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Automated Assembly of the ATLAS ITK Pixel Detector using the Pick&Place Technique(*)

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Summary. — The new upgrade program for LHC foreseen for the 2026, will lead to the replacement of the entire tracking system of the ATLAS experiment (The ATLAS Collaboration, *JINST*, **3** (2008) S08003). The ATLAS vertex detector will be a silicon pixel detector, the largest ever built (13 m^2 active area), with a very high spatial granularity (50 μm × 50 μm), radiation hard (up to 1 Grad) and featuring an unprecedented data rate (thousands of optical links at 5.12 Gbps). The Italian ATLAS Collaboration has the responsibility for the construction, test, and commissioning of about thirty detector rings that will be mechanically located on three cylinders. In this paper, we describe the automated assembly technique developed by the Italian sites involved in the pixel ring construction.

1. – Pixel module loading setup

In Italy, there are two sites deputed for the construction, test, and commissioning of the loaded local supports (Half Ring) that are part of the new ATLAS Outer Endcap [2]. The pixel module loading technique of the two Italian sites is based on a semi-automatic ″pick-and-place” strategy performed by a general-purpose large area precision gantry. The gantry is equipped with a custom head holding the tools needed for gluing, loading and, doing metrology, which is programmed to perform the full module loading procedure on Half Ring with a minimal human intervention.

Both sites purchased the same gantry from PI (Physik Instrumente) with x, y, z and θ stages and honeycomb optical breadboard of 1 m x 0.8 m working area. The repeatability of the gantry positions has been measured to be of the order of 5 μm. The absolute precision is obviously dominated by the mechanical deformations of the gantry and by the head components. However, a large fraction of these imperfections is systematic and can be corrected with an appropriate calibration. The resulting absolute precision over the full working area after calibration is of the order of 20 μm. Figure 1 shows on the left a picture of one of the gantries and on the right the residuals map of the x coordinate. The calibration was obtained by mean of an optical calibration plate

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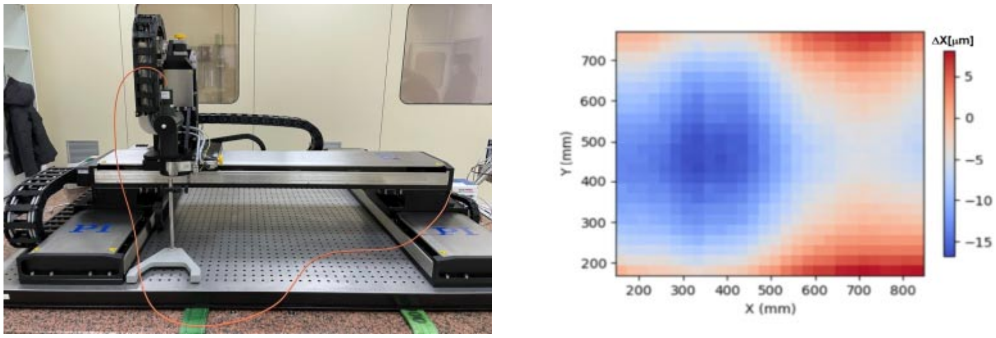

Fig. 1. – Left: PI gantry robot used for pixel module loading. Right: residuals map of the gantry x coodinate after calibration.

and using an automatic pattern recognition procedure. As can be seen from the residuals map, the precision over the full working area is better than 20 μm.

Figure 2 shows the custom heads of the two sites equipped with all the tools needed for loading. A key point of the loading-head design is the suction cups tool mounted on the θ stage with a load cell. In this way during module handling (pick-up, placement and, glue curing) a continuous measurement of the force exerted is available. In particular, during placement above the patterned glue layer, the correlation between load cell weight reading and final glue layer thickness can be used, together with the reading of the position of z stage encoder, to ensure the correct glue coverage and thickness during curing. Pressure control is also useful when the glue is doped with silica spheres of precisely controlled diameter to enforce a minimum glue thickness, because it can prevent excessive forces to be applied on a limited surface of the pixel array bump-bonding.

The z stage of the gantry's head holds the syringe of a volumetric glue dispenser used to deposit a precise SE4445 glue pattern on the Half Ring surface before placement. The geometrical precision of the pattern is guaranteed by the gantry while the uniformity in volume is guaranteed by the volumetric dispenser speed deposition in addition to a cross-synchronisation. The volume and shape of the deposited glue can be checked after each 4-fold pattern deposition by scanning it with the z-profilometer (a chromatic cofocal sensor) held by the gantry y stage, that provides contactless z height measurements with a prescision of 1 μm.

Finally, the z stage holds a camera with a microscopic telecentric lens, allowing precise 0.7 μm measurements on the x-y plane.

Vacuum parking tools are located on the periphery of the gantry breadboards which primary function is to hold modules in position during metrology and pick-up.

2. – Pixel module loading procedure

We describe here the main steps performed for gluing a module on the Half Ring. In this phase, the Half Ring bare support is mounted on its handling frame with the bus tapes already glued on both sides.

- The handling frame is fixed on the gantry's breadboard. A height map of the local support is measured using the z-profilometer to cross-check global and local planarity with respect to the gantry's head.

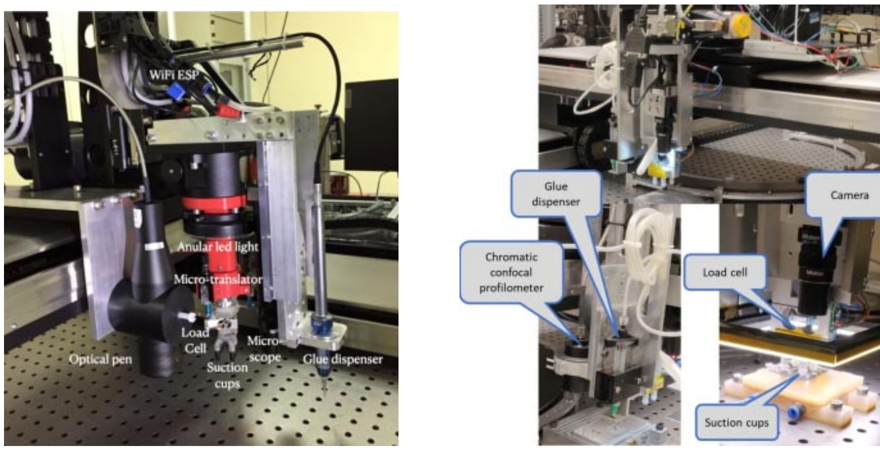

Fig. 2. – Gantry's custom heads holding the tools needed for Half Ring module loading in Lecce site (left) and Genova site (right).

- Half Ring metrology is performed measuring the (x,y) coordinates of the Half Ring fiducial points with respect to the gantry's reference frame (x and y stages encoder readings) and using a microscope fixed on the z stage.
- The module is prepared for loading by manually placing it on the vacuum parking tool using a vacuum pick-up pen. Using the gantry's microscope, the (x, y) coordinates of the module's fiducial points are measured and the module's central position and orientation before pick-up are calculated.
- The pick-up is performed using the suction cups hosted on the gantry z stage (300 g force measured by the load cell). The module is placed on the half-ring in the pre-calculated position without glue (dry-run). This is useful to verify the correct positioning and to measure the module height map when positioned on the Half Ring without glue. The module is then picked up again and left on the gantry's head.

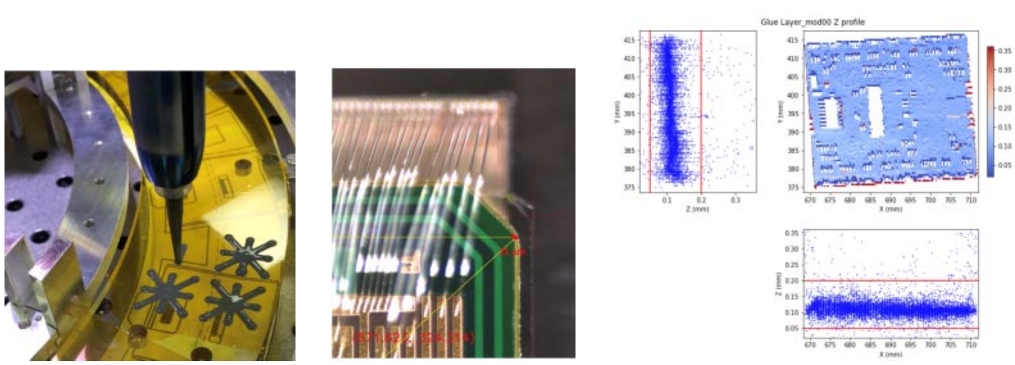

Fig. 3. – Left: glue deposition and glue pattern of snowflakes shape. Center: XY module metrology on half ring after gluing. Right: z metrology of the module on Half Ring.

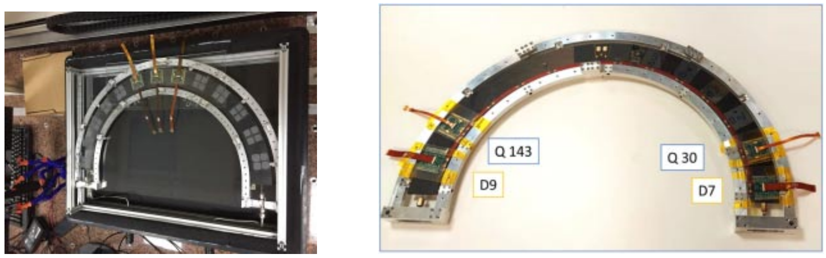

Fig. 4. – Partially loaded Half Rings: old design one without bus tape in Lecce (Left) and final design one with bus tapes in Genova (Right).

- A complete glue pattern having a shape of four snowflakes with eight radial rays is deposited on the Half Ring surface where the module should be placed, a snowflake for each FE chip (see fig. 3 (left)).
- The module is placed in the nominal position and angular orientation above the glue pattern. The applied force is typically 300 g. The module is kept in position by the gantry's head for curing time of the glue (∼30 min) sufficient for a safe release of the gantry's head.
- Using the gantry's microscope, the (x, y) coordinates of the loaded module's fiducial points are measured and the (x, y) residuals calculated (see fig. 3 (center)). Using the z profilometer, the z height map of the loaded module is measured after gluing, and the achieved glue thickness map is calculated by subtracting the dry-run z height map (see fig. 3 (right)). As we can see from fig. 3 (right) the glue thickness is within the specifications (between 50 and 200 μm). The no-planarity compensation is ensured by mixing the glue with 106 μm diameter silicon spheres for a 1% concentration in the total glue weight and using suction cups with good elesticity.

3. – Conclusion

Figure 4 shows the two prototype Half Ring realized in Lecce (left) and Genova (right) for the Loaded Local Support Final Design Review [3]. In Lecce, three modules, one RD53a digital quad e two RD53a quads, were glued on an old design Half Ring. In Genova, four quad modules, two RD53a and two ITkPix v1.1, were glued on a final design Half Ring. All the quad modules were tested before and after loading and using the final cooling system. Finally all the glue thickness and placement positions were inside the mechanical specifications.

REFERENCES

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