performance optimization with respect to the Drive Beam or Klystron options: for each option an optimized AS design has been chosen and the comparison will be performed on that basis. While the work on the next module specification is progressing, with the aim of delivering the 3D model of the CLIC Module for the next phase of the study by the end of 2017, relevant parameters are being supplied to the infrastructure working group that will produce an advanced study of the tunnel and related ancillary systems.

The final goal is to integrate the CDR study with new results, also by extending the first stage of the project down to 380 GeV, and with a cost and power review on time for the next European Strategy meeting in 2019.

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REFERENCES

[1] S. Stapnes [ed.] *et al.*, "A Multi-TeV linear collider based on CLIC technology", CLIC Conceptual Design Report, CERN, Geneva, Switzerland. Rep. CERN 2012-007, 2012. http://cds.cern.ch/record/1500095

[2] P. Lebrun [ed.] *et al.*, "Updated Baseline for a Compact Linear Collider", Geneva, Switzerland. Rep. CERN 2016-004, 2016. http://cds.cern.ch/record/2210892

[3] A. Samoshkin *et al.*, "CLIC Two-Beam Module for the CLIC Conceptual Design and Related Experimental Program", in *Proc. 2nd Int. Particle Accelerator Conf. (IPAC'11)*, San Sebastian, Spain, May 2011, paper TUPC008, pp. 1003-1005.

[4] A. Yu. Baikov, C. Marrelli, and I. Syratchev, "Toward high-power klystrons with RF power conversion efficiencies on the order of 90%", *IEEE. Trans. Elec. Dev.*, 62(10), pp. 3406-3412, 2015.

[5] A. Degiovanni, W. Wuensch, and J. Giner Navarro, "Comparison of the conditioning of high gradient accelerating structures", *Phys. Rev. Accel. Beams*, vol. 19, p. 032001, Mar. 2016.

[6] H. Mainaud-Durand *et al.*, "Fiducialisation and Initial Alignment of CLIC Component with Micrometric Accuracy", in *Proc. 14th Int. Conf. Accel. Align.* (IWAA2016), Grenoble, France, Oct. 2016.