PROGRESS ON MODELLING OF THE THERMO-MECHANICAL BEHAVIOR OF THE CLIC TWO-BEAM MODULE

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Abstract

The luminosity goal of the CLIC collider, currently under study, imposes micrometer mechanical stability of the 2-m long two-beam modules, the shortest repetitive elements of the main linacs. These modules will be exposed to variable high power dissipation during operation resulting in mechanical distortions in and between module components. The stability of the CLIC module will be tested in laboratory conditions at CERN in a full-scale prototype module.

In this paper, the FEA model developed for CLIC prototype module is described. The thermal and structural results for the new module configuration are presented considering the thermo-mechanical behavior of the CLIC collider in its primary operation modes. These results will be compared to the laboratory measurements to be done during 2011 and 2012 with the full-scale prototype module. The experimental results will allow for better understanding of the module behaviour and they will be propagated back to the present thermo-mechanical model.

INTRODUCTION

CLIC [1] is a multi-TeV normal conducting electron positron collider with the power supplied by a secondary electron Drive Beam (DB). The main beam (MB) passes through the Accelerating Structures (AS), where the beam is accelerated by the RF power that is created in Power Extraction and Transfer Structures (PETS) from a low energy, high-intensity DB and transferred through a dedicated RF network (see Fig. 1). The 21 km long linacs are equipped with complex modular 2-m long units. The overall accelerator length of CLIC based on the current design is about 48 km.

The CLIC module is a precision assembly exposed to varying thermal fields in the accelerator caused by ramp up and operation: the estimated thermal dissipation into the RF structures and magnets of a typical CLIC module is about 6.9 kW (3.45 kW/m) [2]. The CLIC module behavior has been studied with a simplified thermo-mechanical model (TMM) [3]. This paper describes the progress on the TMM for the CLIC module using Finite Element (FE) software ANSYS Workbench 13. In the current FEA model, the module components are described in more detail compared to the earlier models, which should result in a more realistic description of the CLIC two-beam module. The focus is on thermo-mechanical effects caused only by the operation of the RF structures (PETS and AS), which constitute the main contributions. Other thermal loads, e.g. from the DB quadrupoles (DB

Q) have not been taken into account for the moment. In addition, gravity and effects due to contacts were also included in the FEA model.

MODEL DESCRIPTION

The TMM was built according to the CLIC baseline module design to be tested in laboratory conditions at CERN [4]. The geometry was created with CAD system and then implemented into ANSYS Design Modeller. The simulation environment created for the TMM coupled fluid dynamics, heat transfer and structural physics. Steady-state thermal and static structural simulations were considered.

The overall optimized model consists of more than 1000 parts. The main components included in the FEM model are shown in Fig. 1. From TMM point of view, the CLIC module geometry consists of three main subsystems: MB, DB and vacuum system assemblies. This separation is done to ensure flexible vacuum connections between the subsystems in order to enable an independent beam alignment. In addition to the main components, the geometry also takes into account beam pipes, waveguides and supports. The waveguides are aligned with flexible choke mode flanges (CMF) between the interconnection of the PETS and AS [2]. The main component materials used in the model are copper OFE (RF structures), silicon carbide (supports) and stainless steel (vacuum components).
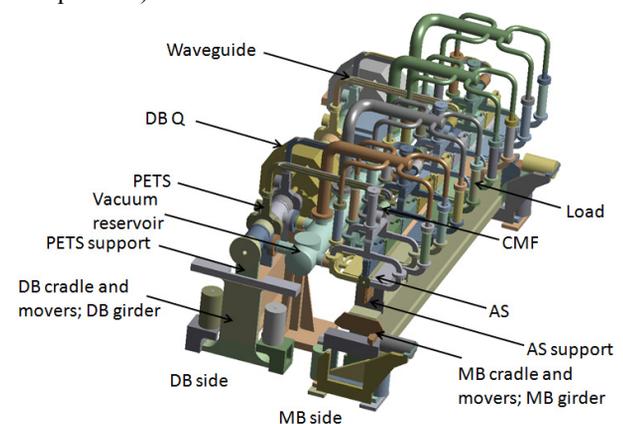
Figure 1: The TMM Configuration Based on the Current CLIC Prototype Module.

Inputs and Assumptions

To obtain the thermal and mechanical response of the structure, the following conditions were assumed:

- Thermal loads into the RF structures;

- Current module layout geometry including real supporting system design;
- All eight AS brazed together as one solid object;
- Vacuum reservoir fixed to the ground;
- MB and DB girders fixed to ground;
- Vacuum reservoir directly connected to the RF structures with flexible bellows;
- Only fixed contacts between components;
- Natural convection of heat to the air.

Contact Modelling and Connections

The contact and joint modelling consists of two main techniques: inclusion of flexible bushing joints to decouple the above-mentioned subsystems and standard ANSYS contacts. Flexible joints are analytically defined as stiffness matrices, which describe the behaviour of the bellows. All standard joints were considered as bonded contacts. Adjacent surfaces of stiffness matrices were thermally coupled.

All contact modelling has been optimized for the lightest possible computation because of the large number of contacts and joints in the model. Sliding effects were omitted in the TMM to keep the solution time acceptable. Moreover, taking sliding effects into account would make the model nonlinear. The current TMM module is constrained longitudinally only from one extremity, whereas the real module is restrained in the middle. This simplification allows for ASs to expand freely along its length and thus, the deformations obtained with TMM should be considered as upper limits, real deformations being most likely smaller.

The current TMM includes also the DB Q, which were omitted from the previous model. The DB Q is mounted on the DB girder and the magnet poles are in contact with the DB drift tube. Thus, the weight of the magnet has an influence to the DB drift tube. The magnet coils are thermally insulated from the poles and the thermal dissipation of the DB Q to the TMM is therefore negligible. For this reason, no cooling condition was applied on the magnets and only the gravitational effect was taken into consideration.

Load Conditions

The induced thermal dissipations are an essential part of the operation of the CLIC RF structures. In the laboratory environment, the thermal dissipation for the RF structures is created by heaters. The total input power for the RF structures in the laboratory is about 3.7 kW which corresponds to the unloaded operation mode of the CLIC module, the worst case scenario.

In the laboratory, for integration reason, the module is not under vacuum and thus, the loading consists only of the thermal loading and gravity, forcing the module to deform during the thermal ramp-up. Including the vacuum condition would naturally cause additional structural deformation of the module. In Table 1 the main cooling parameters are presented.

Table 1: Cooling Boundary Conditions; HTC: Heat Transfer Coefficient

Item	Description	Value
Input flow MB	mass flow	68.6 kg/h
Input flow DB	mass flow	37.4 kg/h
Water input	temperature	25°C
HTC MB	convection to water	5079 W/(m^2·K)
HTC DB	convection to water	1407 W/(m^2·K)
HTC Air	convection to air	4 W/(m^2·K)

The TMM cooling system presented in Fig. 2 consists of distributed water channels, which correspond to the current CLIC cooling design. For the TMM, the water cooling was implemented via the ANSYS FLUID116 element, which is the main element in the thermal-fluid modelling.
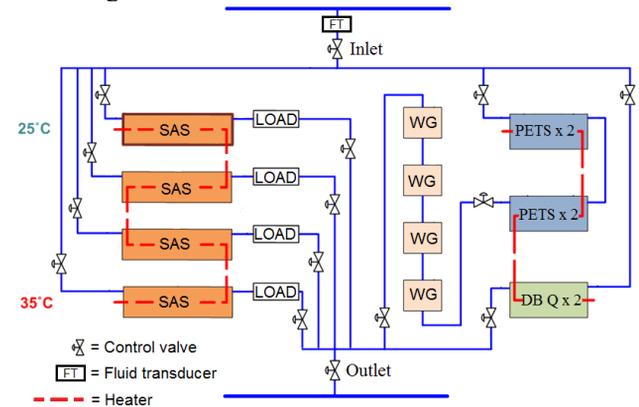
Figure 2: The CLIC module cooling concept; Super AS: two consecutive accelerating structures; WG: waveguide.

Supports

The CLIC RF structures are currently fixed on V-shaped precision supports, which are mounted on the MB and DB girders. The girders are attached to so-called cradles, which serve as articulation point for adjacent girders. The cradles are supported on movers constructed of adjustable high precision linear actuators. The girder end supports are divided into master and slave cradles enabling a coupled support of adjacent girders.

The ANSYS modelling was done to the level of the mounting surface of the lower ends of the actuator. As a result, the estimated stiffness of the actuator support was taken into account. The actuator support, containing six DOF constraints, was reduced to equally stiff linear and torsion springs to ease the computation. Both the master and slave cradle end designs were introduced into the model.

RESULTS AND DISCUSSION

The solution for such a complex model is computationally time consuming and especially the structural FEA requires explicit manual control. The current solution time for the TMM is tens of hours on a

powerful engineering PC used generally for large scale simulations. Based on the module input, both thermal and structural results were obtained. Table 2 summarizes the main thermal and structural results.

Table 2: Thermal and Structural Results of the TMM; G: Gravity, RF: Thermal Load

Item	Value
Max temp. of the module	42°C
Water output temp MB	35.0°C
Water output temp DB	35.0°C
Heat to water / air	3600 W / 120 W
Max. def. at MB line (G)	41 μm
Max. def. at DB line (G)	30 μm
Max. def. at MB line (G, RF)	480 μm
Max. def. at DB line (G, RF)	340 μm

Fig. 3 shows the deformation contour for CLIC prototype module in the TMM model. The maximum deformation occurs at one module extremity, as the structure expands due to thermal effects.
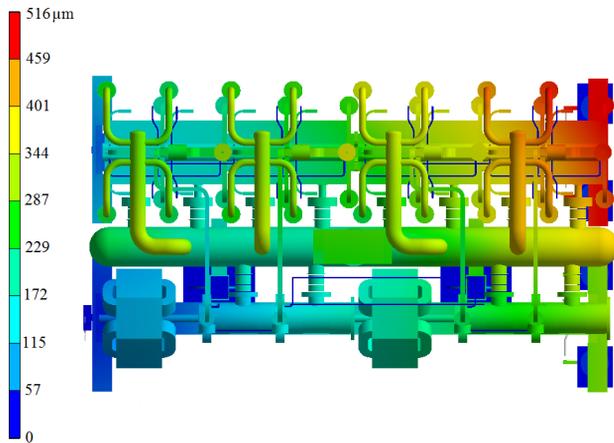
Figure 3: The maximum deformation for the CLIC prototype module obtained with the present TMM model.

The thermal results were cross-checked by comparing the model output power to the input power. The corresponding deviation of the heat balance was less than 1.0 %. Thus the accuracy of the results can be considered as sufficient. The heat dissipation into the environment surrounding via convection was about 60 W/m of a total heat input of 1.85 kW/m. The thermal convection coefficient was considered conservative and thus, higher values can be expected.

According to the results the most significant mechanical distortion origins from the thermal dissipation, which causes the structure to expand mainly in longitudinal direction. The thermal expansion could be shared between more parts by splitting the bonded ASs into separate units. In the current TMM the deformations should be considered as a maximum, because of the used contact modelling. During operation the effect of gravity

is naturally compensated. It should be noted that the vacuum condition is not taken into account in the laboratory module. This will have an influence on the current deformations especially in horizontal direction, where the ASs are interconnected to the vacuum reservoir. However, the current layout includes also vertical vacuum connections, which will compensate the response of the structure under vacuum conditions.

The vertical vacuum connection will not prevent completely from horizontal deformations. For more stable vacuum response, the horizontal force created by the vacuum interconnection, should be compensated with an equivalent one from the adjacent side of the vacuum reservoir and the MB/DB side. Moreover, the supporting system is based on the current approximations and thus, the rigidity of the current system used in TMM is likely to change with the laboratory measurements of the full-scale test module having an immediate impact to the structural behavior of the model.

CONCLUSION

A FE model was successfully built to simulate the current configuration of the CLIC prototype module, enabling an overall assessment of the thermo-mechanical response of the CLIC module. The results are in compliance with the input given, proving thus the accuracy of the model.

Based on the new FEA module configuration, the modelling can be carried out for other types of CLIC modules in the future by modifying the current configuration accordingly. The results of the present model will be cross-checked with the up-coming measurements and improved understanding can be propagated back to the current simulation model.

ACKNOWLEDGEMENT

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