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Development of an Eccentric CAM Based Active Pre-Alignment System for the CLIC Main Beam Quadrupole Magnet

Lackner, F (CERN) *et al*

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Development of an Eccentric CAM Based Active Pre-Alignment System for the CLIC Main Beam Quadrupole Magnet

Presenting author: Friedrich Lackner
Organisation: European Organisation for Nuclear Research (CERN)

Corresponding author: Friedrich Lackner
Organisation: European Organisation for Nuclear Research (CERN)
Email: Friedrich.Lackner@cern.ch

Co-authors: Kurt Artoos, Christophe Collette, Hélène Mainaud Durand, Claude Hauviller, Juha Kemppinen, Raphael Leuxe
Organisation: European Organisation for Nuclear Research (CERN)

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Abstract:

CLIC (Compact Linear Collider) is a study for a future electron-positron collider that would allow physicists to explore a new energy region beyond the capabilities of today's particle accelerators. The demanding transverse and vertical beam sizes and emittance specifications are resulting in stringent alignment and a nanometre stability requirement. In the current feasibility study, the main beam quadrupole magnets have to be actively pre-aligned with a precision of 1 µm in 5 degrees of freedom (d.o.f.) before being mechanically stabilized to the nm scale above 1 Hz. This contribution describes the approach of performing this active pre-alignment based on an eccentric cam system. In order to limit the amplification of the vibration sources at resonant frequencies a sufficiently high Eigenfrequency is required. Therefore the contact region between cam and support was optimized for adequate stiffness based on the Hertzian theory. Furthermore, practical tests performed on a single degree of freedom mock-up will show the limitation factors and further improvements required for successful integration in a full scale quadrupole mock-up presently under design.

1-Introduction

Eccentric cams are commonly used in a wide field of accelerator alignment systems. CERN is currently studying the further development of existing eccentric cam systems which were developed for the Stanford Linear Collider in 1986. The principle has been adopted in several light sources. A main requirement for CLIC is to reach a luminosity of 2.3-5.9.10^{34} $cm^{-2}s^{-1}$ at the beam interaction point [4]. The beam size of 40 nm in the horizontal and 1 nm in the vertical dimension demands four different types of stabilized and actively aligned quadrupole magnets applied on about 4000 modules. The length of the magnets varies between 420 mm and 1915 mm. The theoretic approach of developing adequate hardware for stabilization and alignment is currently based on studying a single degree of freedom oscillator described in [1]. The overall approach requires a rigid alignment stage with an accuracy specified to 1 µm [3].

2-Single degree of freedom mockup

A cam mockup was developed in order to test and optimize all relevant design parameters towards minimum clearance. The platform is based on rigid walls providing a low friction linear motion roller guide (Figure 1). In a first iteration a single cam similar to the design approach seen in [2] is applied underneath the platform. For monitoring the displacement accuracy and repeatability three Distance Offset Measurement Systems (DOMS) [7] are applied on the horizontal plate, currently displaced in an open loop circuit. Improvements on mechanical parts are currently in progress. The mockup concept was theoretically based on a form closed case approach, the system equation (1) is based on the vibration theory whereas $\vartheta_{1,2}$ defines the damping ratio, ω the angular velocity, s and x the follower displacement [6].

$$\ddot{x} + 2\vartheta\omega_n\dot{x} + \omega_n^2 x = \omega_n^2 s + 2\vartheta\omega_n\dot{s} \quad (1)$$

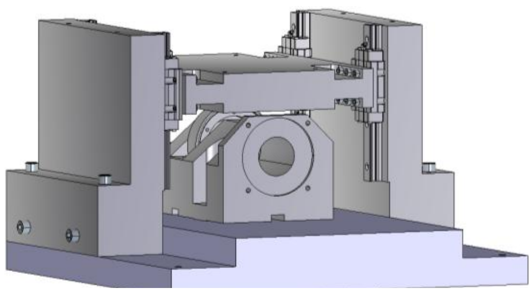

Figure 1: *1 d.o.f mockup with roller guiding.*

In order to optimize the cam rigidity and therefore the Hertz contact stress in the contact plane the prediction of damping ratio is crucial. To accurately predict the value at any design stage by calculation method is difficult. A first approach to measure the damping ratio based on accelerometers and excitation [5] did not provide sufficient information due to the rigid guiding. Measurements will be replicated on the future 5 d.o.f. mockup with interchangeable design approach. The setup is currently optimized and improved by using harmonic drive and cam follower as well as a rotary encoder for closed loop operation.

3-Series of measurements

The eccentric cam mover has a vertical movement range of 10 mm. Its trajectory is sinusoidal [6] which means that a 180 degrees rotation corresponds to the full movement range. In the current setup this translates to 9 million motor steps through transmission in the 1 DOF test setup. The measured cam was supported with a spherical bearing in the first iteration. Due to the sinusoidal trajectory, motor steps transform to vertical movement according to the orientation of the CAM mover. First repeatability tests are showing random uncertainty due to misalignment of the contact axis with respect to the cam axis. The repeatability test was performed on the entire range of vertical plate displacement. This was investigated by cycling the plate 10 times between upper and lower dead center. Within each cycle the plate was stopped 20 times to measure the vertical plate position. Figure 2 (left) shows the results of the repeatability test. Near the lowest position, DOMS in maximum separation, the figure does not provide RMSE values due to the limitation by the acquisition rack's voltage range. Near the opposite end of the movement range, the results are reliable. It can be seen that, as expected, the RMSE values are increasing significantly near the upper and lower limits of stroke. A second set of measurements was performed using a reduced stroke between 1 million and 8 million motor steps. The results are presented in figure 2 (right), the result clearly shows the increasing precision due to reduced stroke operation. The repeatability for the second series of measurement was found to be better than 0.3 µm.

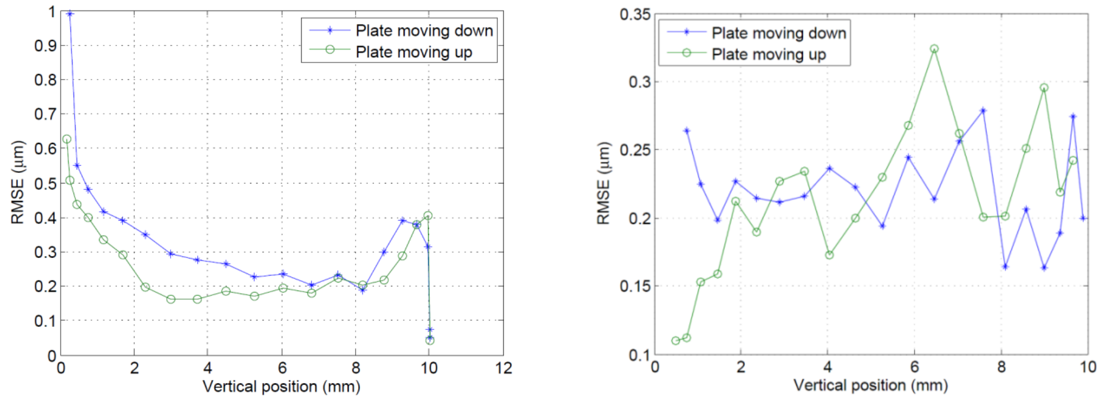

Figure 2: *RMS errors of 1 d.o.f. CAM mover test setup vertical positioning as functions of mean values.(left) Test series within the whole stroke. (right) Test series within a reduced stroke.*

4-Conclusion

A test setup for a single d.o.f. eccentric cam was developed to optimize mechanical properties of mechanical components. The setup is further optimized using state of the art technology for micrometric positioning. First tests based on a spherical bearing show promising results when operating in repeatability mode. The repeatability was found to be better than 0.3 µm when operated with partial stroke. Implementation of harmonic drive, cylindrical roller cam follower and rotary encoder will further minimize the system uncertainties. This will provide important information for future integration of a 5 d.o.f. sysem in the CLIC test module currently under development. The setup will then allow investigating critical information like Eigenfrequency and damping ratio for the integration of the nm stabilization system.

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