ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-THPGW058

DESIGN AND STUDY OF A 6 DEGREE-OF-FREEDOM UNIVERSAL ADJUSTMENT PLATFORM FOR HL-LHC COMPONENTS

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Abstract

In the accelerator domain, the safe and easy alignment of components located in radioactive areas is a main concern. The position of devices, such as magnets and collimators, has to be adjusted in a fast and ergonomic way to decrease the ionizing dose received by the personnel. Each equipment type has its own unique set of requirements such as the weight, or the desired position accuracy. The two opposite approaches are, on one hand, a simple and time-consuming manual adjustment, using regulating screws and shims, and on the other hand, the use of precise and expensive automatic positioning stages and platforms. In the frame of the High Luminosity LHC project, in order to fulfil the safety and technical requirements of alignment for lightweight components, a standardised system is under development. Its target is to provide an easy, low-cost and fast adjustment capability for several type of components that could be embarked on it. This paper describes the design, the study and the test results of such a universal adjustment solution. The engineering approach, the lessons learned ("know how"), the issues to be addressed and the mechanical components behaviour are presented.

INTRODUCTION

The LHC will increase its integrated luminosity by a factor 10 beyond its original design value with the replacement of more than 1.2 km of components in the Long Straight Sections (LSS) around the ATLAS and CMS detectors [1]. In order to ease the adjustment of the lighter components of the LSS, mainly vacuum equipment, beam instrumentation and collimators, a Universal Adjustment Platform (UAP) is proposed as a part of the Full Remote Alignment strategy adopted for the HL-LHC baseline [2]. The UAP has all the adjustment knobs located on the transport zone side and provides an intuitive repositioning kinematics. A concept of adjustment platform is proposed and qualified, to be integrated, scaled and easily adapted by the equipment owners to support their components. After a description of the platform itself, the first prototype and the associated results of the qualification tests are detailed.

UNIVERSAL ADJUSTMENT PLATFORM

Description of the Platform

The UAP performs the adjustment of lightweight (less than 2t) accelerator components, with accuracy of ±50 µm, by using a set of standardised joints and adjustment jigs. Figure 1 shows the conceptual schematic of the typical UAP mechanics and groups all main subcomponents of the system. Each UAP consists of three subcomponents (Figure 1):

- The Top plate (green in Figure 1) is the support for the accelerator equipment to be adjusted. This part is customizable by the platform equipment owner and can be adapted to the needs of the supported equipment;
- The Bottom plate (blue in Figure 1) is the stationary platform base, fixed to the tunnel floor support. This part includes adjustment jigs and knobs axes. It can be also customizable by the user;
- A set of standardised components: vertical adjustment jigs, radial adjustment jigs, joints and knobs, which are used to adjust the position of the Top plate w.r.t. the Bottom plate.

The UAP standardised components will be produced in series to decrease the overall cost of the system. The equipment owner (user of the specific UAP) will be in charge of the design and integration of the Top and Bottom plates and to scale them to the dimensions of the component installed on the Top plate. The design process is assisted by the UAP design guidelines.

An initial survey of the possible use cases of the platform for HL-LHC components showed that platforms could be divided into two categories:

- Smaller components weighing less than 300 kg (Small UAP), i.e. for valves, beam position monitors;
- Heavier equipment, weighing less than 2000 kg (Big UAP), i.e. for collimators and small masks.

The design methodology for Small and Big UAP will be the same, however each type will need a dedicated family of joints and adjustment jigs to comply with the maximum load requirements.

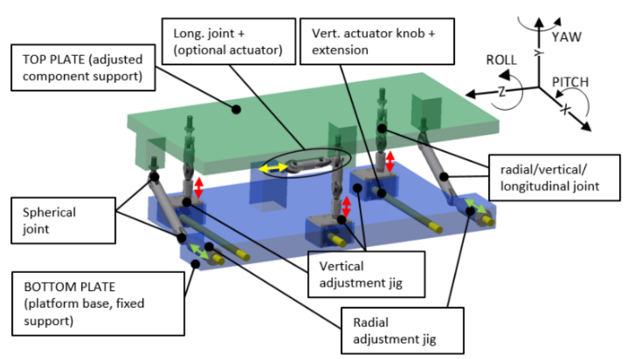

Figure 1: UAP conceptual schematic.

Operation Scenarios

Since the regulation knobs will all be present on the transport side of the platform, three possible operation scenarios can be implemented:

- Manual operated UAP (Figure 2a) – in the low radiation zones, where longer personnel access is possible;
- Fully motorized UAP (Figure 2b) – for high radiation zones, where limited or no access is provided;

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- Temporary motorized UAP (Figure 2c, 1-3) with a mobile plug-in adapter for intermediate level radiation zones, where access is limited, but feasible for short periods. It allows local adjustment from a safe distance to decrease radiation dose to personnel [3].

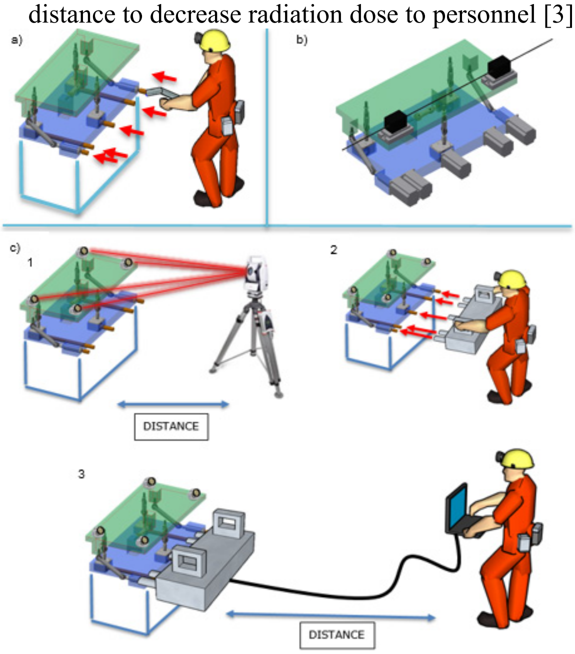

Figure 2. UAP operation scenarios.

Platform Integration and Design Approach

The main objective of the UAP project is a standardisation of the kinematic configuration for all future platforms. Considering the project requirements, the solution chosen is to use a modified "Stewart platform" configuration, derived from the CLIC DBQ adjustment platform [4]. Here, the support's geometry was changed from a "hexapod-type" to a "vertical-horizontal-longitudinal" configuration (Figure 1). Three vertical adjustment jigs (red, Figure 1), linked via double spherical joints to the Top plate of the platform, perform the vertical movement, pitch and roll rotations of the Top plate. The vertical jigs are displaced homogenously in a triangular pattern. Two jigs are placed at the rear of the Bottom plate and one on the front. Two radial adjustment jigs (green in Figure 1) with appropriate joints, drive Top plate movement along X axis and yaw rotation. The radial jigs are placed at the extremity sides of the Bottom plate. For the longitudinal direction alignment, two options are considered:

- A configuration with only one double-spherical joint (yellow in Figure 1), to perform all rotations, but will block the displacement in Z axis. In this case, the platform will only provide a 5 Degrees Of Freedom (DOF) adjustment;
- With a longitudinal adjustment jig, driving double spherical joint linked to the TOP plate. In this case, the platform will provide a 6 DOF adjustment, as the Z direction will be driven by an adjustment jig.

Such a kinematic configuration provides:

- A three-point support of the Top plate and the distribution of the vertical adjustment jigs over the Bottom plate. The vertical adjustment jigs operate as a 90 degree gearbox, so with such a pattern of adjustment jigs, their knobs can be connected to the adjustment jigs from one side of the platform (Figure 1);
- Radial adjustment jigs embedded on the sides of the Bottom plate (Figure 1), with all knobs accessible from one side of the platform;
- This results in the creation of an intuitive platform adjustment configuration. Vertical supports mainly act on the Y translation, roll, and pitch rotations. Horizontal supports have a main impact on X translation and yaw rotation. Longitudinal support acts on Z displacement.

UAP PROTOTYPE

To verify the assumptions of the project and identify possible future issues, prototype series of standardised components and a preliminary prototype of Small UAP were designed and manufactured at CERN.

Standardised Components

- The vertical adjustment jig was designed as a worm gear jack (Figure 3). Radial and axial backlash on the piston screw were minimized to 10 µm by selecting the appropriate design tolerances.

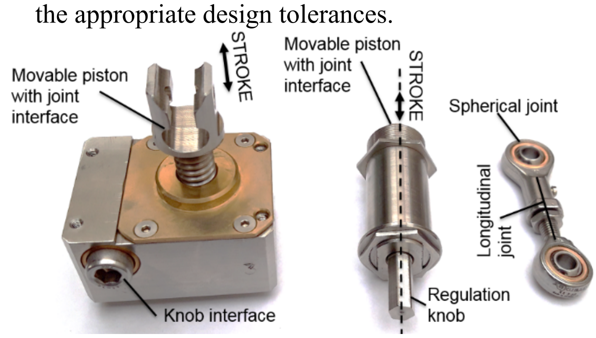

Figure 3. Left to right: vertical, radial adjustment jigs and double-spherical joint.

- The radial adjustment jig was designed as a precise screw adjuster (Figure 3). Thanks to such a design, the radial jigs knobs are also accessible from the Bottom plate transport side of the platform. The radial and axial backlash on the piston were minimized to 10 µm by selecting the appropriate design tolerances.
- The (double) spherical joint linked by longitudinal joint (Figure 1, 3) will provide the necessary DOF for the Top plate and for the radial/vertical adjustment jig. For prototype purposes, standard and market accessible spherical joints with studs were used in the test series (Figure 3), with a typical backlash of 20 µm.

Platform Prototype

The prototype platform (Figure 4) was designed to be as simple and as cost efficient as possible. The standardised jigs were embedded into the Bottom plate. The Bottom plate, the Top plate and other plate 'like' components were designed for CNC cutting (i.e. water, plasma or laser), in order to minimize the cost of the parts. The machining was

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limited to drilling and threading the necessary holes. The front "knobs" panel was designed as a plate with machined bearings sockets to support the axes of the vertical jigs knobs.

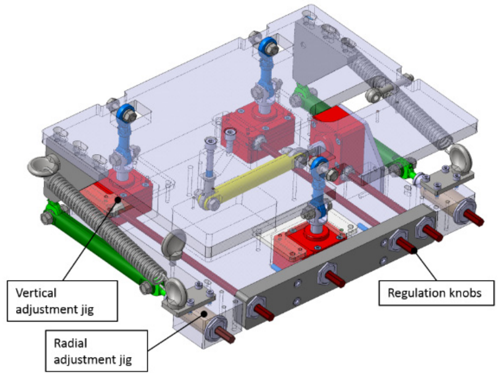

Figure 4. Small UAP prototype design.

PRELIMINARY TEST RESULTS

The objective of the UAP prototype preliminary tests was to validate the standardised components' functionality and ergonomics, and to estimate the impact of components backlash and stiffness on the platform kinematics.

Jigs Radiation Test

The adjustment jigs design is mainly based on stainless steel and bronze materials. The chosen grease was Molycote BR2 plus. The series of radial and vertical jigs were irradiated at the Fraunhofer Institute in Euskirchen, Germany, with γ-irradiation to reach a total ionizing dose of 3 MGy (considering the worst-case of 2 MGy predicted for HL-LHC operation). The samples showed no visible damages or performance loss after the irradiation.

Jigs, Joints and UAP Prototype Tests

The jigs and joints were tested first to verify the components' backlash and adjustment resolution. For the vertical jigs pre-series, the piston axial backlash was in the range of 10 - 60 µm along the piston stroke. For the radial jigs the piston axial backlash was in the range of 1-15 µm. The jigs adjustment resolution was of 1 µm. The measured backlash for spherical joints was typically of 20 µm.

Once the standardised components were tested, the assembled platform measurements were performed. The basic set of tests were carried out with the following results:

- Directional backlash (w/o TOP plate load): < 90 µm;
- Stiffness in vertical: 0.8 µm/kg;
- Torque on adjustment knobs with 200 kg load on the platform: 0.25 – 2 Nm;
- Lateral stiffness (platform loaded 100 – 300 N horizontally in each direction): < 0.5 µm/kg;
- Lateral displacement of Top plate under vacuum force (2 kN applied along the X direction (Figure 1): 1.5 mm of shift;
- Stability tests – several cycles of adjustment followed by several days of platform stability measurements: no drift of position was detected.

An adjustment ergonomics test was also performed. The platform was loaded with a 100 kg load and equipped with measurement targets, to follow its position using a laser tracker. A random set of platform positions and rotations was generated as the adjustment set points. Two configurations of adjustment actions were tested: first only shifts (single/all axis), then shifts combined with rotations. The operator's role was to reach the position as fast as possible, with the platform's position adjusted within +/- 50 µm (typical LHC adjustment requirement). Each adjustment always took less than 15 minutes (comparing to 1 h of typical adjustment time for similar object) to reach the requested position (Figure 5). The platform adjustment time depends on the operator's experience and is shorter after several cycles of adjustment. Moreover, all adjustments were done in 2-iteration steps: 1) preliminary measurement – adjustment; 2) measurement – fine adjustment – position check. By increasing the number of adjustment iterations, the final adjustment accuracy can be lower than 20 µm.

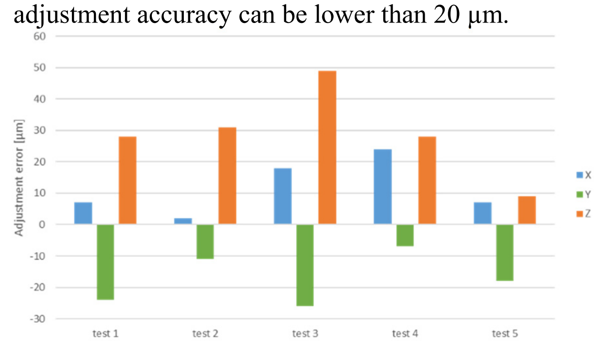

Figure 5. Example - adjustment error result.

CONCLUSION

The preliminary test of the platform brings very promising results for the final UAP version. The ergonomics and functionality tests confirmed the easy and fast adjustability of the platform. Some updates in the design are necessary to reduce the backlash of jigs and joints. This will be the target of a second phase of UAP prototype tests, which is now under preparation. Adjustment ergonomics tests fulfilled the time and precision requirements.

Once the prototype of the platform will be validated, the industrialization process of the standardised components can start. In parallel, the production, design and qualification tests of the Big UAP prototype will be performed.

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