

STUDY OF THE THERMO-MECHANICAL BEHAVIOR OF THE CLIC TWO-BEAM MODULES

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Abstract

The final luminosity target of the Compact Linear Collider (CLIC) imposes a micron-level stability requirement on the two-meter repetitive two-beam modules constituting the main linacs. Two-beam prototype modules are being assembled to extensively study their thermo-mechanical behaviour under different operation modes. The power dissipation occurring in the modules will be reproduced and the efficiency of the corresponding cooling systems validated. At the same time, the real environmental conditions present in the CLIC tunnel will be studied. Air conditioning and ventilation systems have been installed in the dedicated laboratory. The air temperature will be changed from 20 to 40°C, while the air flow rate will be varied up to 0.8 m/s. During all experimental tests, the alignment of the RF structures will be monitored to investigate the influence of power dissipation and air temperature on the overall thermo-mechanical behaviour.

This test program will allow for better understanding the behaviour of the CLIC modules and the results will be propagated back both to the numerical modelling and the engineering design.

INTRODUCTION

CLIC [1] is a multi-TeV normal conducting electron positron collider, whose current design foresees the construction of two meters long repetitive modular units for the two 21-km long main linacs, resulting in a total collider length of about 48 km.

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, that is drawn using Power Extraction and Transfer Structures (PETS), is transferred from the DB to the MB through a dedicated RF network (Figure 1). During normal operation modes, the estimated power dissipation per module is about 7 kW [2], thus resulting in time-varying non-uniform thermal fields.

The thermo-mechanical modelling of CLIC two-beam modules is then useful to predict structural deformations affecting the final alignment of modules which will be compensated by re-adjustments with the linear actuators integrated in the supporting system. Finite element models of CLIC modules have been already developed in the past [3][4], nevertheless the experimental validation of this numerical modelling is necessary.

Two-beam prototype modules are, therefore, being assembled to extensively study their thermo-mechanical behaviour under different operation modes. The power dissipation occurring in the modules is reproduced according to the baseline values and the efficiency of the corresponding cooling system is validated.

In this paper, the experimental test area developed to study the thermo-mechanical behaviour of two-beam modules is described and the thermal test program started for the first CLIC prototype module type 0 is presented.

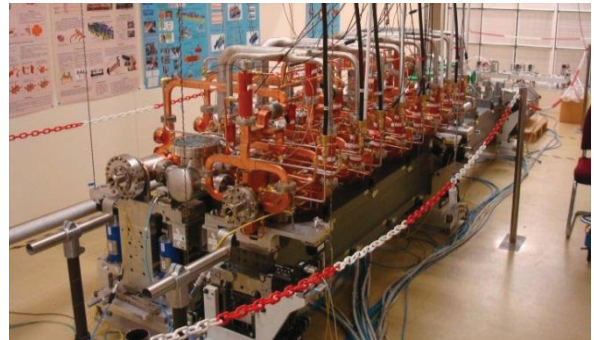


Figure 1: The CLIC prototype module type 0 assembled in the experimental test area for the thermal test program.

EXPERIMENTAL TEST AREA

The thermal test program, started in early 2013 and aimed at validating the current CLIC baseline module, foresees the construction of four prototype modules representing the main CLIC two-beam module types. These prototype modules, where simplifications have been implemented as the modules will not be tested without RF and beam, are being assembled in a dedicated laboratory at CERN.

In the middle of 2012, the first CLIC prototype module type 0 was assembled and installed in the laboratory [5] (Figure 1). The estimated power dissipation occurring inside the module is reproduced by electric heaters, while the resulting heat is removed by the cooling system integrated in the RF structures. The temperature and air speed conditions inside the CLIC tunnel are reproduced in the laboratory by an air conditioning and ventilation system designed for this purpose. During the experimental tests, the resulting temperature distribution inside the module can be measured and the influence of power dissipation and of different ambient conditions on the beam misalignment can be studied. A more detailed description of heating, cooling and air conditioning system is given in the next sections.

Heating System

The power dissipation inside the CLIC prototype modules is reproduced by electric heaters; the main requirements for the CLIC prototype module type 0 are summarized in Table 1, while the heating scheme is shown in Figure 2. Straight tubular heaters are used for the AS and PETS units, while cartridge heaters for the Drive Beam Quadrupoles (DBQ); silicon rubber heaters are used to reproduce power dissipation for the Compact Loads (CL).

Two different control methods are used for regulating the power of the heaters: Solid State Relays (SSR) have been chosen for heaters of the AS, PETS and DBQ, while Semi-Conductors Relays (SCR) for the CL. The aim of this specific choice is to test and compare the two different systems for controlling the power. Temperature interlocks are integrated inside the electrical system as well; if the temperature increases above a certain value due to an unexpected malfunction of the system, the electricity supplied to the heaters is cut.

Table 1: The Power Dissipation for the CLIC Prototype Module Type 0.

RF structure	Heat power (W)
AS	410
PETS unit	220
DBQ	150
CL	150

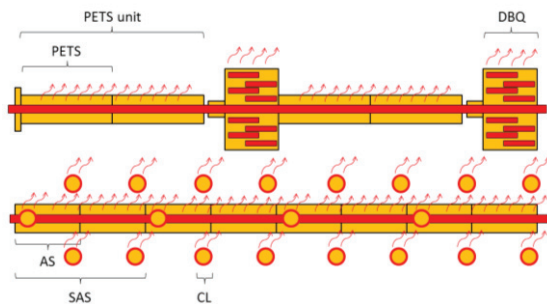


Figure 2: The heating system layout for the CLIC prototype module type 0.

Water Cooling System

The power dissipation generated inside the RF structures of two-beam modules is being removed by integrated water cooling channels; the cooling scheme of the CLIC prototype module type 0 is shown in Figure 3. It is worth noting that the AS and PETS units are cooled in parallel, while the corresponding loads are cooled at the end. Solenoid control valves are regulating the flow rate inside each line of the cooling system and the temperature of the outlet water after each double AS (so-called SAS) and PETS unit can be regulated via a Proportional-Integral-Derivative (PID) controller adjusting the position of these valves. The water is supplied by an external

water chiller at a desired constant temperature, while the inlet pressure is set via a pressure regulating valve.

The temperature sensors are placed throughout the system to monitor the temperature of both the RF structures and the cooling pipes.

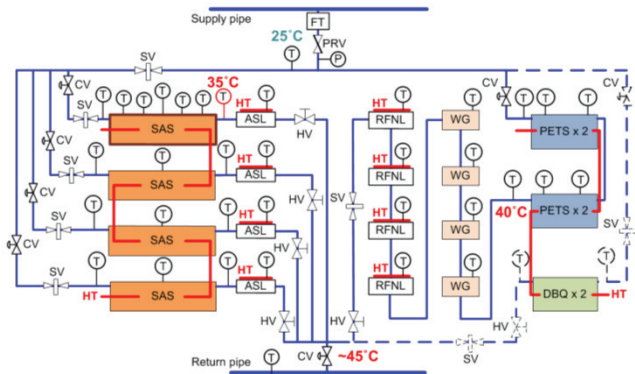


Figure 3: The cooling system layout for the CLIC prototype module type 0 (FT=flow transducer, PRV=pressure regulating valve, P=pressure transducer, T=temperature sensor, HT=heater, CV=control valve, SF=safety valve, HV= hand valve).

Air Conditioning and Ventilation System

The influence of the ambient conditions on two-beam module alignment is studied by reproducing the same air temperature and speed as in the CLIC tunnel. Based on CLIC requirements [1], an air conditioning and ventilation system has been implemented for this purpose. During the thermal tests, the room temperature can be changed from 20 to 40°C, while the air speed can be varied from 0.2 to 0.8 m/s. The layout of the Heating, Ventilation and Air Conditioning (HVAC) system is shown in Figure 4. Notice that air circulation around the prototype modules is forced by two sets of fans installed on the two sides of the laboratory; the first set of fans is pushing the air towards the modules, while the second one is sucking it from the opposite side. Air is recirculating through a lateral corridor where cooling and heating coils are installed for regulating the room temperature.

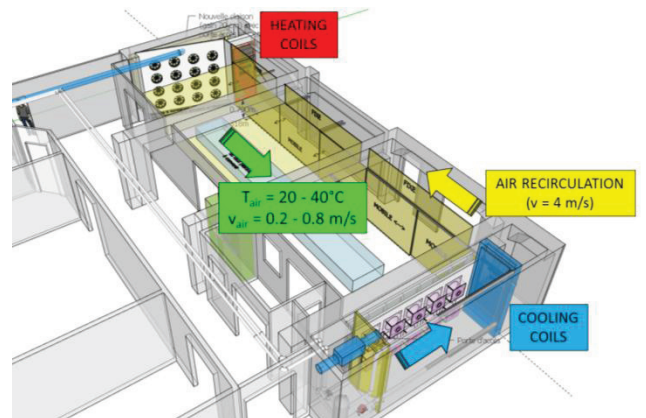


Figure 4: The HVAC system for reproducing the CLIC tunnel conditions during the thermal tests.

Data Acquisition and Control System

The cooling system and the temperatures of the RF structures are continuously monitored and recorded throughout the tests. Additional thermocouples are installed around the prototype modules to measure the air temperature in different planes transverse to the beam direction. Pressures and flow-rates of the water cooling system are measured in real time as well.

The data acquisition process is managed through a user friendly interface created in LabVIEW, while the transducer signals are acquired using National Instruments (NI) CompactDAQ system. In particular, the NI DAQ modules for thermocouples and PT100 sensors allow for conditioning and acquiring the signals at the same time. The NI output signal modules are used to control the duty cycle of the electric heaters as well as the opening position of the control valves. The parameters of the PID controller for regulating the outlet temperatures of the cooling system are defined through the same LabVIEW interface.

THERMAL TEST PROGRAM

Five different steps have been defined for the thermal test program that already started for the CLIC prototype module type 0 [6]. During the experimental tests, ambient and load conditions are changed gradually to study their influence on the beam alignment. Laser tracker and wire positioning system (WPS) system are used during each step for measuring the alignment of the RF components in steady-state conditions [7]. The parameters taken into account for each step are summarized below:

- STEP 0: the air speed is changed gradually up to 0.8 m/s to study the influence of vibrations induced by the air circulation on the WPS measuring system.
- STEP 1: the room temperature is varied from 20 to 40°C, while no active heating and cooling is present for the MB and DB. The temperature and the alignment of the RF structures are measured.
- STEP 2: the SAS and corresponding loads are heated gradually up to the maximum power, while the water cooling system is removing the heat generated inside; the PETS and DBQ are not heated. The temperature and the alignment of the RF structures are measured and these measurements are repeated for different values of air temperature (20 and 40°C) and speed (0.4 and 0.8 m/s).
- STEP 3: similar to STEP 2, but the heating and cooling are active for the PETS and DBQ only and not for the SAS.
- STEP 4: both MB and DB structures are heated gradually up to the maximum power reported in Table 1, while the water cooling system is removing the heat generated inside. The temperature and the alignment of the RF structures are measured and these measurements are repeated for different values of air temperature (20 and 40°C) and speed (0.4 and 0.8 m/s).

CONCLUSIONS

Micron level stability of the two-meter repetitive modules constituting the two main linacs is one of the most important requirements to achieve the luminosity goal for the CLIC collider. Structural deformations due to thermal loads and related to the RF power dissipated inside the modules affect the alignment of the linacs and therefore the resulting luminosity performance.

Finite elements models (FEM) have been previously developed to investigate the thermo-mechanical behaviour of the CLIC modules and to foresee corrective actions to compensate induced misalignments by means of re-adjustments of the supporting system.

Full-scale prototype modules are being assembled in a dedicated experimental test area to study their thermo-mechanical behaviour. Experimental tests on the CLIC prototype module type 0 have been started in early 2013 to validate the results of the FEM study and the improved understanding will be propagated back to the model.

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