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Validation of CLIC Re-Adjustment System Based on Eccentric Cam Movers – One Degree of Freedom Mock-Up

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Abstract. *Compact Linear Collider (CLIC) is a 48 km long linear accelerator currently studied at CERN. It is a high luminosity electron-positron collider with an energy range of 0.5-3 TeV. CLIC is based on a two-beam technology in which a high current drive beam transfers RF power to the main beam accelerating structures. The main beam is steered with quadrupole magnets. To reach CLIC target luminosity, the main beam quadrupoles have to be actively pre-aligned within 17 µm in 5 degrees of freedom and actively stabilised at 1 nm in vertical above 1 Hz. To reach the pre-alignment requirement as well as the rigidity required by nano-stabilisation, a system based on eccentric cam movers is proposed for the re-adjustment of the main beam quadrupoles. Validation of the technique to the stringent CLIC requirements was started with tests in one degree of freedom on an eccentric cam mover. This paper describes the dedicated mock-up as well as the tests and measurements carried out with it. Finally, the test results are presented.*

Keywords: CLIC, main beam quadrupole, eccentric cam mover, alignment

1. Introduction

CLIC main beam (MB) will be steered using approximately 4000 quadrupole magnets which are divided into four types. Quadrupole length varies between 420 mm and 1915 mm depending on the type. To reach the design luminosity of $2.3\text{-}5.9\cdot10^{34}$ $cm^{-2}s^{-1}$, the CLIC main beam has to be stabilised to 1 nm in vertical and 40 nm in horizontal direction above 1 Hz [1]. This will be performed by a nano-stabilisation system which requires high stiffness from the re-adjustment system on top of which it will be installed. In order to implement beam based alignment and beam based feedback, the MB quadrupole magnets and their associated beam position monitors (BPM) will have to be pre-aligned with a precision and accuracy of 14 µm rms in 5 degrees of freedom (d.o.f.).

A system based on eccentric cam movers was chosen for the CLIC MB quadrupole re-adjustment. Cam mover based alignment systems are already in use in several accelerators and synchrotrons and with less stringent requirements. Cam movers provide both good resolution and high stiffness [2]. Each assembly consists of 5 cam movers which are used to manipulate a magnet within 5 d.o.f. It is a 3 point support contact with 4 interfaces with respect to the basement.

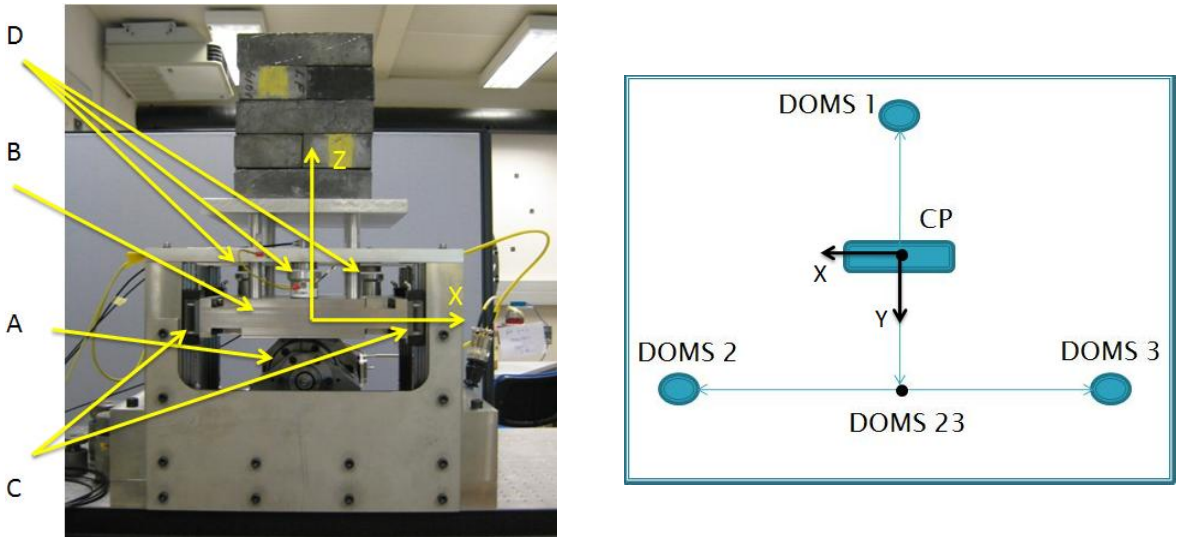
2. One degree of freedom tests

Validation of the CLIC MB quadrupole re-adjustment system based on eccentric cam movers was started with tests in 1 d.o.f. The cam mover used in the first tests is based on the design used at the SLS [3]. The entire assembly was further developed by minimizing clearances and implementing state of the art components (gearbox etc.). This section will present the 1 d.o.f. mock-up and the repeatability tests carried out using it.

One degree of freedom mock-up

Figure 1 (a) presents the 1 d.o.f. mock-up described in [4]. The cam mover (A) is installed under a cam follower plate (B). The plate is attached to rigid walls with four low friction linear guidings (C). The guidings limit the plate's motion to one degree of freedom (z in figure 1 (a)). The plate (B) weighs 35 kg. An additional weight of 100 kg is mounted on top of the plate.

The goal of the 1 d.o.f. mock-up is to test the cam mover's repeatability. For this, the upper plate's vertical position is measured using capacitive Dimensional Offset Measurement Systems (DOMS) with below 0.1 µm resolution [5]. The DOMS are shown by arrows (D) in figure 1 (a).



(a) **(b)**

Fig. 1. (a) Side view of the one degree of freedom mock-up. (b) Top view of the DOMS sensors measuring the upper plate's z-position viewed from above. CP is the contact plane between the cam mover and the upper plate.

Figure 1 (b) shows the setup to measure the upper plate's z-position. Three DOMS were used instead of one to have redundancy and to measure the inclination of the upper plate. The vertical position of the contact plane (CP in figure 1 (b)) between the cam mover and the upper plate can be calculated based on the DOMS readings.

Test methods

A cylindrical enclosure (housing) acts as the mechanical interface between the cam mover and the cam follower. In the case of the 1 d.o.f. mock-up, the upper plate (B in figure 1 (a)) acts as the cam follower. Linear movement of the housing is realized by rotating an eccentric cam shaft which is mounted inside the housing. A bearing is installed between the cam shaft and the housing.

Two different types of bearings were tested; spherical roller bearing and cylindrical roller follower. In addition, two types of housings were tested; again with cylindrical and spherical outer surfaces. Both housings have induction hardened surfaces. Three different configurations were built using these bearing and housing types and tested in the 1 d.o.f. mock-up.

Table 1 is showing the three tested configurations. Bearing references are listed in the table in addition to bearing and housing types. Configuration 1 consists of a spherical roller bearing and a cylindrical housing. Configurations 2 and 3 both have a roller follower bearing. The only difference between the bearings used in configurations 2 and 3 is the outer ring. It is cylindrical in configuration 2 and crowned in configuration 3. The housing is cylindrical in configuration 2 and spherical in configuration 3.

Table 1. Configurations tested in the 1 d.o.f. mock-up.

Configuration No.	Bearing type	Bearing reference	Housing type
1	Spherical roller bearing	SKF 22209 E	Cylindrical
2	Roller follower	IKO NAST 45 ZZUU	Cylindrical
3	Roller follower	IKO NAST 45 ZZUUR	Spherical

For each configuration, preparatory tests were carried out to find the the best parameters for the repeatability test. The optimized parameters were: the number of data acquisitions after each sequence, the number of test drives in a test series, the settling time after a sequence and before data acquisition and the stepper motor reference speed.

A test series was performed based on the optimised parameters to find out the cam mover repeatability within the whole stroke of 10 mm. In the beginning of the test, the cam follower plate was at its upper dead center. One test drive consisted of two parts. First, the plate was driven from the upper dead center to the lower dead center (PI/2 evolution) and vice versa in the further iteration. The cam mover was stopped 20 times per PI/2 evolution for measurements. This procedure was repeated 10 times. The mean values and root mean square errors (RMSE) were calculated between corresponding measurement points of all the 10 test drives of the test series.

The cam mover's range in vertical motion (stroke) is 10 mm. This translates through the planetary gear and the worm gear to nine million micro steps of the stepper motor. The repeatability test series was repeated with a reduced stroke of the cam mover. One million steps were omitted from both ends of the stroke.

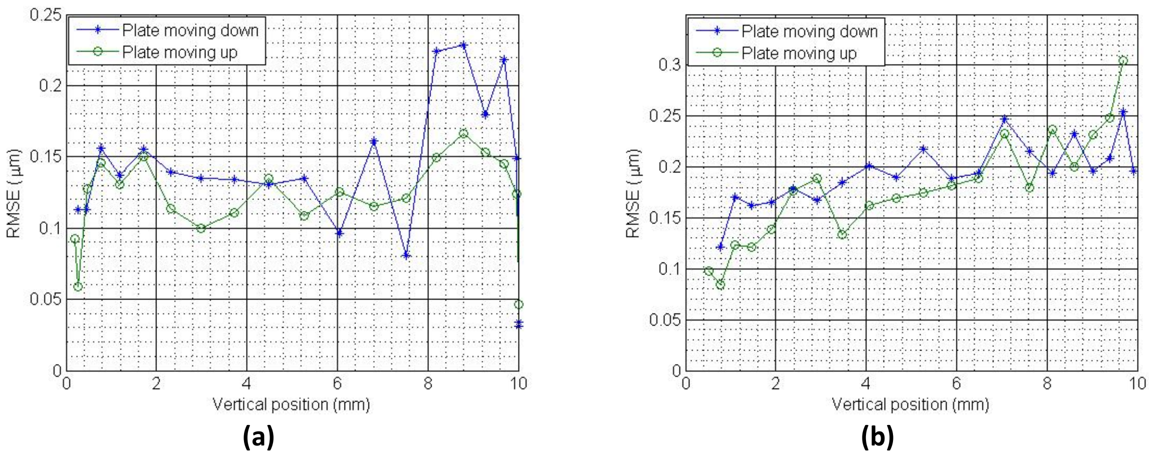


Fig. 2. Repeatability as a function of measured vertical position of the cam follower plate using configuration 1 in the 1 d.o.f. mock-up. The range is (a) the full stroke of 9 million steps, (b) between 1 and 8 million steps from the upmost position.

3. Results

The results of the repeatability tests of configuration 3 are shown in figure 2. Figure 2 (a) presents the full stroke of nine million steps and 2 (b) presents the reduced stroke. As can be seen in figure 2, the cam mover's repeatability in 1 d.o.f. with this configuration was below 0.3 µm within the whole range.

Configuration 3 had best repeatability with full stroke. The full stroke repeatability was below 1.0 µm and 0.4 µm for configurations 1 and 2 respectively.

Configuration 2 had the best repeatability, below 0.2 µm, with reduced stroke. For configuration 1, the repeatability was below 0.35 µm and for configuration 3 below 0.3 µm. Configurations 1 and 2 had better repeatability with the reduced stroke than with the full one. For configuration 3, the results were better with full stroke than with partial stroke.

4. Discussion and conclusions

The CLIC main beam quadrupoles have to be pre-aligned within 14 µm in 5 d.o.f. A system based on eccentric cam movers is proposed for the re-adjustment. The system's validation process was started with repeatability tests in 1 d.o.f.

The cam mover was tested with three different bearing and housing configurations in 1 d.o.f. The repeatability of all of the three configurations was below 1.0 µm. The roller follower had better repeatability than the spherical roller bearing with both outer rings and housings. With reduced stroke, the differences between the configurations were negligible.

Clearances inside the spherical roller bearing allow small lateral movement whereas the roller follower blocks it. The 1 d.o.f. mock-up diminishes efficiently movements in x- and y-directions. Therefore all of the effects of the clearances might not have been visible in the 1 d.o.f. test results.

A 5 d.o.f. mock-up will be built for the validation of the sub-micrometric resolution cam mover system. The cam mover design has been further improved from the one used in the 1 d.o.f. mock-up. The structure is now more rigid, clearances between parts are smaller, worm gear and stepper motor have been changed and there is a zero backlash bearing reducer instead of a planetary gear. Both bearing types will be tested also in 5 d.o.f.

In addition to positioning precision, the re-adjustment system has to provide a rigid support for the MB quadrupoles. The system's eigenfrequency should be as high as possible. This has been taken into consideration in the cam mover design optimization process. The validation of the 5 d.o.f. concept will show if a further iteration in the re-adjustment system design will be required.

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