STATUS OF CLIC MAGNETS STUDIES

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Abstract

R&D Magnets activities for CLIC Project have now entered a new phase with the design & manufacturing of several prototypes investigating the most challenging aspects of the Project. As concerning the CLIC magnet system, challenges can be related to pure technical aspects (e.g. the Final Focus QD0 quadrupole where a gradient of more than 550 T/m is requested) or to industrial production choices (e.g. the main beam quadrupoles where compactness and high tolerances are requested for the mechanical assembly, or the drive beam quadrupoles where a production of more than 40000 units is needed). In this paper the key aspects of the magnets presently under study such as the main beam, drive beam and final focus quadrupoles will be presented and discussed. Available results on prototypes and measured performances will also be addressed.

INTRODUCTION

The "Compact Linear Collider" Project (CLIC) is getting acceleration along its R&D phase [1]. Achieving the next milestones like the conceptual design report (CDR) that will be released at the end of 2011 and the starting of the approved program of tests (with and without beams) need the realization of complete elements like the CLIC modules the basic "bricks" of the ~48 km of main and drive beams linacs.

The CLIC magnetic system is based on standard (room temperature) electro-magnet technology with some exceptions like the superconducting wigglers needed for the dumping rings and the use of hybrid design (electro-magnetic plus permanent magnets) for some specific very high gradient quadrupoles in the final focus system closed to the interaction region.

In 2009 CERN decided to start a magnet prototype program in order to:

- provide the needed prototypes for the CLIC R&D phase and Test Programs;
- investigate with prototypes and/or models the most challenging magnets in terms of: design, performances, procurement aspects (manufacturing technologies, big series production, etc.)

In the following sections we will describe the most relevant cases of magnet analysed and prototype procured, as other studies launched like the "census" of all the magnet families for the CLIC complex (3 TeV layout) and the design and finite element analysis of the machine detector interface (MDI) region including the final focus system with its anti-solenoid.

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MAIN BEAM QUADRUPOLE (MBQ)

CLIC linacs design is characterized by the presence of the two beams (the drive beams providing the energy for the acceleration of the main beams up to the interaction energy) installed on a common modular structure called "Module". The two linacs will consist in the assembly of 20924 modules of 2-m length each (Figure 1).

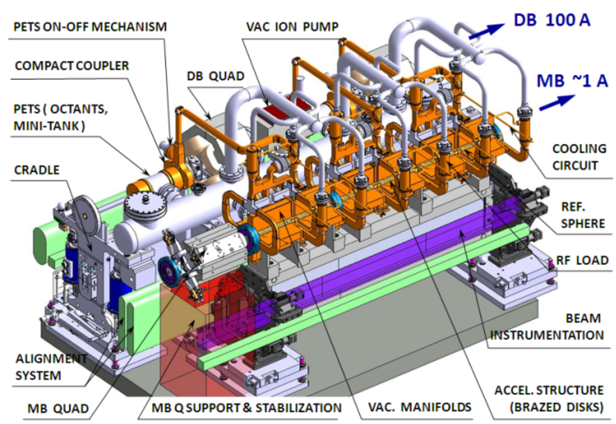

Figure 1: View of a typical CLIC Module.

The major module components are identified by tags. Among them we remark the main beam quadrupole (MBQ). The CLIC layout consists of 5 main types of linac modules (type0 to type4), the types1 to 4 are characterized by the presence of a MBQ magnet of different length for the different module type but with the same cross section and same nominal quadrupole gradient.

In total 3992 units of MBQ of four different magnetic lengths (from 350 mm in Type1 to 1915 mm in Type4) are needed. In 2009 it was launched the design and procurement of one quadrupole prototype needed for the active stabilization studies [2]. Accordingly with CLIC baseline parameters, main characteristics of the MBQ are:

- Nominal gradient: 200 T/m
- Magnet aperture: 10 mm
- As much as possible compact and sound magnet design: this in order to fit with space and requirement for the individual active stabilization at the nm level. For such reasons the option of solid quadrants was chosen.

Following the CLIC test programs approved meanwhile, the number of prototypes to be procured was then increased to four: two type1 and two type4 magnets. At the moment we have assembled one type1 and one type4 prototype. Powering tests were fully successful and magnetic measurements and first stabilization tests are ongoing.

In Figure 2 the MBQ type4 assembled is shown and Table 1 presents the main parameters.

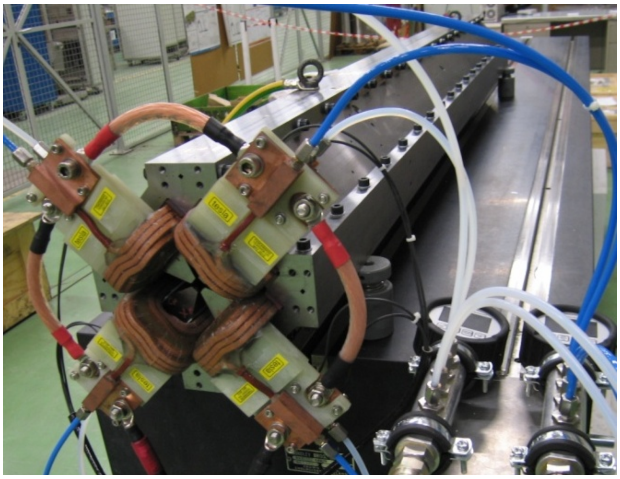

Figure 2: The assembled type4 MBQ magnet.

Table 1: Type 4 MBQ Main Parameters

TYPE4 MBQ Main Parameters	
Aperture Ø	10 mm
Gradient	200 T/m
Magnetic Length	1915 mm
Integrated Field Gradient Error	< 0.1% over a circle of 4 mm radius
Current	126 A
Current density	6.1 A/mm^2
Voltage	30.4 V
Power	3831 W
Weight	~ 400 kg

DRIVE BEAM QUADRUPOLE (DBQ)

The DBQ are also visible in the Figure 1 (two units in each CLIC Module). The main characteristics of this family of magnets is the large number needed (41848 units in CLIC 3 TeV layout) and the very wide functioning range for the gradient along the "Decelerator" linac (more than 90% of tunability required). These aspects necessitate a program of industrialization studies in the future years in order to optimize the performances, power and cost.

A magnetic design to check that the maximum integrated gradient fits with the available longitudinal space was developed at CERN and an order for a series of eight magnets was placed in June 2011 in the european industry in order to procure the magnets needed for CLEX the future CLIC test facility (with beam). Reference (CERN study) main design parameters for the DBQ are listed in Table 2.

Table 2: DBQ Main Parameters

DBQ Main Design Parameters (CERN study)	
Magnet cross-section (Max)	390 x 390 mm
Magnet Length (Max)	286 mm
Aperture Ø	26 mm
Gradient (Nom.)	63 T/m
Integrated Field Gradient Error	< 0.1% over a circle of 11 mm radius
Gradient Tunability	From 10 to110% of nominal integrated gradient.
Magnetic Length	194 mm
Current (Nom.)	93 A
Current density (Nom.)	3.6 A/mm^2
Voltage (Nom.)	9.2 V
Power (Nom.)	860 W
Weight	~ 135 kg

FINAL FOCUS QD0 SHORT PROTOTYPE.

Probably the most exotic magnet in the 3 TeV CLIC magnetic layout is the QD0 part of the Final Focus doublet (QF1+QD0) and last magnet of the beam delivery system.

As it's shown in the Figure 3, in CLIC optic layout baseline (L*= 3.5 m) the QD0 is placed really "inside" the experiment detector and is the most critical element of the so called machine detector interface (MDI).

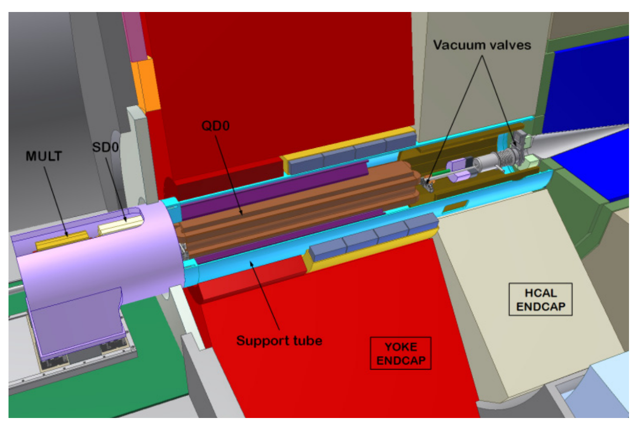

Figure 3: view of MDI with the QD0 inside the detector.

The magnet must be design taking into account the following relevant boundary conditions:

- Extremely high nominal gradient (575 T/m)
- The magnet must be actively stabilized in the nm range (Note: magnetic length = 2700 mm)
- Presence of the post collision line vacuum chamber (of opposite beam) running along the QD0.

These three conditions had driven the choice of the magnet technology and design toward a hybrid design: an electromagnet quadrupole with low current density (to avoid cooling water in the coils) and boosted by the presence of permanent magnet inserts in order to achieve the needed gradient and tunability. The procurement of a short prototype (see Figure. 4) to prove the validity of the proposed design was launched in 2010 [3].

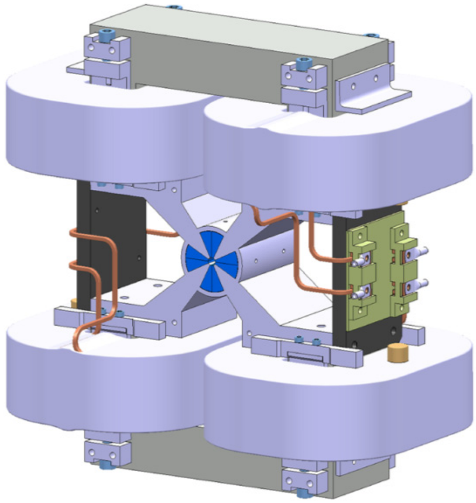

Figure 4: View of the Short QD0 Prototype.

The prototype is now under assembly. In Figure 5 are shown the core elements: the single-piece quadrupolar structure (in Permendur) with the permanent magnet block inserted. Table 3 contains the main design parameter of the prototype and of the extrapolated full magnet.

Table 3: QD0 Main Parameters

QD0 Main Parameters	Short prototype	Real magnet
Iron Length	100 mm	2700 mm
Aperture Ø	8.25 mm	8.25 mm
Gradient*	500-535 T/m	575 T/m
Integrated Field Grad. Error	< 0.1% over a circle of 1 mm radius	
Current	15.4 A	
Current density	1 A/mm^2	
Voltage	13.8 V	136.4 V
Power	213 W	2100 W
Weight	~ 130 kg	~ 1500 kg

**Depending by the permanent magnet material utilized*

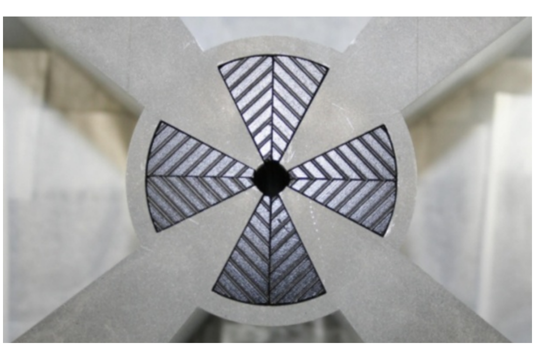

Figure 5: Detail of the QD0 central part assembly.

The magnet was magnetically measured in the configuration with only permanent magnet blocks and the gradient is in very good agreement with the computations. The production of the 4 coils is under completion at CERN and the magnet will be fully assembled and widely tested with an "ad hoc" developed rotating coils system (shaft diameter of 7.75 mm) in the next months.

OTHER STUDIES AND ACTIVITIES

To complete the presentation of the ongoing studies and activities on CLIC Magnet System R&D, we also mention:

- The finite element analysis simulation of the complete MDI region taking into account the QDO magnet, the SC antisolenoid (needed to protect QD0 from the detector solenoid field), the detector solenoid, and the ancillary supporting structures. This study will permit to check and optimize the magnetic design of this critical area and to define the electromagnetic design parameters (ex. inductances, shielding masses, discharging scenario, etc.).
- The release of the CLIC magnets catalogue covering all the magnets of the different sub-system of CLIC complex. All magnets (when possible grouped in families following their characteristics as dimensions, magnetic field requirements, etc.) were analyzed providing a "conceptual design" (including a 2D finite element analysis) and evaluating the main design parameters like: overall dimensions, mass, powering and cooling needs and cost. This work will permit to provide a complete and sound estimation of the CLIC magnet system total cost, powering and services needed, that are key elements of the global cost and technical analysis of the CLIC Project (that will be part of the conceptual design report).

CONCLUSION

Several magnet prototypes needed for the approved CLIC Test Programs (with and without beams) have been assembled or are under assembly. The measuring phase of this first generation of prototypes is now starting.

REFERENCES

[1] D. Schulte (CERN), "CLIC Conceptual Design and CTF3 Results": *invited talk at this Conference.*

[2] M. Modena (CERN), A. Vorozhtsov (CERN and JINR), "Design and manufacture of a main beam quadrupole model for CLIC": *to be presented at MT-22 Conference, 12-16 September, Marseille - France*

[3] M. Modena (CERN), D. Tommasini (CERN), A. Vorozhtsov (CERN and JINR), "Design and manufacture of a hybrid final focus quadrupole model for CLIC": *to be presented at MT-22 Conference,12-16 September, Marseille – France.*