

THERMO-MECHANICAL TESTS FOR THE CLIC TWO-BEAM MODULE STUDY

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Abstract

The luminosity goal of CLIC requires micron level precision with respect to the alignment of the components on its two-meter long modules, composing the two main linacs. The power dissipated inside the module components introduces mechanical deformations affecting their alignment and therefore the resulting machine performance. Several two-beam prototype modules must be assembled to extensively measure their thermo-mechanical behavior under different operation modes. In parallel, the real environmental conditions present in the CLIC tunnel should be studied. The air conditioning and ventilation system providing specified air temperature and flow has been installed in the dedicated laboratory. The power dissipation occurring in the modules is being reproduced by the electrical heaters inserted inside the RF structure mock-ups and the quadrupoles. The efficiency of the cooling systems is being verified and the alignment of module components is monitored. The measurement results will be compared to finite element analysis model and propagated back to engineering design. Finally, simulation of the most possible CLIC machine cycles is accomplished and preliminary results are analysed.

INTRODUCTION

CLIC [1] is a multi-TeV normal conducting electron positron collider. The layout foresees the construction of two 21-km long main linacs within a total collider length of about 48 km. Both the main and the drive linac will be of 2 meters long repetitive units.

In CLIC, 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). The power is drawn from the DB, using Power Extraction and Transfer Structures (PETS), and is transferred to the MB, through a dedicated RF network. The estimated power dissipation per module is 7 kW during normal operation modes; therefore a dynamic heat load is created.

A finite element model (FEM) of a two-beam module is required, to predict the temperature and displacement of the various components, due to thermal and vacuum loads, leading to beam misalignment. As the CLIC stability requirements are a major factor, models have been already created; however, the mathematical model has to be validated with the necessary experimental data.

One two-beam prototype module has already been assembled [2] and its thermo-mechanical behaviour has been studied under different operation modes. The thermo-mechanical model has been compared to the

experimental values and the cooling system has been validated.

In this paper, the experimental procedure followed to study the thermo-mechanical behaviour of two-beam modules is described and the comparison with the numerical results is presented.

EXPERIMENTAL TEST AREA

The first CLIC prototype module type 0 was assembled and installed in the laboratory (Fig. 1). Its objective is to be tested without RF, beam or vacuum conditions. The estimated power dissipation occurring inside the module is reproduced by electric heaters, which can be adjusted to any loading scenario required. The resulting heat is removed by the water cooling system integrated in the RF structures. The water is then cooled by an external chiller, providing a desired constant temperature. The control of the cooling system is able to adjust the temperature of each component [1]. The ambient conditions inside the CLIC tunnel are reproduced in the laboratory by an air conditioning and ventilation system which can achieve a wide range of operating conditions, in terms of both air temperature and speed. During the experimental tests, the resulting temperature distribution inside the module is measured by sensors (accuracy 0.1 K), positioned on multiple positions along every component, as well as in the cooling circuit and in ambient air. The data are acquired and a user friendly interface, created in LabVIEW software, allows for quick monitoring and control of the system parameters, such as water flow, pressure and heating power.

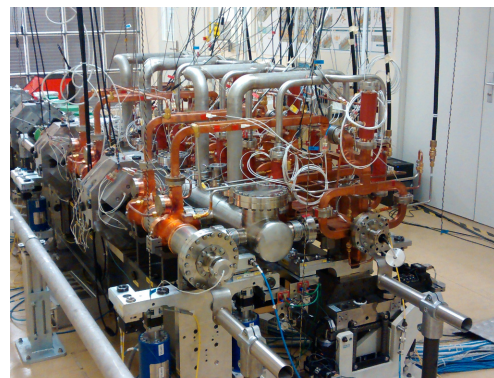


Figure 1: Two beam module, type 0.

The influence of power dissipation and of various ambient conditions on the beam alignment can be studied through two measuring systems. Firstly, the displacement of the two girders is constantly monitored through a Wire Positioning System (WPS) with 5 μm accuracy. Secondly,

the various beam components (accelerating structures, PETS and quadrupoles) are tracked with a laser system with 10 μm accuracy on short range, thus allowing the exact measurement of the movement of each component.

MODEL DESCRIPTION

A finite element model has been developed with ANSYS, in order to investigate the thermo-mechanical behaviour of the CLIC modules and to foresee the alignment of the components [3]. The geometry used is that of the CLIC prototype module type 0 with some simplifications, to ease the meshing process and reduce computational time (Fig. 2). These include deleting small features, filling holes and using one-dimensional elements on the cooling channels.

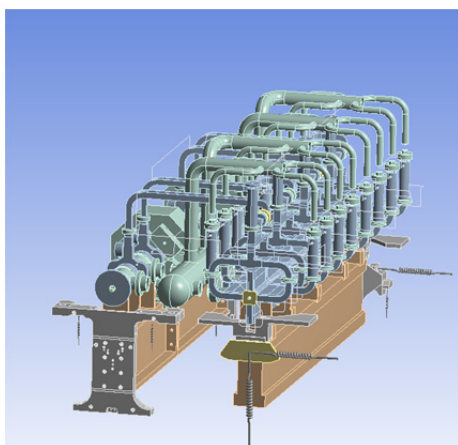


Figure 2: Two beam module FEA model. The RF components (grey) and the vacuum network (green) are supported by the girders (brown).

Each of the two girders has three linear actuators, two vertical and one horizontal, which create five degrees of freedom, represented in the model as springs. Super Accelerating Structures (SAS) and PETS are placed on the girders V-supports, with fixed and sliding contacts in the middle and on the extremities, respectively. The vacuum reservoir is connected with the PETS and the SAS with bellows that have been modelled by using stiff elements with six degrees of freedom (axial, angular, lateral and torsional). The heating system is introduced in the model with two heater elements, placed inside the RF structures, as in the experiment. The water cooling of the MB is divided in four branches, one for each SAS and one for each PETS. The line elements represent accurately the temperature and pressure distribution in the cooling circuits. The solid parts are connected with the fluid elements through surface elements. In order to have a direct comparison with the experimental results, temperature and displacement probes were placed at the same position as the real sensors [4].

TESTING PROCEDURE

The testing procedure consisted of three different phases. First, a series of validation tests was conducted, to evaluate the accuracy of the results compared to analytical calculations. Subsequently, five initial steps have been realised [5], gradually changing the ambient conditions and measuring the effect on the module. Later, the applied power was increased reaching the nominal values [6]. Finally a series of machine cycle operations has started to study all the possible operating states of the CLIC machine at different ambient conditions, including the transients between operation modes.

Validation Tests

In order to validate the experimental results, a series of tests was conducted. Firstly, the cooling circuits were tested independently to verify that the water and power flow is evenly distributed. Subsequently, the input power from the heaters was measured to calibrate their output to nominal values. Furthermore, it was checked the total input power matches the dissipated power to air and water [7].

Machine Cycles

Finally, a series of tests started, that would simulate different operating scenarios, including the studies of the transitions between two operating states. The states are summarized below [8]:

- Mode 1: Nominal Operation where the power is increasing according to machine start up procedure. Firstly the DB quadrupoles are powered, with no active beams. Subsequently the DB is activated and once the system reached steady condition, the MB is also activated.
- Mode 2: At this mode a SAS breakdown is simulated. Starting from the nominal operation state, the SAS break down, their power stops and the RF loads power is reduced. The PETS on/off mechanism [9] is activated and the PETS power is reduced to 25%. The test continues with the reverse procedure until power is restored and nominal operation state is reached.
- Mode 3: The scenario of PETS breakdown is simulated. The procedure is similar to Mode 2, starting and finishing at the steady state nominal operation mode.

Modes 2 & 3 are possible either in the case of a breakdown in a single module or in the case of a total loss of MB or DB in the CLIC machine, respectively. The tests will be repeated at several ambient speed-temperature pairs, to study the module stability at various tunnel conditions.

Table 1: Temperature (°C) Results at Steady State Conditions, for Experiment and Simulation

Component	No beams, Powered up DBQ			DB operational, no MB			DB and MB operational		
	Measured	FEM	Diff.	Measured	FEM	Diff.	Measured	FEM	Diff.
SAS#1	23.7	24.7	1.0	29.5	31.1	1.6	29	30	1.0
SAS#2	24.3	24.7	0.4	32.2	32.4	0.2	31.5	31.1	-0.4
SAS#3	24.4	24.7	0.3	32.2	32.2	0.0	31.5	30.9	-0.6
SAS#4	24.2	24.7	0.5	32.2	32.5	0.3	31.5	31.2	-0.3
PETSu#1	22.7	24	1.3	25.9	28	2.1	26.4	28	1.6
PETSu#2	23.2	23.9	0.7	29.4	29.9	0.5	30.1	29.9	-0.2
DBQ#1	37.6	39.3	1.7	34.4	32.2	2.2	33.2	31.8	1.4
DBQ#2	36.1	38.4	2.3	33.6	33.9	-0.3	31.8	33.6	-1.8

PRELIMINARY RESULTS

Experiments for Mode 1 have already been conducted and analysed, along with their respective simulations. Relevant results are shown in Table 1. The temperature is measured on each component and the average value is given. The measured and simulated (FEM) temperatures are in agreement, considering the sensor accuracy of 0.1 K.

TRANSIENT CONDITIONS

During the machine cycles tests, the transients were studied. The time constants indicate the time needed from a component to reach 63.2% of the desired state during heating up and they are presented in Table 2. Time constants are an indicator of how fast the components can change operating modes.

Table 2: Time Constants of Various Components [10]

Component	Time constant τ (min)
SAS	5.1
PETS	17.5
DBQ	55.0

CONCLUSIONS

Structural deformations due to thermal loads related to the RF power dissipated inside the modules affect the alignment of the linacs and therefore the resulting luminosity performance.

A testing program has started in order to validate the thermo-mechanical properties of a prototype module on every operating mode. At the same time, the already developed FEM model was updated and the results were compared to the experimental results. The transients between subsequent modes were also studied during the experiments.

A good agreement between the complex simulation model and the temperature measurements has been established. Displacement data have been taken as well and the comparison with the model is under finalisation.

Results are always propagated back for model improvements. More prototype modules will be assembled and tested in the future, allowing for better

understanding of the CLIC machine, including vacuum and RF loading.

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REFERENCES

- [1] M. Aicheler et al., CLIC Conceptual Design Report (CDR), Vol. 1, <http://cds.cern.ch/record/1500095>.
- [2] D. Gudkov et al., “Experience on Fabrication and Assembly of the First CLIC Two-Beam Module Prototype”, WEPFI055, IPAC2013, Shanghai, May 2013 (2013); <http://jacow.org>.
- [3] R. Raatikainen et al., “Improved Modeling of the Thermo-mechanical Behavior of the CLIC Two-Beam Module”, TUPPR033, IPAC2012, New Orleans, USA, May 2012 (2012); <http://jacow.org>.
- [4] S. Griffet et al., “Strategy and validation of fiducialisation for the pre-alignment of CLIC components”, WEPPD073, IPAC2012, New Orleans, USA, May 2012 (2012); <http://jacow.org>.
- [5] F. Rossi et al., “Study of the thermo-mechanical behavior of the clic two-beam modules”, WEPFI056, IPAC2013, Shanghai, China, May 2013 (2013); <http://jacow.org>.
- [6] F. Rossi, “Thermal tests Program for CLIC Prototype Module Type 0”, <https://edms.cern.ch/document/1277574/>.
- [7] Y. A. Cengel, *Heat and Mass Transfer, A Practical Approach*, (McGraw-Hill, 2007).
- [8] E. Adli, “Studies of Selected Failure Modes in the ILC and CLIC Linear Colliders”, EUROTeV, 2009.
- [9] I. Syratchev et al., “High power operation with beam of a CLIC PETS equipped with on/off mechanism”, TUPPR019, IPAC2012, New Orleans, USA, May 2012 (2012); <http://jacow.org>.
- [10] E. Daskalaki et al., “CLIC Module: Nominal Operation Mode, Temperature Results”, <https://edms.cern.ch/document/1377008/1>.