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STATUS OF CLIC MAGNETS STUDIES AND R&D

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Abstract

Since 2009 the CERN Magnet Group (CERN-TE-MSC) started R&D activities in order to focalize the most challenging and interesting cases to be studied among the magnets needed for CLIC the Compact Linear Collider. In the last four years several theoretical studies, models and prototypes were realized mainly in two domains: magnets for the modules, the modular elements that are composing the backbone of the two-beam linac structure of CLIC, and for the Machine Detector Interface (MDI) including the final focus elements and the anti-solenoid. In this paper we revise the status for the procured magnets. Among them the Drive Beam Quadrupoles, Main Beam Quadrupoles, Steering Correctors all challenging for the required compactness, performances and production size, and the QD0 final quadrupole and the SD0 sextupole, challenging for the high performances required in terms of gradients and stability.

INTRODUCTION

The Compact Linear Collider project (CLIC) has passed the Conceptual Design Report (CDR) milestone release in 2012 [1]. The CDR contains a complete description and analysis of all the main systems and components including the magnet system. In addition to the studies done for the CDR, a "CLIC Magnet Catalogue" was also recently completed. In the catalogue, composed by 5 documents [2], a systematic analysis of each magnet type present in CLIC complex is done. Dimensions, main operational parameters as well as procurement price (taking into account production learning curves) are assessed. Beside these studies, a prototype procurement plan covering the most critical types of magnets was also launched in 2009 [3] and up to date 11 prototypes were procured and are now under test and measurement at CERN and at other laboratories. Other 7 prototypes will be completed in the next months. In the following sections the most relevant studies and prototype results are presented and discussed.

MAGNETS FOR THE LINAC MODULES

The CLIC linacs are characterized by the presence of two beams (the Drive and the Main Beams) installed on a common structure called "modules". In the CLIC 3 TeV layout a total of 41848 Drive Beam Quadrupoles (DBQ) and 4020 Main Beam Quadrupoles (MBQ) will be installed on 20924 modules of 2-m length each.

MBQ Prototypes Status and Results

Three versions of MBQ Type1 (the shorter type with a magnetic length of 250 mm) and one Type4 unit (same cross-section but with magnetic length of 1850 mm) were built. Figure 1 depicts the reference cross section of the most recent Type1 version (dimensions in mm).

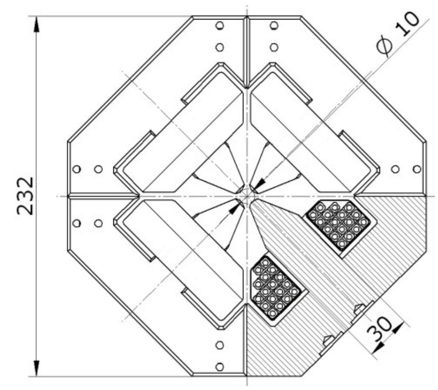

Figure 1: MBQ Type1 reference cross-section.

Iron machining quality has impressively improved through the successive procurements: the achieved tolerances on the last manufactured set of quadrants are a remarkable ±7 µm for all the critical surfaces (pole profiles and quadrant mating surfaces) [4]. The magnet was measured at CERN Metrology Lab and at Magnetic Measurement Lab with stretched and oscillating wire technique. Results of dedicated assembly tests indicate that the main point limiting now the field quality is the achievable precision on the assembly of the quadrants set [5]. Activities on this aspect are now ongoing mainly within the PACMAN Marie Curie program recently started at CERN [6].

MBQ Steering Correctors Prototypes

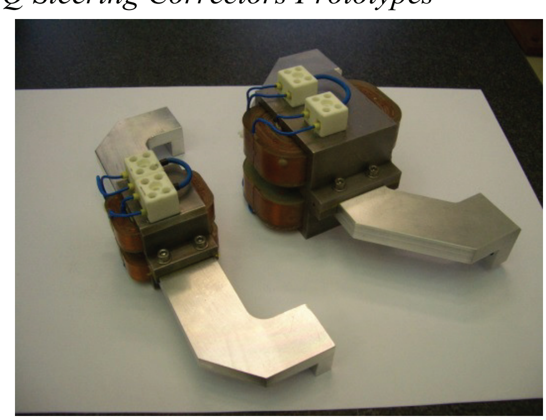

Figure 2: Type1 and Type4 Steering correctors.

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The baseline solution for steering the CLIC Main beam is provided by small dipoles correctors mounted at one extremity of the MBQ. Two different correctors prototypes (for MBQ Type1 and 4) were built at CERN in 2012 and are shown in Figure 2. Main parameters are reported in Table 1. Magnetic and functional tests have to clarify important aspects. Having to provide correction on individual bunches, these magnets are operated at 100 Hz. The possible impact on MBQ active stabilization system must be assessed. An alternative solution (nano-positioning capability provided by the nano-stabilization system) is also under study as a dedicated research line within PACMAN Program.

Table 1: Steering Dipole Correctors Main Parameters

	Dipole Type1	Dipole Type4
$\int Bdl$	1.16×10^{-3} Tm	4.057×10^{-3} Tm
Gap aperture	12 mm	12 mm
N.of turn per coil	112	374
Current / Voltage	1.02 A / 0.91 V	0.72 A / 3.26 V
Power / Weight	0.93 W / 0.6 kg	2.35 W / 2.1 kg

DBQ Prototype Status and Results

The DBQ with its 41848 units is the most populated magnet family in CLIC. For this reason and for the very tight space available, it is a critical magnet to be investigated as concerning power and cooling consumption, and design optimization towards industrial procurement. The R&D is proceeding on two main directions: an electro-magnetic normal conducting design (EM) and a tunable permanent magnet (PM) design.

EM Version. A series of 8 quadrupole is under procurement in industry (Danfysik). Two first units were delivered and measured. The magnet design optimizes the very tight available space. The magnet provides a nominal gradient of 62 T/m but is suitable for the very wide gradient range requested along the drive beam (ratio 10/1). Main parameters are given in [7]. Figure 3 reports the results of the measured vs. computed gradient homogeneity for the three different working points.

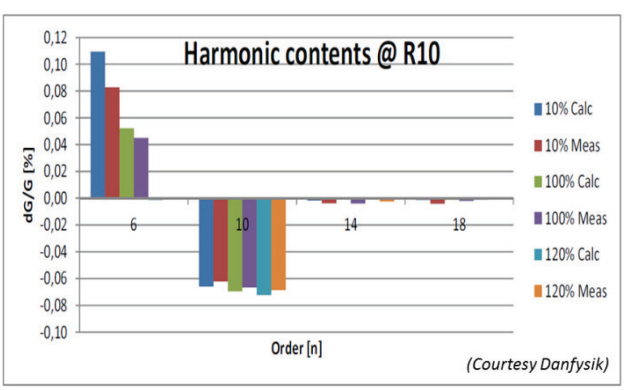

Figure 3: DBQ prototype magnetic measurements results *(courtesy of Danfysik)*.

Tunable PM Version. This design is developed by ASTeC at Daresbury Lab. (UK). The innovative idea is to design a fully mechanical tunable PM quadrupole family for the drive beam. In order to cover the entire gradient range needed, a minimum of 2 variants are necessary: a high gradient and a low gradient version. The high gradient quadrupole prototype [8] was built at Daresbury Lab and successfully measured at CERN in 2012, while the low gradient prototype is close to completion and will be measured in the 2nd part of 2014. Figure 4 shows the high gradient prototype during magnetic measurement. It provides a gradient variable between 15 and 60 T/m.

Figure 4: DBQ PM version prototype during the magnetic measurement at CERN.

The advancement on the low gradient prototype procurement is reported at this conference in a dedicated paper [9].

MAGNETS FOR THE MDI

The magnets of the MDI are technically the most challenging of the all CLIC complex. This is due to: the extremely high gradients required for quadrupole QD0 and for the sextupole SD0; the requirement of compactness and integration of the post-collision beam pipe; the compatibility with an active stabilization of the magnets in the nanometre range.

QD0 Hybrid Quadrupole

QD0 design, for gradients toward 575 T/m, was studied in details and the procurement of a short prototype has then followed. The magnet is based on an innovative hybrid design (resistive coils + PM blocks) and it was successfully built and measured at CERN [10]. The magnet was tested in two configurations: with SmCo PM

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blocks, the material most adapted for an accelerator application due to the high resistance to radiation, and with NdFeB blocks, more performing in terms of achievable high gradients (~11%) but much less resistant to radiation. As concerning cross-section parameters (dimensions, gradient, ampere-turn, etc.), the short prototype is fully representative of a "full-size" magnet. A complete magnet will be manufactured assembling several "short" central modules on full-size return yokes and coils.

SD0 Hybrid Sextupole

In order to investigate the very important and challenging aspect of extremely precise modules assembly necessary for both QD0 and SD0 magnets, we recently decided to build a full size SD0 prototype. In fact SD0 sextupole design is based on the same hybrid concept proposed for the QD0. Figure 5 depicts the SD0 prototype how it will be built at CERN.

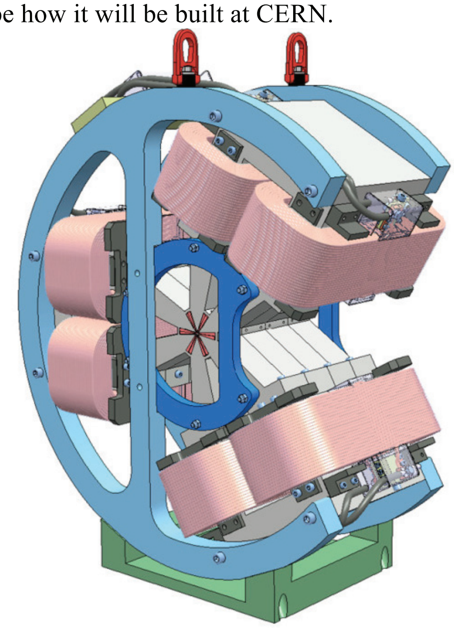

Figure 5: CAD model of the SD0 prototype.

Antisolenoid Studies

The use of the innovative hybrid magnet design for the final focus with L*=3.5 m layout (being L* the distance between the interaction point and the start of the QD0), requires the presence of an antisolenoid in order to shield the QD0 PM blocks from the external magnetic field generated by the experiment detector solenoid. This aspect was deeply studied being also critical from the experiment/accelerator integration point of view, and a magnetic design for an antisolenoid optimized for the most critical layout (the SiD experiment) is available [11].

NEW DEVELOPMENTS

New PM Studies for CLIC Transfer Lines

Seen the successful studies and procurements done together with ASTeC at Daresbury Lab, we have recently improved the collaboration activities proposing a new subject of studies (followed by prototypes procurement) for two challenging magnets of the CLIC Transfer line system: the dipoles of MB RTML (Main Beam Ring Transfer line to Main Linac) and the dipoles of DB TAL (Drive Beam Turn Around Loop).

MDI Studies within LCC Collaboration

Within the Linear Collider Collaboration (LCC) we are studying an alternative design for QD0 that could be convenient and applicable for the International Linear Collider project (ILC), and eventually also for CLIC providing it fulfils the mechanical stability requirements (more stringent in CLIC respect to ILC).

This alternative version will be a super-ferric design. It will be hybrid (electro-magnetic coils + permanent magnet inserts) and very similar to the CLIC QD0 baseline but with small super-conducting coil packs assembled on a warm quadrupolar structure. A conceptual design of this version is presented at this conference [12] where advantages and challenges of this solution are discussed.

CONCLUSION

R&D activities for CLIC magnet system started in 2009. In these elapsed 5 years a wide program of studies and prototypes procurement was developed. Thanks to a "CLIC Magnet Catalogue" studies, today we have a comprehensive and clear vision of the main requirements and challenges of the complete baseline of CLIC magnet system.

Up to date 11 prototypes were completed, and others 7 are under manufacturing.

Studies and prototypes are investigating the most critical CLIC magnets in terms of:

- Required performances (ex. QD0 and SD0 magnets of the final focus system)
- Design optimization due to tight space requirements and procurement industrial aspects (ex. the 41848 DBQ and the 4020 MBQ quadrupoles needed for the 2-beams Modules of the main linacs).

Other studies of critical elements were completed or are on going:

- An antisolenoid system for the MDI.
- Main beam steering by dipole correctors or by MBQ nano-positioning.
- Innovative design for some of the transfer line dipoles (planned within the collaboration with ASTeC at Daresbury Lab. UK).
- Under the aegis of Linear Collider Collaboration, we have recently started to study new solutions (super-ferric designs) for hybrid magnets for ILC MDI.

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