DESIGN AND STUDY ON A 5 DEGREE-OF-FREEDOM ADJUSTMENT PLATFORM FOR CLIC DRIVE BEAM QUADRUPOLES

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Abstract

Since several years CERN is studying the feasibility of building a high energy e+ e- linear collider: the CLIC (Compact LInear Collider). The pre-alignment precision and accuracy requirement for the transverse positions of the linac components is typically 14 micrometers over a sliding window of 200m. One of the challenges is precise adjustment of Drive Beam quadrupole's magnetic axis. It has to be done with micrometric resolution along 5 DOF in a common support's coordinate system. This paper describes the design and study of a solution based on flexural components in a type of "Stewart Platform" configuration.

The engineering approach, the lessons learned ("know how"), the issues of adjustment solution and the mechanical components behaviors are presented.

INTRODUCTION

The 42 km long Drive Beam section of the Compact Linear Collider (CLIC) requires over 41000 quadrupole magnets, spaced ~1m apart [1]. To keep the drive beam focused, all of the Drive Beam Quadrupoles (DBQ) magnetic axis will have to be aligned within +/-20 µm r.m.s. with respect to a straight reference line inside a sliding window of 200 m [2].

In the CLIC Conceptual Design Report [1], a solution based on components pre-aligned on common girders has been proposed. The girders are supported by linear actuators to provide the functionality of micrometric adjustment.

A strategy of short range alignment has been proposed including the fiducialisation process, e.g. the determination of the position of the reference axis/zero of the component with respect to external alignment references called fiducials [3].

The first tests to perform the adjustment of the DBQ according to 5 Degrees-Of-Freedom (DOF) have shown that it cannot be achieved by solutions based on shimming [4]. Taking into account the number of DBQs that will need to be pre-aligned if CLIC is built one day, a new solution of adjustment was mandatory.

A prototype of DBQ adjustment platform allowing 5 DOF regulations was tested at CERN in the beginning of 2014 and is described in this paper.

DBQ ADJUSTMENT AND CONSTRAINTS

Inaccuracies of DBQ manufacturing and not ideal repeatability of its material properties cause difference in position and orientation between quadrupole theoretical and real magnetic axis. Due to this fact a solution allowing adjustment of DBQ X-Y position and roll, pitch, yaw angles (Fig.1) was needed.

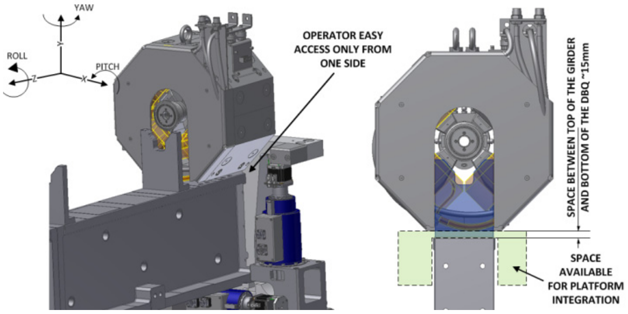

Figure 1: View of DBQ typical assembly geometry on the supporting girder.

After analysis of possible manufacturing errors and alignment requirements, it was decided that the unit should provide an adjustment range of ±1 mm in X and Y positions and ±4 mrad in roll, pitch, yaw, with Z position blocked. Regulation resolution should be lower than 5µm. All setting actions should be ergonomic for the user (intuitive, access constraints minimized) and cost should be minimized.

Taking into account the DBQ assembly position on its girder, the biggest challenge was to integrate all mechanical components of regulation unit inside the available free space (Fig.1). As the girder modification was not an option, the only possible location was the 15mm thick space under the quadrupole and on both sides of the girder. Furthermore, dense packing of other components of the two-beam module forced to locate the regulation knobs on operator accessible side of Drive Beam girder.

ADJUSTABLE SUPPORT SOLUTION

Considering the project requirements and constraints, the best solution was to use a modified "Stewart platform" configuration as DBQ adjustable base. On the contrary to typical "Stewart" solution, the support's geometry was changed from "hexapod-type" to "vertical-horizontal-longitudinal" (Fig.2). This choice allowed:

- the distribution of the vertical platform supports in the free space on the girder sides and the fitting of the radial supports in the gap parallel to the platform;
- the creation of an intuitive platform adjustment configuration. Vertical supports mainly affect Y position, Roll, and Pitch. Horizontal supports have main impact on X position and Yaw. Longitudinal

support length is constant (Z displacement blocked);

- the removal of backlash and limiting amount of mechanical parts by use of flexural supports.

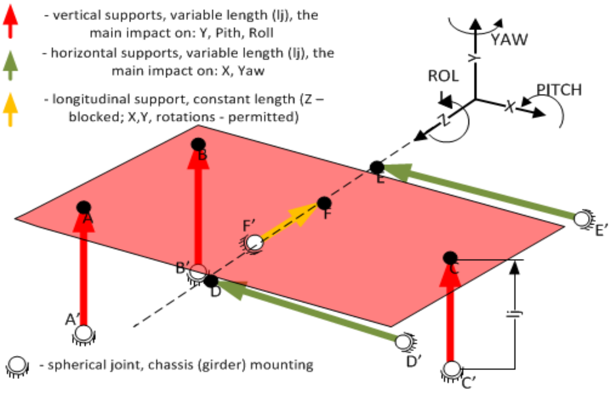

Figure 2: Modified 5 DOF "Stewart platform".

The platform design was adapted to fit into the available space. It consists of two main components (Fig.3):

- the girder mounting frame - used as a rigid support connected to the girder, adapted as a base for all platform supports, profiled to give necessary degrees of freedom for the platform;
- the DBQ platform – a movable component fastened to the quadrupole, integrated with the sockets of vertical supports, screwed to the radial and longitudinal supports.

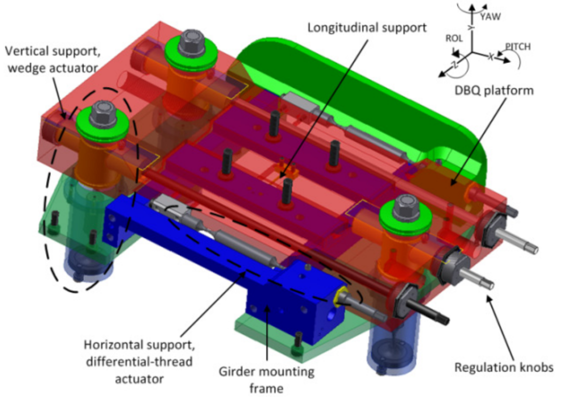

Figure 3: 3D model of DBQ adjustment platform.

The vertical and horizontal supports heads were designed as prismatic joints providing ±1mm linear sliding movement along their axes (Fig.4). Longitudinal support is a flexible rod of fixed length.

The vertical support heads are driven by wedge-based mechanism, with 1:15 ratio. The wedge position is adjusted by turning of the trapezoidal thread screw (Fig.4). The vertical support head stroke is 0.1mm per knob revolution. All supports screws knobs are accessible on one side of the platform.

The horizontal support heads are driven using differential-thread mechanism. Compilation of M10x0.5 and M12x0.75 threads results in a final stroke of 0.25mm per knob revolution.

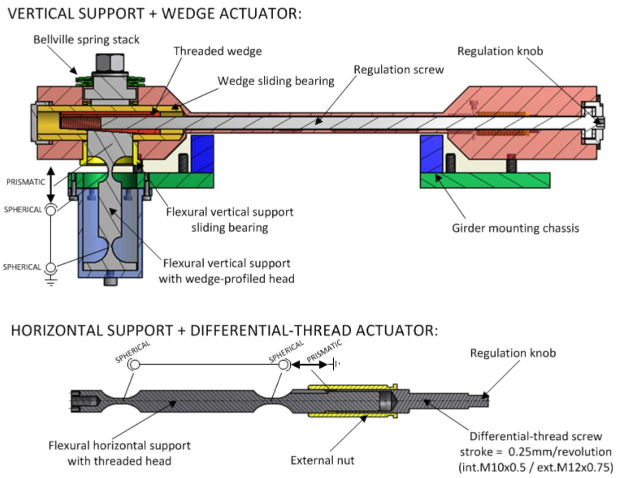

Figure 4: Operating principle of vertical and horizontal supports actuation.

TESTS AND RESULTS

All tests were performed using a specially designed test bench (Fig.5) including the CLIC girder-shape supporting block, on which the adjustment platform was installed. A "dummy" DBQ was installed on the platform and equipped with two high precision Wire Positioning Sensors (cWPS) [5] and one 2-axis inclinometer. The sensor readings allow the computation of the position and orientation of DBQ mechanical axis, with respect to the stretched wire considered as the reference of alignment.

All regulation knobs were equipped with potentiometric absolute position sensors (Fig.5), allowing reading of the actuator positions.

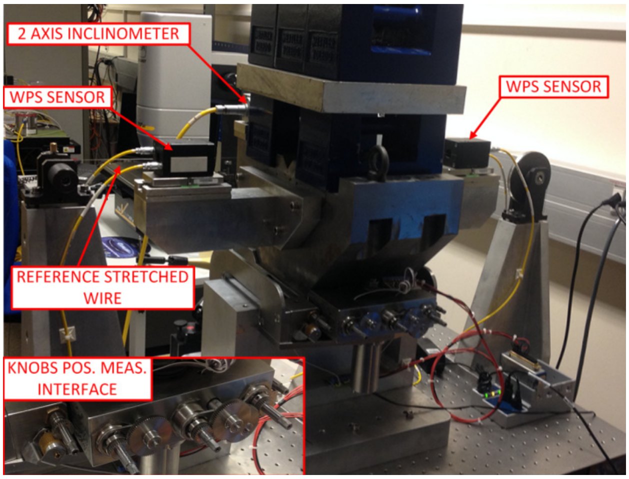

Figure 5: DBQ support test bench.

In parallel, a mathematical model of the DBQ platform was made to compare the measurement results with theoretical rigid body model kinematics. The modelling was done using *SimMechanics – Simulink* software.

The following tests have been performed:

- the long term stability of the adjustment devices with the nominal load of platform (170 kg);
- the regulation resolution;

- the impact of horizontal or vertical (separately) supporting joints adjustment on DBQ position and orientation. Horizontal or vertical supports are adjusted synchronically (same Δ on horizontal or vertical "actuators") or symmetrically (Fig.3.: ΔD-D' = - ΔE-E' or ΔA-A'=ΔB-B'= -ΔC-C');
- several tests of DBQ position/orientation adjustment.

The stability test has shown that adjusted position of DBQ was stable along the time. No drift or material creeping were observed. The tests of DBQ position disturbing using lateral and vertical forces at the level of ~200N has shown that DBQ returned to setting position after disturbing force disappears.

The regulation resolution test showed that feasible adjustment values are: 1µm for vertical supports; 2 to 4µm for horizontal supports.

The test of regulation of horizontal or vertical supports has shown that there is no big impact on vertical quadrupole position when the adjustment is performed using horizontal supports and vice-versa. Figure 6 shows the measurements monitored during the adjustment of the platform when both horizontal supports were displaced synchronically from -1 mm to 1 mm w.r.t. "0" – center of horizontal support position. The test was done with a displacement step for the horizontal actuators equal to ~50µm.

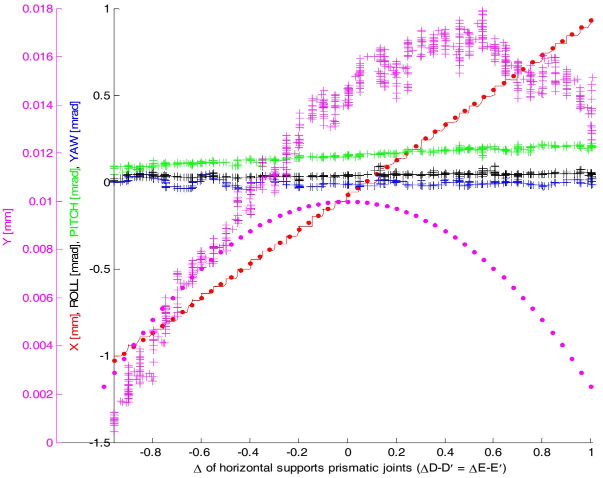

Figure 6: Two horizontal joints synchronic displacement impact on DBQ position and orientation.

The dotted lines show the theoretical coordinate values, while the coloured crosses show the measurements carried out. The theoretical angles values for this test are equal to "0". We can see that X-DBQ position is proportional to horizontal joints position. Y-DBQ position changes only by 18µm when X position changes 2mm. The non-homogenic variation in angles and ~8µm difference of Y DBQ position can be explained by innacuracies of the model and the non ideal behaviour of vertical supports (real flexural components kinematics with balancing load is not equal to the theoretical rigid body model behaviour).

Similar results were obtained during the tests of vertical supports' adjustment. The impact on radial displacement was not bigger than ~20µm when displacing platform vertically in the range of <-1,1> mm w.r.t. vertical supports' central position.

The test of DBQ position/orientation adjustment showed that the setting of the desirable quadrupole coordinates may be easy and fast. The manual adjustment of position within 2µm and orientation within 40 µrad takes approximately 10 minutes (Fig.7). The implemented strategy was: coarse angles adjustment, coarse position adjustment, fine angles adjustment, fine position adjustment.

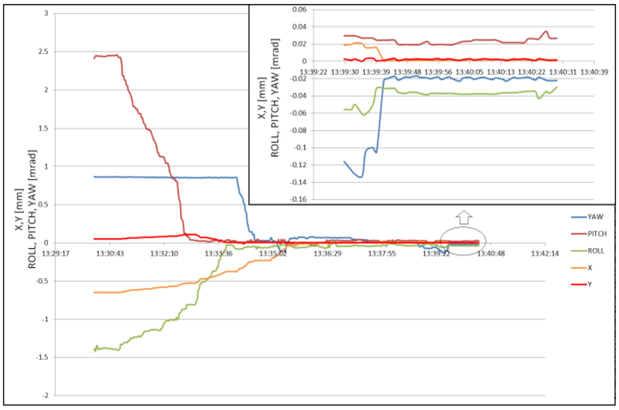

Figure 7: DBQ position adjustment example.

CONCLUSIONS

The measurements performed on 5 DOF adjustment platform have shown that the main objectives of the project have been achieved. The device provides intuitive, ergonomic adjustment of the DBQ within the technical requirements (adjustment ranges of ± 1mm, resolution lower than 5 µm) and the small space available above and around. One of the main advantage of this solution is that it can be easily motorised to make the alignment more precise and accurate, even remotely, when beam is on.

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