euspen's 17th International Conference & Exhibition, Hannover, DE, May 2017
www.euspen.eu

Development of an automated assembly machine for the particle tracking system of the ALICE detector upgrade at CERN

Ivo Widdershoven, Arjan van der Wel, Ivo Hamersma, Henny Spaan

IBS Precision Engineering, Eindhoven, the Netherlands

Widdershoven@ibspe.com

Abstract
As part of the upgrade of the ALICE detector at CERN (the European Organization for Nuclear Research), IBS Precision Engineering has developed a series of machines for automated assembly of sensor modules. The main requirements are to achieve a 5 µm positioning tolerance of chips and to join them to a flexible printed circuit with about 70 interconnects per chip. In addition, chips need to undergo multiple measurements, functional tests and inspections during the assembly process.

Keywords: Automated assembly, machine vision, CERN, Big Science

1. Introduction

ALICE (A Large Ion Collider Experiment) is one of four detectors (Figure 1a) of the Large Hadron Collider (LHC) at CERN (European Organization for Nuclear Research). ALICE studies quark-gluon plasma, a state of matter thought to have formed just after the Big Bang [1]. During the LHC shutdown in 2019/2020, CERN will upgrade the ALICE Inner Tracking System (ITS) with a new low-material and high-resolution tracker, improving features like spatial resolution, tracking efficiency and read-out rate capabilities [2].

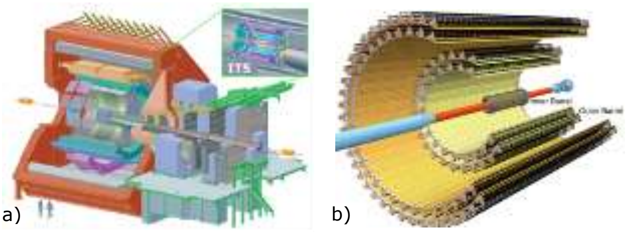

Figure 1. a) Cross-sectional view of ALICE detector, with detail of Inner Tracking System. b) Schematic of new ITS (pictures courtesy CERN).

The new ITS consists of seven concentric layers of pixel detectors (Figure 1b). The pixel sensor element is a silicon chip of 15 mm by 30 mm, incorporating a matrix of charge collection diodes (pixels, with a pitch of 30 µm). The passage of particles through a pixel chip is read out and the trajectory of the particle can be accurately determined.

The key module of the new ITS is the Hybrid Integrated Circuit (HIC) consisting of a Flexible Printed Circuit (FPC) carrying an array of pixel chips. IBS Precision Engineering was tasked with the development and realization of seven machines for the automated assembly of HICs, to be delivered to CERN and six other sites around the world. Together, these machines will enable the assembly of over 30.000 chips.

2. Functional requirements of the assembly machines

The main assembly requirement is the positioning accuracy of the chips to within 5 µm with respect to external reference features.

Additional functional requirements include:
- Optical inspections (chip edge, contact pad cleanliness).
- Optical measurement of chip dimensions.
- Electrical testing of chips using needle probe card.
- Self-validation and correction during assembly process.
- Enabling the joining process of chips to FPS by means of laser soldering (in vacuum to eliminate oxidation).
- Optical detection of Ø 0.2 mm solder balls before soldering.

The machine design aims to meet all the requirements at a challenging cost-of-goods target.

3. Chip assembly strategy

The chips have a thickness of either 50 µm or 100 µm and exhibit undesired warping (Figure 2a); during the assembly process, they need to be 'flattened' on vacuum chucks. The goal is to position an array of chips (supplied in trays, Figure 2b) onto a vacuum chuck within 5 µm accuracy. The chips are held in place on this "assembly chuck" while the FPC is mounted and joined. The corners of the chip feature markers, for optical position measurements with a high-resolution vision system.

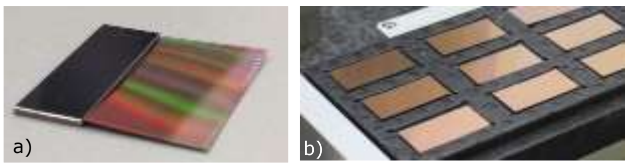

Figure 2. a) Chip showing warp up to 1mm. b) Tray with chips.

Two challenges arise:
1) Accurately measuring chip position while in the tray is not feasible. The warp makes it difficult for the vision system to focus and also affects the lateral positions of the markers.
2) The lateral position of the chips in the tray is not well-defined, and can vary by about ±1 mm.

As a result, the first pick-up of each chip from the tray is performed "blind" and the position of the chip on the gripper will not be known. In order to be able to proceed with the assembly process, the machine includes a "pre-positioning chuck", an additional vacuum chuck used to flatten the chip, allowing its position to be measured before it is placed onto the final assembly chuck.

4. Machine layout

The concept sketch in Figure 3 shows the tray, the pre-positioning chuck and the assembly chuck. An XYZ stage positions the three modules involved in the assembly procedure: gripper, vision system and soldering laser.

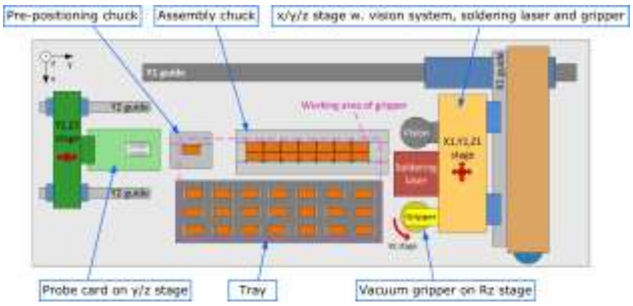

Figure 3. Schematic diagram of assembly machine (top view).

As the assembly operation is mostly planar, the required stroke of the vertical (Z) axis is small. This stroke was minimized to 4 mm, allowing use of an elastic flexure guide, see Figure 4.

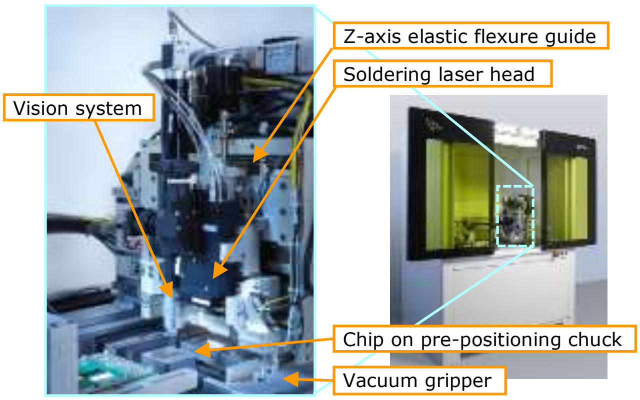

Figure 4. Assembly machine and close-up of Z-axis with critical modules

5. Pre-positioning chuck

In the design of the vacuum chucks, the vacuum levels were differentiated over the chip area, to obtain sufficient flattening at the corners where the chip markers are located. Figure 5a also shows the reference markers of the pre-positioning chuck. These markers are placed on a raised surface, so that they are at the same focus height as the markers on the chip surface.

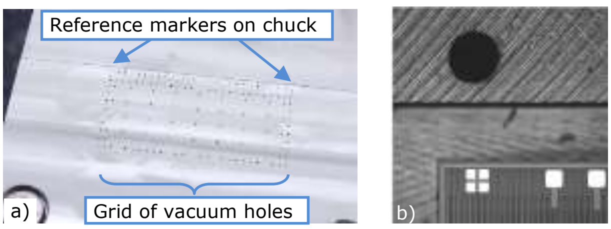

Figure 5. a) Pre-positioning chuck. b) Vision image showing reference marker on pre-positioning chuck (circle) and chip marker (square).

An example of an image captured by the vision system is shown in Figure 5b; by measuring two chip markers with respect to the two reference markers, the position and orientation of the chip is determined with sub-micron accuracy.

6. Assembly and inspection sequence

The chip positioning sequence proceeds as follows:

- Chip is taken from tray and placed on pre-positioning chuck; its position is measured by the vision system.
- Chip picked up and positioned correctly on assembly chuck.
- Measure chip position on assembly chuck.
- Optional re-positioning, only if required.

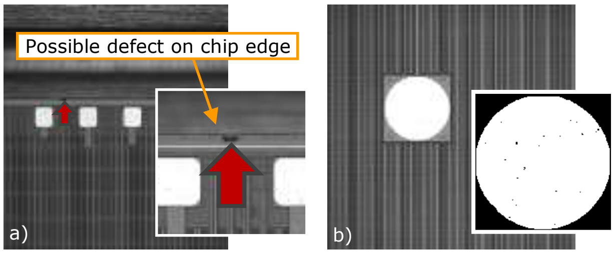

Figure 6. a) Edge inspection. b) Cleanliness inspection

The vision system also performs optical inspections and measurements of the chips during the sequence (Figure 6):

- Integrity of the edges (e.g. crack detection and evaluation).
- Dimension measurements of the chip (i.e. check correct dicing of the chips), with sub-micron repeatability.
- Cleanliness of the contact pads (to prevent that contamination affects the soldering joints).

Rejected chips are discarded and replaced by a new chip.

When all chips have been placed on the assembly chuck, the FPC is mounted on top (Figure 7). Laser soldering is performed to create interconnects between the FPC and the chips.

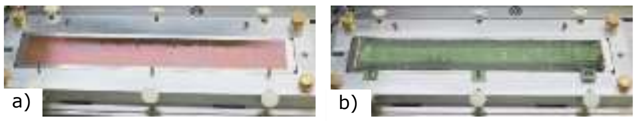

Figure 7. a) Assembly chuck with 14 chips. b) FPC mounted, prepared for joining of FPC to chips.

8. Assembly results

Figure 8 shows the position accuracy of 14 chips on the assembly chuck, measured by the vision system in a final validation. Chips in the top row are always positioned correctly at first attempt; chips in the bottom row typically require one re-positioning, due to the fact that these chips are rotated by 180° with respect to the orientation on the pre-positioning chuck; this rotation adds to the positioning error. Final acceptance is only achieved when all chips are positioned within the 5 µm tolerance (red circle).

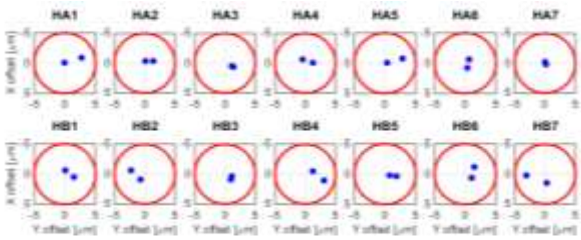

Figure 8. Positioning accuracy of 14 chips on the assembly table. Blue dots show position errors of chip markers, within the 5 µm tolerance.

9. Conclusion and outlook

The design of the machine has been shown to meet all critical requirements; in May 2016, the first assembly machine was delivered to CERN and extensive process testing was started. By the end of 2016, six additional machines were realized and delivered to institutes around the world.

References

[1] https://home.cern/about/experiments/alice
[2] http://aliceinfo.cern.ch/ITSUpgrade/