DESIGN, TESTING, AND VALIDATING THE CLIC MODULE PRE-ALIGNMENT AND ALIGNMENT SYSTEMS

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Abstract

The Compact Linear Collider requires micron-level alignment of the key accelerator components within the two 21 km main LINACs to achieve the desired luminosity. Several Super Accelerating Structures (SAS) will be pre-aligned on a single common support structure to within 14µm. This common support structure will then be actively aligned relative to a Machine Reference Network, and in operation beam-based alignment will be used to achieve the final 1 µm alignment required. A design for the SAS pre-alignment system has been created, prototyped, and tested, and shown to match the design performance within 2.3 µm/turn, and to meet the specification requirements. A design for the active girder alignment system has also been created, prototyped, and initial testing has begun. This testing indicates that the system works as designed. Finally, the testing required to confirm this, and to fully validate the CLIC alignment procedure, is discussed.

CLIC MODULE ALIGNMENT

The Compact Linear Collider (CLIC) is a proposed electron-positron collider with a centre-of-mass collision energy up to 3 TeV [1] and a high luminosity of $1.5 \times 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ [2]. CLIC will use a two-beam acceleration process where RF power extracted from a low-energy high-intensity Drive Beam is used to accelerate a high-energy Main Beam. The luminosity requires an extremely low Main Beam normalised vertical emittance (20 nm) at the end of the LINACs [3]. As the main source of emittance growth is the misalignment of the accelerator components, tight position tolerances for the Two Beam Module (TBM) components are required [3, 4].

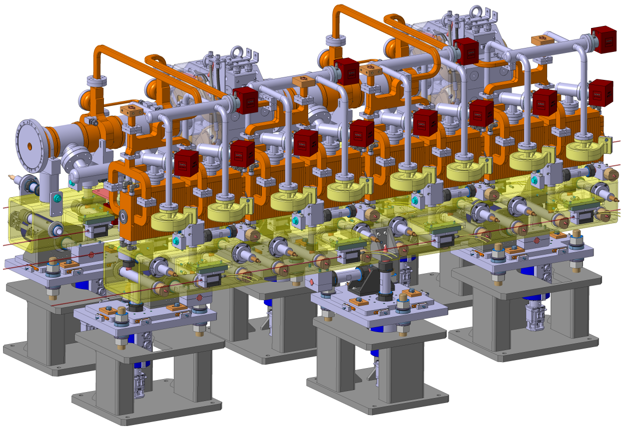

Figure 1: A CLIC Two Beam Module (TBM)

The CLIC TBM mounts the Drive Beam and Main Beam components on two separate structural members, or girders. These components are pre-aligned relative to each other with a Coordinate Measuring Machine (CMM) before the module installation in the tunnel. This technique was developed and demonstrated as part of the PACMAN project [5].

The Super Accelerating Structures (SAS) must be pre-aligned to the Machine Reference Network (MRN) to within 14 µm. To account for manufacturing errors in the SAS and girders, the aim of the pre-alignment system is a resolution of 1 µm over a range of 3 mm. Once installed in the tunnel the structural support members will be actively positioned relative to the MRN with a resolution of <1 µm over a range of 6 mm. A standard rectangular-section steel beam is used to optimise the stiffness of the girder while reducing the material cost of each module. A schematic is shown in Fig. 2.

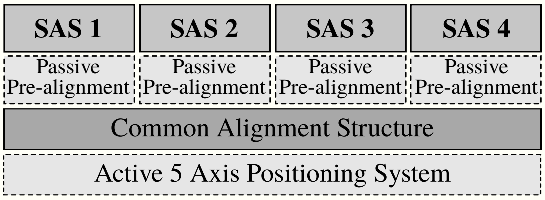

Figure 2: A schematic of the CLIC TBM alignment system.

ACCELERATING STRUCTURE PREALIGNMENT

The SAS pre-alignment system (Fig. 3) consists of six universal joints [6], which are very stiff in one axis but accommodate movement in all other axes. These are configured to perfectly constrain the SAS position by three vertical joints, which define the vertical position, pitch, and roll, two lateral joints, which control lateral position and yaw, and a single longitudinal joint which defines the longitudinal position. Two micro-adjustment mechanisms produce a 30µm – 40µm change in SAS position per manual revolution and allow the sub micron positioning of the SAS. As pre-alignment is only performed once or twice, component wear is negligible, but appropriate materials (e.g. sintered bronze) will still be used. The kinematics of this system intrinsically accommodate thermal expansion of the structures within the specification.

For integration, the joints and adjustment mechanisms are installed within the structural steel profile. To test the functionality of the pre-alignment system, a test programme was carried out.

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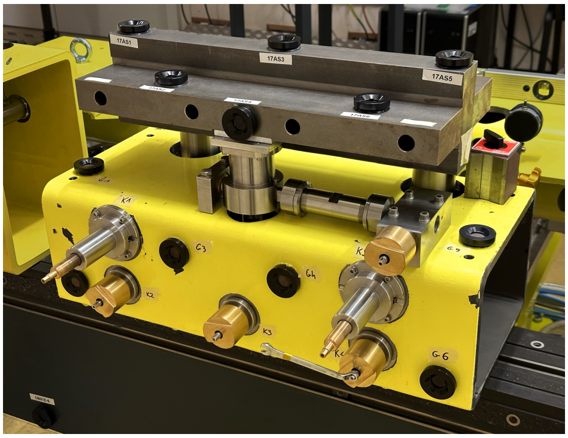

Figure 3: The CLIC SAS Pre-alignment Platform Prototype.

Firstly the motion of the axes was individually characterised. Fig. 4 is an example of the translation produced by turning the Vertical 2 adjustment point a given number of turns, where the trendline provides the average adjustment rate (gradient) and the average backlash (x-intersect). For all the axes measured, the average adjustment rate was within 2.3 µm/turn of design (standard deviation 1.6 µm/turn), and the average backlash when changing direction was 19.9 µm (standard deviation 6.8 µm). It should be noted that backlash was not intentionally avoided during testing, and can be eliminated by correct operational procedure.

Secondly, the adjustment platform was tested using a laser tracker. The platform was moved to a series of predetermined positions by turning the adjustment points a known number of revolutions. These positions were chosen to characterise the ability of the platform to move in all six degrees of freedom. The measured position of the SAS was compared to the predicted position based on a MatLab Simulink model of the support. A table of these results is given in Tab. 1. The per-turn errors are between 1-3µm, and <1µrad, consistant with the previous testing. All tests relied upon manually counting revolutions, which introduced error. When replicating the CLIC pre-alignment procedure the SAS was positioned to <1 µm in all axes.

Table 1: The per-turn differences between the measured and predicted displacements (µm/µrad).

Movement	Tx	Ty	Tz	Rx	Ry	Rz
Vertical	0.38	1.13	-0.5	0	-0.01	0
Radial	-0.89	1.56	-1.44	-0.01	0.01	-0.01
Longitudinal	-1.94	2.61	-0.17	-0.01	0	0.01
Pitch	0	-0.5	-0.25	-0.17	0	0
Roll	1.06	0.44	-0.44	-0.17	-0.38	0.01
Yaw	0.83	3.06	-0.39	-0.01	0	-0.21

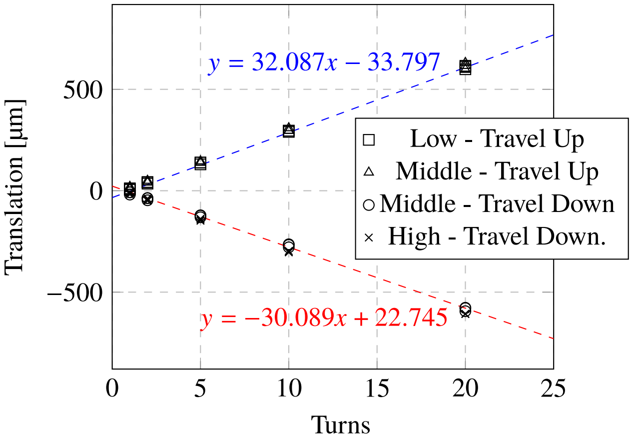

Figure 4: The translation of the Pre-alignment Prototype Vertical 2 (central) axis measured at three points of travel, and in both directions.

ACTIVE GIRDER ALIGNMENT

The active girder positioning system is kinematically similar to the pre-alignment platforms; relying on six universal joints to perfectly constrain the position of the girder, however larger joints used for the required stiffness [7]. The girder is moved using five high resolution linear actuators and the position will be measured by Wire Position Sensors (WPS). The longitudinal position is fixed. Joints allow the girder to expand due to temperature changes. Sliding component materials have been chosen to reduce wear.

An actuator control system has been created using LabView and used to perform the initial testing. This used a single comparateur to measure the girder position, and therefore only measured pure translation. As with the SAS pre-alignment system, the physical prototype has been compared to a digital replica within Matlab Simulink. This model can be seen in Fig. 6. Using this model it is possible to simulate the effect of moving the linear actuators by a certain number of steps, or a known actuator displacement.

A plot showing the measured and predicted displacements of the girder (Fig. 7) is given in Fig. 5. The motion of the girder closely matches the simulation. A small amount of

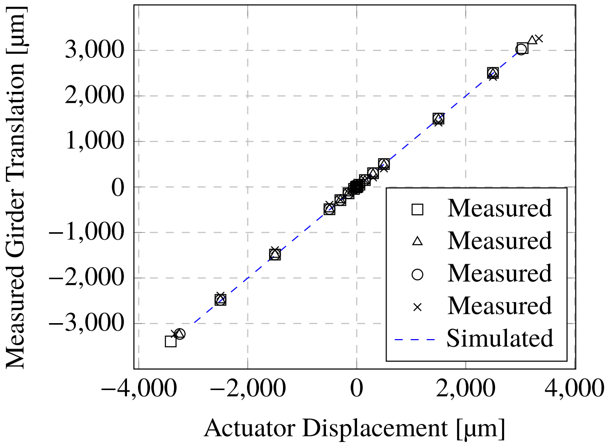

Figure 5: The translation performance of the Pre-alignment Prototype Vertical 2 (central) axis.

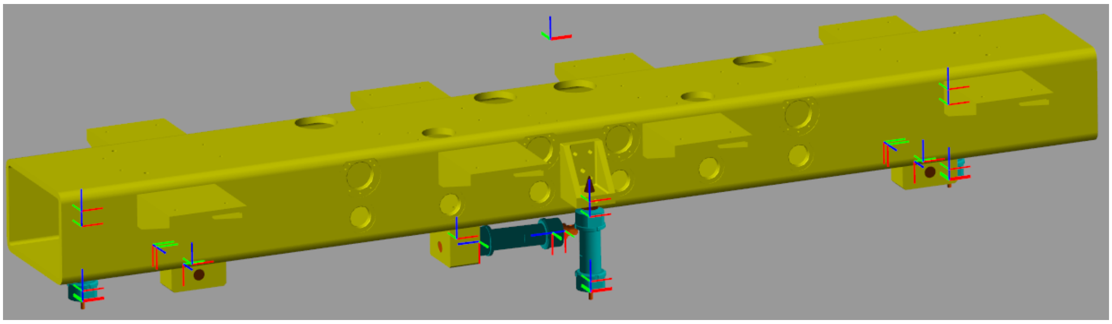

Figure 6: The MatLab Simulink kinematic model of the active girder positioning system.

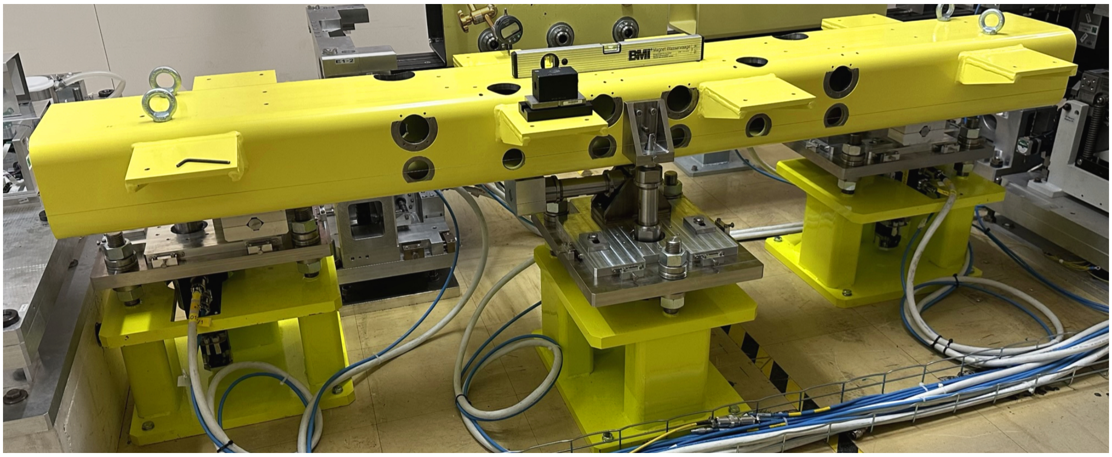

Figure 7: A photo of the prototype girder and the active positioning system.

backlash (<20 µm) was measured when returning the actuators to the zero position but is not visible on the scale of Fig. 5. This could be due to the calibration of the actuator home switches, or due to unintended clearance within the joints, and requires further study. The girder positioning system is susceptible to parasitic motion, where a ±3 mm translation in the vertical axis is expected to produce a ±35 µm translation in the lateral axes, and vise-versa. This is a known affect which can be corrected for in the lateral axes, and is less significant in the longitudinal axis. Parasitic motion also impacts the axis of motion, but is a second order affect on the scale of nanometres, so is not of concern here. Further testing will integrate the two alignment systems, and verify the full CLIC alignment scheme.

CONCLUSION

The CLIC SAS pre-alignment platform has been shown to meet the specification requirements, allowing the <1 µm positioning of the SAS in six axes over >2.5 mm. When measured directly and with a laser tracker the per-turn errors are between 1-3 µm, and <1 µrad, and the average backlash is 19.9 µm, however both of these can be entirely eliminated by following the correct alignment procedure. A prototype active girder alignment system has been assembled and initial tests have been performed. The results of these tests have been positive and indicate the system functions as designed. Further testing is needed to fully demonstrate the CLIC alignment concept. This will include a feedback system using wire position sensors, integrating the pre-alignment and active alignment systems, and vibration stability testing.

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