Prototypes with descriptive report (technical, design and fabrication) of the hardware prepared for the test module

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Abstract:
The present report describes the main components of the CLIC Two-Beam Module prototype and the corresponding fabrication process from the engineering design to the assembly. The aim is to validate all the technical systems (e.g. RF, vacuum, alignment, cooling) in an integrated and compact approach. This module will undergo to intensive thermo-mechanical tests to simulate the CLIC operating conditions.
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1. EXECUTIVE SUMMARY

The CLIC two-beam module prototype has been designed, fabricated and assembled to conduct a test program, aimed at the validation of all the technical systems (e.g. RF, vacuum, alignment, cooling) in an integrated and compact approach. This prototype will undergo intensive thermo-mechanical tests to simulate the CLIC operating conditions.

The aim of the prototype is also to validate the fabrication strategy of the different components, and to develop the assembly procedures of the CLIC two-beam module. This information will be used for the design of the series production.

To simplify the manufacturing and reduce the cost of the prototype some of the ultra-precise RF components are replaced by mock-ups specially designed to provide reliable test results. During the fabrication of the mock-ups, several solutions for further design and production optimization are found and will be implemented in the next prototypes. The assembly sequence and serviceability are validated as well. They will be improved for the next prototypes thanks to the optimization of the component design and to the development of new auxiliary equipment.

The lesson learned from the assembly of the first module has been applied to the second module of this type, currently under fabrication until the end of summer 2013.

2. INTRODUCTION

This report focuses on the first two-beam module [1] prototype type 0 which has been built for a test program to be conducted without RF and without beam in a dedicated laboratory. The aim of this first prototype is to show the feasibility of the proposed solutions for the different technical subsystems, such as RF, supporting, pre-alignment, vacuum and cooling systems. Also the feedback from the experience of the production and assembly of different components is received and integrated in the future two-beam modules. The real RF components have very high machining complexity and production cost. There are several parallel programs to test the proposed solutions for RF components. To simplify the production, reduce the cost and avoid overlapping with other test programs, some of the real components were replaced by mock-ups whenever possible. The integration of subsystems requires the development of dedicated assembly procedures due to extreme compactness of the two-beam module. The description of each subsystem with corresponding mock-ups, their engineering design as well as assembly procedure of the full module is described. The test program with the list of dedicated tests is also recalled.
3. CLIC TWO-BEAM MODULE EXPERIMENTAL PROGRAM OVERVIEW

The two-beam linear accelerator being studied at CERN involves the design and integration of many different technical systems, tightly bound and influencing each other. For the construction of the two main linacs (each of them composed of two beams), it has been decided to proceed with a modular design. The repetitive 2-m long two-beam modules of a few types were defined [2]. A 3D view of a typical module is shown in Fig. 1.

![Fig. 1: Typical two-beam module.](image)

The prototype test program consists of two subprograms:

A) TEST PROGRAM IN THE LABORATORY WITHOUT BEAM

The program foresees the construction of four prototype modules assembled together with the following starting sequence of types (T): T1-T0-T0-T4. The corresponding layout is shown in Fig. 2. Their aim is to show the feasibility of the proposed technical solutions for the RF, supporting, pre-alignment, stabilization and vacuum systems. The cooling system has been built and it will be used to simulate the thermo-mechanical behaviour of the entire module. A transport test representing the real transport in the tunnel will be also carried out.
B) TESTS IN THE CLIC EXPERIMENTAL AREA (CLEX) WITH BEAM

A second generation of three additional modules, taking into account the lessons learnt during the string test study in the laboratory, are being prepared for future test with beam in the CLEX area of CTF3 (CLIC Test Facility).

The schematic layout of the CLEX prototype modules (TM) installation is shown in Fig. 3. Testing of the AS alignment on girder by using probe beam and the wakefield monitors (WFM) in low- and high-power conditions and after a breakdown is of prime importance. In addition, the breakdown effect on the beam is going to be explored. Besides that, feasibility of alignment and stabilization systems in a dynamic accelerator environment must be confirmed. The RF network phase stability, vacuum system performance with RF and cooling system dynamics due to beam loss and power flow changes also need to be verified.

4. SUPPORTING AND ALIGNMENT SYSTEM

All the RF components of the CLIC Two-Beam Modules are installed and aligned on an innovative supporting and alignment systems. The supporting system is mechanically articulated throughout the entire length of the DB linac. The mechanical continuity of the MB supports is interrupted only by the individual supports of the MBQs. The supporting system is constituted out of several components (girders, V-shaped supports, cradles, U-clamps, etc.) to fulfil the various technical requirements for support and stabilization of the RF components.

The alignment and repositioning system is constituted of actuators, alignment plates, cWPS (capacitive Wire Positioning System) and oWPS (optical Wire Positioning System) sensors and a HLS (Hydraulic Levelling System) network.
4.1. GIRDERS

The fundamental supporting components of such a system are the so-called girders. The girder design constraints are mainly dictated by the beam physics and RF requirements. The position of the girders is monitored and re-aligned. The length of the girder for both MB and DB of the Module Type-0 is 1946 mm and its structural material is SiC (silicon carbide).

For the two-beam modules in the lab, several manufacturing techniques and strategies [3] have been explored.

For the MB girders an integrated approach has been adopted, comprising both, supporting and positioning systems. The girders are made of hollow tubes glued together to form the entire structure.

For the DB girders, the positioning system was supplied separately. The girders are made of two sections brazed together.

Another significant difference in the girder manufacturing consists of the fact that the girders of the MB have been fabricated with a pre-stressed configuration, whereas the DB girders have been grinded without any pre-stress. Therefore mock-up loads mounted on the MB girders were used to commission the MB girders as shown in Fig. 4.

![Figure 4: From left to right: DB and MB girders.](image)

4.2. V-SHAPED SUPPORTS

The V-shaped supports (see Fig. 5) provide the interface between the RF components and the supporting system underneath. Consequently, they have to be fixed and well-positioned on the top side of the girder. The V-shaped supports for the DB were brazed on the girder, instead the MB V-shaped supports were glued and screwed. As for the girders, all V-shaped supports of the Module Type-0 are made of SiC.

![Figure 5: From left to right: DB and MB V-shaped supports.](image)
The V-shaped supports shall insure the positioning of the RF components so that the particle beam passes through the axis (see Fig. 6). The tolerance field of this axis is represented by a cylinder of 10 μm diameter. The positioning of the axis is well-defined and controlled according to the precisely referenced interfaces on the girder and cradles.

![Figure 6: Schematic representation of the tolerance field for the beam axis of the RF components.](image)

4.3. CRADLES, ACTUATORS AND ALIGNMENT SENSORS

The girder itself is supported on its extremities by the so-called cradles (see Fig. 7), which are mechanically connected to the actuators and house the alignment sensors. Each girder extremity is equipped with one cradle. The surfaces with which the cradles come in contact to the girders are machined with micrometric precision. The girder extremity is always rigidly connected to the cradle.

![Figure 7: Cradle assembly including actuator.](image)

The repositioning of the girders is achieved with the help of these actuators. The actuators are used to provide the vertical and lateral displacements to the corresponding cradles. Three (3) high resolution linear actuators are assembled on each (master) cradle as illustrated in Fig. 7 and 8. The actuators have a required displacement accuracy of 0.5 μm over ±3 mm moving range and they use a high resolution stepper motor for acquiring the necessary torque. All movements are controlled by absolute position sensors of 50 nm resolution.
Figure 8: Cradle assembly including actuators and alignment sensor.

The cradles are equipped with alignment sensors and inclinometers, as illustrated in Fig. 8. The interfaces of the cradle on which such sensors are assembled have also micrometric precision. Each cradle hosts the following instrumentation:

- 1 inclinometer,
- 1 capacitive Wire Positioning System (cWPS) sensor,
- 1 optical Wire Positioning System (oWPS) sensor.

The combination of measurements of the before mentioned sensors provides the accurate positioning of the beam axis. Therefore, the alignment of the collider and its successful operation are reassured.

5. RF STRUCTURES AND NETWORK

The first module T0 in the Lab is equipped with mock-ups for RF components and RF structures. Their main features are listed below:

- Simplified internal RF geometry;
- Real mechanical interfaces to demonstrate manufacturing and assembly procedures;
- Real reference surfaces for positioning and alignment, therefore the same accuracy;
- For the reliable test of the vacuum system, the surface area of the internal volume coincides with the surface area of the RF volume of the real structures;
- The cost of the components reduced, while keeping the necessary functionality for the tests.

5.1. ACCELERATING STRUCTURES

On the first prototype module T0 in the Lab, a 2 meter long accelerating structure mock-up is used (see Fig. 9). In order to reduce the price of the components and simplify their production, the real RF geometry was replaced by a simplified shape.
The assembly of the accelerating structure mock-up consists of several brazing, electron beam welding and TIG welding operations (see Fig. 10).

All the parts of the mock-up were machined within the required tolerance of 10 μm, and the first structure was successfully assembled and installed on the MB girder.

5.2. PETS

All the PETS mock-up (Fig. 11) interfaces correspond to those designed for CLIC module PETS. The assembly procedure is very similar. It consists of brazing, electron beam welding and TIG welding operations (see Fig. 12). In order to reduce the price of the component, the
high-precision octants were replaced by a copper block with holes and slots to provide the same internal volume and surface area for the future vacuum test.

**Figure 11.** PETS mock-up assembly.

**Figure 12.** From left to right: PETS pre-assembly; EBW of PETS couplers.
5.3. RF NETWORK

The RF network mock-up connects PETS and AS (see Fig. 13). The internal geometry of the choke mode flange, hybrid and splitter was simplified to reduce the component cost. The main mock-up features are listed below:

- Bended waveguide WR90, with relaxed tolerances;
- Real cooling system of waveguides;
- RF symmetrical flanges for the RF interfaces.

![RF Network](image13)

**Figure 13. RF network.**

Assembly of the RF network mock-up consists of brazing (see Fig.14), intermediate machining and welding operations.

![RF Network](image14)

**Figure 14. RF Network mock-up after final brazing operation**
6. VACUUM SYSTEM

The vacuum system consists of central vacuum tank (see Fig. 15), located between main beam and drive beam, and four vacuum network subassemblies (see Fig. 16), forming the so-called vacuum network. They connect the central vacuum tank to the accelerating structure loads. One ion pump and two NEG cartridge pumps are installed on this central tank to provide the required vacuum level of $10^{-9}$ mbar. The components of the vacuum system ready for assembly are shown in Fig. 17.

Part of the vacuum system is also the vacuum chamber inside the drive beam quadrupole (DB quadrupole) as shown in Fig. 18.

![Central vacuum tank](image1)

*Figure 15. Central vacuum tank.*

![Vacuum network](image2)

*Figure 16. Vacuum network.*

The vacuum system components are produced out of bended stainless steel tubes welded together. The UHV interconnection flanges are used for the interfaces.

![Central vacuum tank and vacuum networks](image3)

*Figure 17. From left to right: central vacuum tank, vacuum networks.*
7. DRIVE BEAM MAGNET SYSTEM

For the first prototype module, it was decided to replace the real quadrupoles by dedicated mock-ups. These mock-ups have the same interfaces and weight as the real ones. The 3D model and mock-up are shown in Fig. 19.

The mock-up is produced out of stainless steel to provide the same weight as a real DB quadrupole.

8. COOLING SYSTEM

Each prototype module component has a cooling system [4] equipped with standard Swagelok connectors, which are connected via copper cooling tubes following the agreed cooling layout (see Fig. 20). The cooling system will be able to extract about 8 kW dissipated power per module.
9. INSTRUMENTATION SYSTEM

BPM mock-ups mechanically connected to PETS on one side and to the DB quadrupole vacuum chamber on the other side were designed with the same external volume as the real ones. Fig. 21 illustrates the sub-assembly composed of PETS interconnection, BPM and vacuum chamber.

![Figure 21](image)

Figure 21: From left to right: PETS connection interface, BPM mock-up, DB vacuum chamber.

10. ASSEMBLY OF THE MODULE

The assembly of the prototype module started with the installation of the supporting and alignment system on the floor. The installation of other components was done following the assembly flowchart, as detailed shown in Annex 1. Several positioning tests were done throughout the different installation phases [3, 4]. Actuators and girders have been successfully qualified. After installing the RF accelerating structures and PETS on the respective girder V-shaped supports, the vacuum system and RF network were connected to them. One of the last operations was the installation of the cooling system.
11. TEST PROGRAM DESCRIPTION

The dedicated laboratory at CERN was equipped in order to perform all the tests planned on the first prototype module and the ones under assembly. The planned tests are the following:

- Alignment measurements during the assembly
- Control of the articulation points of the supporting and alignment system with installed module components;
- Thermal tests;
- Vacuum tests (1st part);
- Alignment measurements under vacuum;
- Vacuum tests (2nd part);
- Transport tests.

The detailed thermal tests program for the CLIC Prototype Module Type 0 is available in EDMS [5].
12. FUTURE PLANS / CONCLUSION / RELATION TO OTHER EUCARD WORK

The assembly of the first prototype module has been completed. The different technical systems have been integrated and, although the module will not be tested with beam and RF, all the mechanical interfaces have been kept equal to those for the real CLIC module. The same applies for the vacuum internal volumes.

The integration of all technical system in a very compact module was very challenging. We had the possibility to learn about fabrication and assembly procedures of micro-precision components. During the fabrication and assembly of the prototype module and subsystem components, future design optimization solutions were investigated. As an example, some brazing operations of the RF network could be replaced by TIG welding. This would lead to reduction of the fabrication time and of the final cost.

The thermo-mechanical validation is currently under way. The thermo-mechanical tests for the first prototype module started at the end of 2012. All details are described in the report prepared for the deliverables D9.2.1.

The second prototype module is under fabrication and is going to be installed by the end of current year 2013. The improvements based on the experience from the first prototype module assembly have been implemented.

In total a string of four prototype modules will be assembled in the dedicated laboratory for technical system validation and thermo-mechanical testing.

Three additional fully fledged modules are foreseen to be tested with beam and RF in the CLIC Experimental Area. The first one is currently under fabrication and the assembly will be completed by the end of 2013.

13. THE FEEDBACK FROM COMPONENTS MANUFACTURING, MODULE ASSEMBLY AND TESTS WILL BE USED IN FURTHER DEVELOPMENT OF THE CLIC MODULES.

AKNOWLEDGEMENTS

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14. REFERENCES


ANNEX 1: GLOSSARY

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<td>AS</td>
<td>Accelerating structure</td>
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<td>CL</td>
<td>Compact Load</td>
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<td>DB</td>
<td>Drive beam</td>
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<td>DBQ</td>
<td>Drive Beam Quadrupole</td>
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<tr>
<td>MB</td>
<td>Main beam</td>
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<tr>
<td>MBQ</td>
<td>Main Beam Quadrupole</td>
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<td>PETS</td>
<td>Power Extraction and Transfer Structure</td>
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<td>PETSu</td>
<td>PETS unit</td>
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<td>RFN</td>
<td>RF network</td>
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<td>SAS</td>
<td>Super Accelerating Structure</td>
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<td>Waveguide</td>
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ANNEX 2: ASSEMBLY FLOWCHART