IMPROVED MODELLING OF THE THERMO-MECHANICAL BEHAVIOR OF THE CLIC TWO-BEAM MODULE

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Abstract

Micron-level stability of the Compact LInear Collider (CLIC) two-beam modules, two-meter repetitive units constituting the main linacs, is one of the most important requirements to achieve the final luminosity target. High power dissipation during normal operation modes of modules will result in misalignments in and between different elements of the linacs, thus affecting the final resulting luminosity.

In this paper, updated finite element models of CLIC two-beam modules are presented and the structural behaviour of them is studied in more detail than in the earlier simulations. In particular, the models have been refined by improving the modelling of actuators and bellows as well as studying the most updated versions of CLIC modules. Based on the main operation modes of the CLIC collider, the results of thermal and structural analysis of two-beam modules are presented.

These numerical results will be validated by experimental tests to be performed in 2012 with full-scale CLIC prototype modules. They will allow for better understanding the thermo-mechanical behaviour and they will be propagated back to numerical modelling.

INTRODUCTION

CLIC [1] is a multi-TeV normal conducting electron positron collider, where the Main Beam (MB) passes through the Accelerating Structures (AS) and is accelerated by the RF power extracted from a low energy and high-intensity Drive Beam (DB) using Power Extraction and Transfer Structures (PETS). The power is transferred from the DB to the MB through a dedicated RF network (Figure 1).

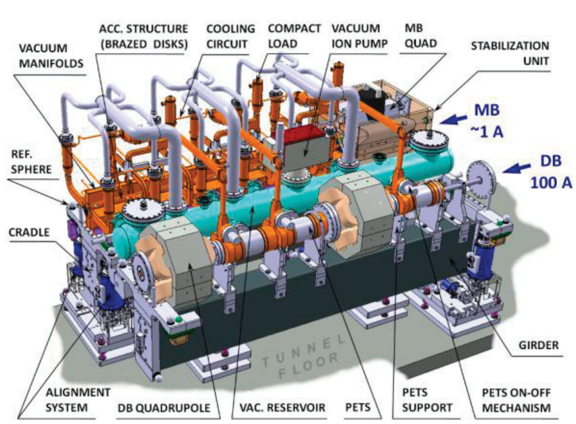

Figure 1 CLIC two-beam module typical configuration.

The total length of CLIC is about 48-km and both 21-km long main linacs are constituted of two meters long repetitive modular units.

During normal operation, the CLIC two-beam modules are subject to time-varying non-uniform thermal fields. The estimated power dissipation from the magnets and RF structures is about 7 kW per two-beam module (3.5 kW/m) [2]. The thermo-structural behaviour of the CLIC two-beam modules has been previously studied by different finite elements models gradually refined over the years [3][4]. This paper describes the recent improvements done to the previous model. In particular, the contributions of gravity and vacuum loads to the overall thermo-structural response of CLIC modules have been considered in the simulation and their influence on the final module configuration is presented.

TWO-BEAM MODULE OVERVIEW

The present study is focused on the current CLIC baseline module to be validated in a dedicated laboratory at CERN [5]. The program foresees the construction of four prototype modules representing the main CLIC two-beam module types. Nevertheless simplifications are implemented as the modules will not be tested with RF and beam.

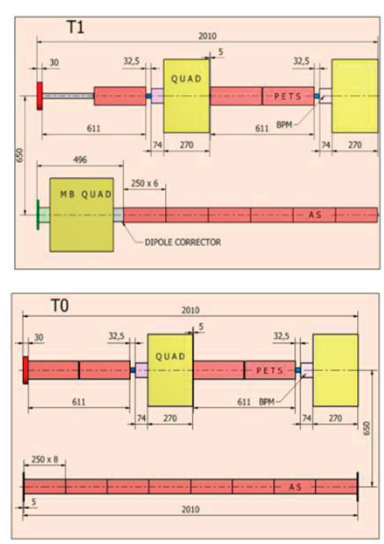

Figure 2 CLIC module scheme (T1 = type 1, T0 = type 0).

The configuration of CLIC modules type 1 and type 0 is presented in Figure 2. Type 1 differs from type 0 due to the presence of one quadrupole on the MB line.

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Moreover, type 0 has a higher number of AS (8 instead of 6) installed on the MB as well as more PETS (4 instead of 3) for the DB.

The aim of prototype modules is to prove the feasibility of the proposed technical solutions for the different systems (such as pre-alignment, stabilization, cooling and vacuum systems) as well as of the overall integration. The RF system conceived for these first experimental tests is composed of several mock-ups of RF structures and RF components, without internal RF geometry, but with real reference surfaces for positioning and alignment as well as real mechanical interfaces to validate manufacturing and assembly procedures.

Each module comprises two girders supporting the RF structures by means of V-shaped supports. All girders are mechanically interconnected via a system called "snake system" that provides an accurate alignment of the two linacs by means of dedicated articulation points and linear actuators positioned at the extremity of each girder.

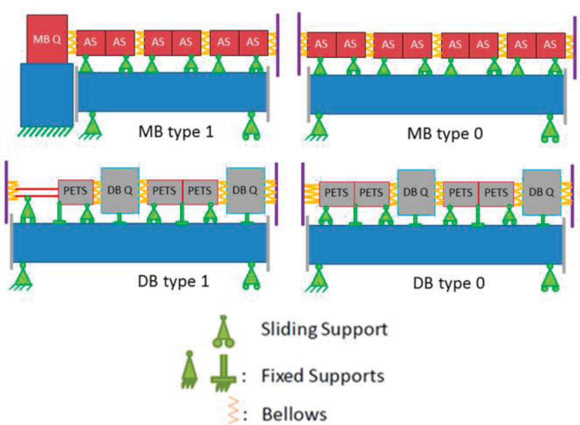

Figure 3 Constraints on the DB and MB girders for the CLIC modules type 1 and type 0.

The ultra-high vacuum level (10^{-9} mbar) is provided via a central reservoir concept equipped with vacuum pumps to which the AS and PETS are connected through bellows. The thermal behavior of the prototype module is simulated by means of special heaters installed inside the RF structures to reproduce the power dissipated by the main RF structures and removed by an integrated cooling system.

For CLIC modules, adjacent RF structures are connected through bellows to decouple the longitudinal and transversal degrees of freedom. System constraints are shown in Figure 3. For the prototype module type 0, representing a simplification of corresponding CLIC module type 0, bellows between adjacent accelerating structures are replaced by rigid connections. The calculated results of CLIC modules type 0 and type 1 are discussed first, while those of prototype module type 0 are presented afterwards.

MODEL DESCRIPTION

The geometry of the main components constituting the module under study has been simplified and implemented in ANSYS Workbench. Shell elements have been used for modelling thin-walled structures like the central vacuum tank, while solid elements have been used for the other components like girders and RF structures.

On the basis of the thermo-fluid dynamics analysis simulating the integrated cooling system, the temperature distribution resulting from the heat dissipation inside the module is derived. The thermal results are then used to calculate the structural response of the system due to the resulting temperature gradient; vacuum and gravity loads are considered in the simulation as well. The module cooling scheme is shown in Figure 4, while corresponding water mass flow rates and convection coefficients are given in [4]. Cooling systems for type 1 and type 0 are exactly the same except for the presence of MB quadrupole in module type 1.

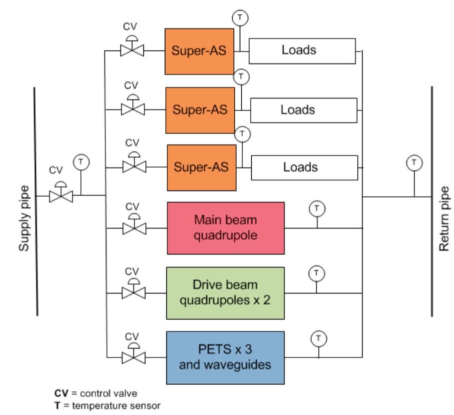

Figure 4 Cooling scheme for CLIC module type 1.

Linear actuators supporting girders as well as bellows connecting different RF components have been modelled using equivalent stiffness elements, thus improving the overall computational time of the finite elements model.

AS and PETS units are supported by V-shaped supports: they are rigidly fixed in the middle, while they can slide over side supports along the longitudinal direction to cope with axial deformations. DB magnets are fixed to the common DB girders (Figure 3). MB magnets have separate supports. Multi-point constraints have been used to model the mechanical configuration existing between different components of the system. Finally, linear elastic behaviour of the material has been considered in the simulation.

RESULTS AND DISCUSSION

The effect of thermal loads due to RF power, as well as of vacuum and gravity loads has been studied for each module configuration (CLIC type 1, CLIC type 0 and prototype type 0).

Table 1 summarizes the results of the thermo-fluid dynamics analysis. The inlet temperature of water is 25°C and, due to the heat generated inside the module by RF power, the water temperature increase is almost 10°C for

AS and 5 °C for PETS. For the overall module the water temperature increase is about 20 °C.

The results of the thermo-structural analysis in terms of resulting deformed shapes due to applied thermal RF loads are presented in Figure 5 and Figure 6, while the contributions of the other external loads (vacuum and gravity) are summarized in Table 2. Concerning prototype type 0, the highest deformation is found for the applied RF load and occurs along the MB line. This is explained by the fact that all AS constituting the main beam are brazed together, thus providing internal fixed constraints between consecutive structures; the eight AS are then fixed in the middle and free to expand in the axial direction along the other supports. For CLIC module type 0 the thermal expansion is almost four times lower, since bellows have been used to decouple the longitudinal deformation due to the temperature increase as consequence of RF power.

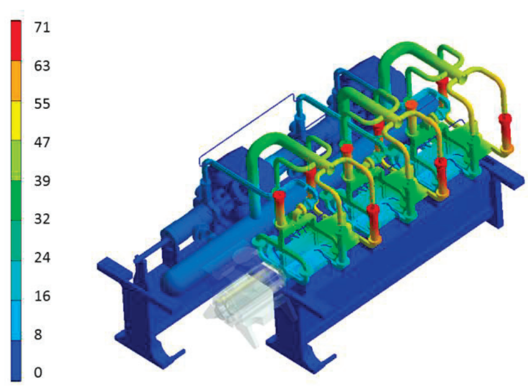

Figure 5 Deformed shape of CLIC module type 1 due to applied thermal RF loads (values in μm).

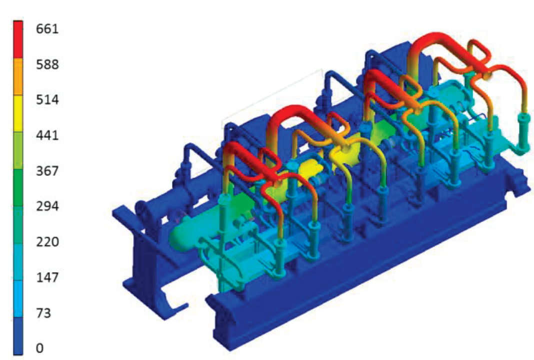

Figure 6 Deformed shape of prototype module type 0 due to applied thermal RF loads (values in μm).

Table 1 Resulting temperatures inside the modules.

Temperature [°C]	**CLIC type 1**	**CLIC type 0**	**Prototype type 0**
Max temp. of module	41	40	43
Water output temp. MB	35	35	35
Water output temp. DB	28	30	30

Table 2 Resulting displacements on the DB and MB lines due to thermal, vacuum and gravity loads.

Displacements [μm] (location and load type)	**CLIC type 1**	**CLIC type 0**	**Prototype type 0**
MB (RF load)	40	50	183
DB (RF load)	16	15	47
MB (vacuum load)	130	49	30
DB (vacuum load)	54	10	131
MB (gravity load)	23	31	27
DB (gravity load)	36	36	40

CONCLUSIONS

The luminosity goal of CLIC collider imposes micron level stability of its two-meter repetitive elements, the CLIC modules, constituting the two main linacs. Thermal loads due to RF power dissipated inside the modules produce deformations affecting the alignment of the linacs and therefore the resulting luminosity. Other external loads, such as vacuum and gravity, give additional contributions to the final misalignments in and between different elements.

Finite elements models have been realized to study the thermo-mechanical behaviour of different CLIC modules to predict all those deformations affecting the final alignment of modules and to compensate them by means of re-adjustments to be performed using the integrated linear actuators.

Experimental tests are planned in 2012-2013 to validate the results of this study and improved understanding will be propagated back to the simulation models.

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