01005 production goes industry wide

Satoshi Kataoka, Production Manager, Assembléon Asia Pacific Region and Eric Klaver, Commercial Product Manager, Assembléon, The Netherlands

The introduction of the 01005 chip components in 2004 was a challenge to the whole electronics equipment assembly industry. The components' miniature size made them difficult to see, let alone place reliably with high accuracy. Designers were reluctant to design them in – even for cellphones and PDAs where space is critical. Even now, 'mainstream' mass production has avoided them as being too challenging.

Their use has therefore mainly so far been confined to modules, where they increase integration levels while improving RF characteristics and consuming less energy. So, in fact, 01005 components have been mass produced, but by a specialized industry.

Now, though, 01005 devices are finding their way into standard consumer products. Contract manufacturers and OEMs are increasingly demanding that pick & place equipment handle the components to continue to reduce end-product dimensions and costs. Many more companies are therefore preparing for 01005 components, and are getting nervous about the prospect. Many will have heard of atrocious first-pass yields caused by misplacing the devices.

The chip components do indeed present the ultimate challenge for equipment manufacturers (Figure 1), but there is now huge experience in placing them. Assembléon machines have accepted them since 2005, and its A-Series machines have shown themselves to be inherently suited to them. The steady, controlled movement of multiple placement heads working in parallel makes for a very controlled placement process. Much more so than the gantry systems that dominate the industry, in which a single head moves at ultra-high speeds. A gantry head has a large mass, which makes it very difficult to avoid damaging the fragile components. Speeds therefore have to be (more than) halved when placing 01005 components, so increasing the costs per placement – the exact opposite of industry requirements. And, even running at half speed, the gantry placement process is not properly controlled.

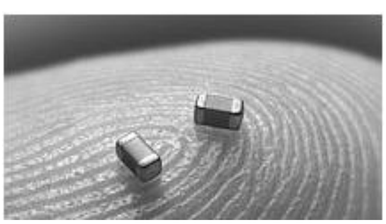

Figure 1: In 2004, Murata Manufacturing Co., Ltd. introduced the market's smallest chip component: the 01005 capacitor (0.01 x 0.005 inch; 0.4 x 0.2 mm or 0402Metric).

Results of Assembléon's research consistently demonstrate that, for successful placement, equipment assemblers must look at the process as a whole. Mixing these small components with larger ones is difficult for stencil printers, for example.

Components are also still being packaged in paper tape, creating new problems with paper dust. When choosing a placement system, it is the defect level that is important. Processes must be continually monitored to avoid placement defects. That done, stenciling and placement processes are now mature, and quality can achieve the same <10 defects per million achieved with larger components.

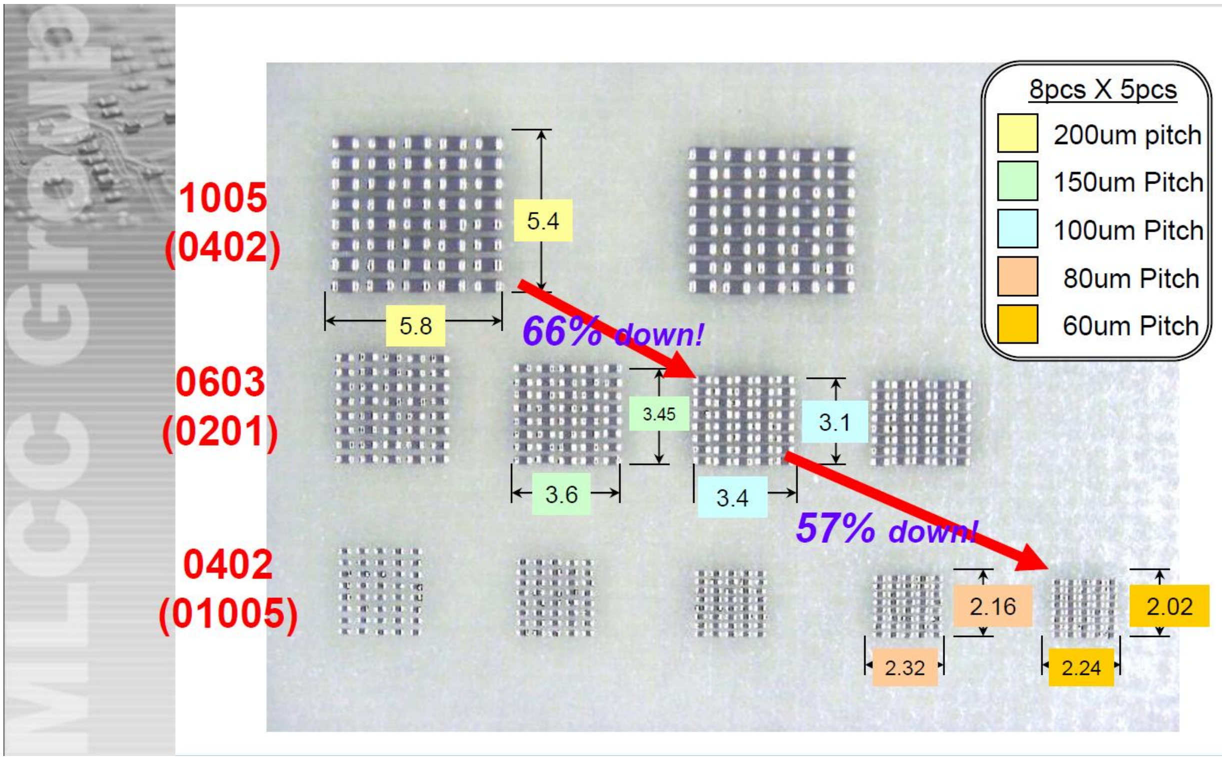

Figure 2: 01005 components reduce board area by 57% over 0201 components, which themselves reduced board area by 66% over 0402 types (source Murata).

<u>The 01005 pick process</u>

The pick process must be very stable for 01005 components. As component interspacing must be very narrow (Figure 2), the pick-up point of the nozzle must be in the center of the component. Although the component will be picked up and aligned successfully when the nozzle is off-center, placing may be unsuccessful as the nozzle offset (Figure 3) can result in placement offsets or may interfere with a neighboring component that has already been placed.

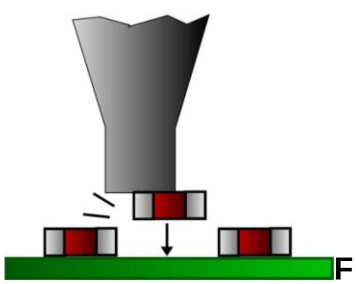

Figure 3: Nozzle offset while placing 01005 components

Assembléon's intelligent tape feeders, launched in 1998, anticipated the SMT trend toward miniaturization. Each feeder is calibrated with 30 µm index repeatability so that – even then – they could deal with 01005 components and whatever lies beyond.

The tape must be accurately positioned for a successful 01005 pick, but the type of packaging is becoming a determining factor for successful 01005 pick and placement.

Unlike conventional pneumatic, mechanical or high speed electrical tape feeding systems, feeders in a parallel pick & place system are allowed a longer index time without reducing output. The longer index time gives more time to control the index motion. By controlling the tape movement using acceleration and deceleration profiles, the component will remain as stable as possible in its cavity. An additional benefit of handling tapes with care is to reduce the effects of static electricity and the amount of paper dust when separating the cover tape from its carrier. Static electricity affects the position in the tape (disappearing, tilting, rotating component, etc). Paper dust influences the overall quality of the end product as it prevents good soldering of these small components.

The relatively large 8 mm wide tapes are just not suitable for 01005 components. The industry has recognized this by introducing a new tape (Figure 4) that is fast becoming standard: 4 mm antistatic embossed tape with a 1 mm pitch. Assembléon 4 mm feeders will fully support this new tape, also significantly reducing tape waste.

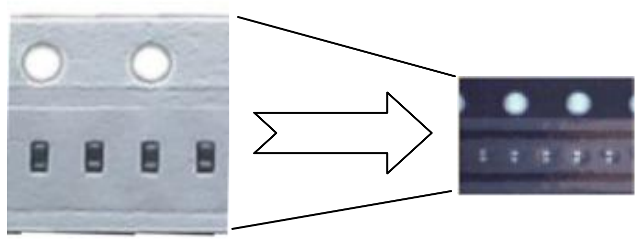

Figure 4: The industry is moving from 8 mm to 4 mm tape [source: Murata].

Controlled pick – avoiding component damage from the start
Well, not entirely from the start, since components have been handled already: a pick & place action has already taken place when the component was placed into the tape pocket. Equipment assemblers should know the characteristics of this operation.

To ensure the complete process is under control, the first step is to pick the component with a controlled force, avoiding possible component damage. Assembléon's A-Series incorporates an advanced algorithm that takes measurements to ensure that every pick is performed with controlled low forces. To ensure that what is measured is also correct, it is compared against a measured “blueprint”. Assembléon’s 6-sigma approach ensures that any mismatch will ensure the proper corrective action.

01005 alignment and transfer

Assembléon’s laser alignment unit measures components on-the-fly with an advanced interpolation algorithm of approximately 1 µm, the most accurate alignment for 01005 available The laser alignment unit can determine whether a 01005 component is attached to the nozzle on-edge or tombstoned, particularly important for (flatter) resistors, see Figure 5.

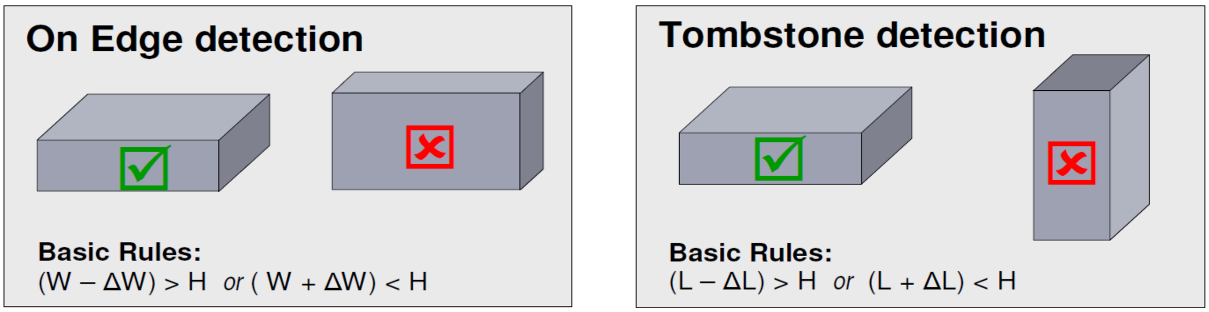

Figure 5: Assembléon’s laser alignment unit can determine whether a 01005 component is attached to the nozzle on-edge or tombstoned, particularly important for (flatter) resistors.

The unit provides non-contact high-speed positional feedback of components and determines position and dimensions by collecting and analyzing the shadows (Figure 6).

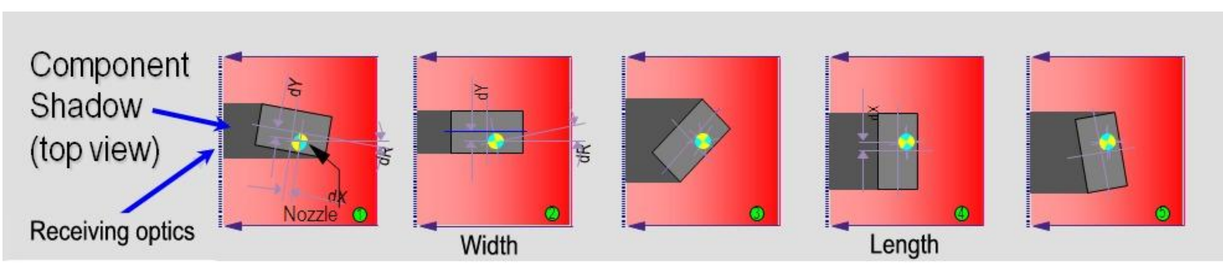

Figure 6: Shadow projections provide non-contact high-speed positional feedback on components.

The laser alignment unit also has a continuous presence check. This ensures that the component stays in its correct placement position right up to the moment when the nozzle moves down with the component to place it.

A number of tests checked the capability of the component laser alignment unit. A 01005 resistor component was first measured 100 times using the same setting. The results showed a standard deviation of less than 1 µm. Next, over 500 different 01005 resistor components were measured with a length deviation of 0.0239 mm and width deviation

0.0243 mm (both at 3-sigma, over 500 components). Length and width values are slightly larger than component specification as the measurement on the component outline included leads, which are slightly swelled out.

Placement force definition
There are two parts to the placement force: the moment of impact, followed immediately by a dwell placement force (Figure 7). For 01005 placement, very low, accurate and stable placement force control is crucial. The smaller the area of contact between nozzle tip and component, the higher the stress on the component. The best placement force of 01005 chips is 2 N or lower (but check component vendor specifications).

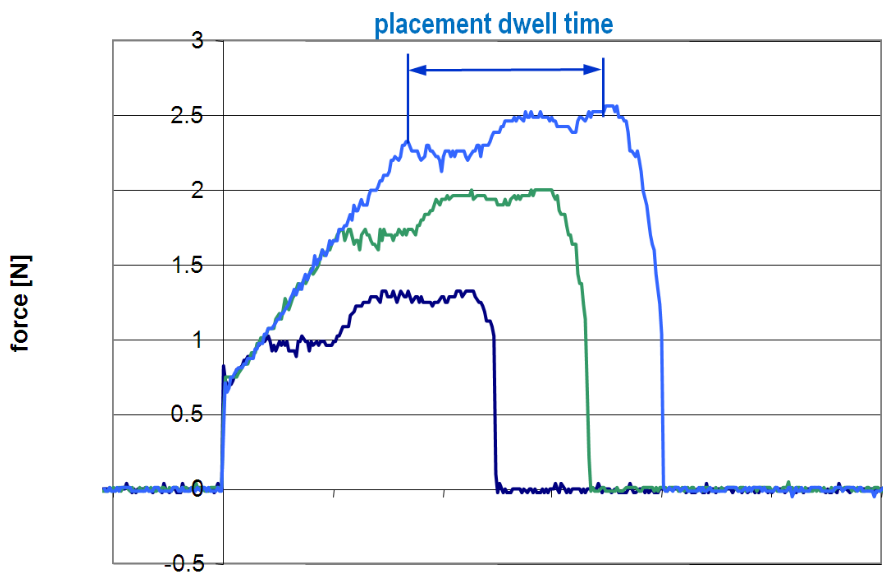

Figure 7: The moment of impact is followed by a dwell placement force.

A typical conventional placement action comprises the following actions:

a) The nozzle with component moves downwards with a maximum allowed speed and decelerates when the bottom of the component reaches a defined "search" height, which is well defined above the surface of the boards.
b) The nozzle with the component then moves down at "search speed" until it has reached a position that is a little lower than the PCB surface ("over-travel") to ensure the component is placed.
c) The dwell force is controlled by a mechanical spring, which is compressed to the defined length (over-travel length). This is normally defined with reference to the assumed board height.

Most systems use this method, but it does not guarantee successful 01005 placement. The A-Series placement process is such that there is no impact force, with the force being built up towards the required dwell force (also known as static force).

<u>Placement dwell force</u>
On conventional systems, the length of the mechanical spring determines the placement dwell force according to:

$$F_{placement} = F_{pretention} + zC$$

Where C is the spring factor (gr/mm) and z is the over-travel length (mm). For 01005 components, both the spring factor and over-travel length should be very small due to the required placement force and dwell force. The dwell force can vary considerably because the actual compression of the spring is influenced by:

- PCB height differences
- PCB warp
- PCB stiffness/elasticity (or correct board support)
- Transport parallelism
- Condition of the mechanical spring.

Advanced Z-servo mechanism
Reliable placement and consistent dwell force demand the decoupling of all these factors from the placement force control process. Instead of a conventional mechanical spring, Assembléon uses an advanced Z-servo mechanism.

Figure 8 shows the closed-loop active placement force control process of the A-Series. This achieves the required placement dwell and force regardless of component type, PCB type, condition of PCB, warp and transport system. The A-Series active force control system dynamically monitors the placement force using the closed loop system integrated in the placement head.

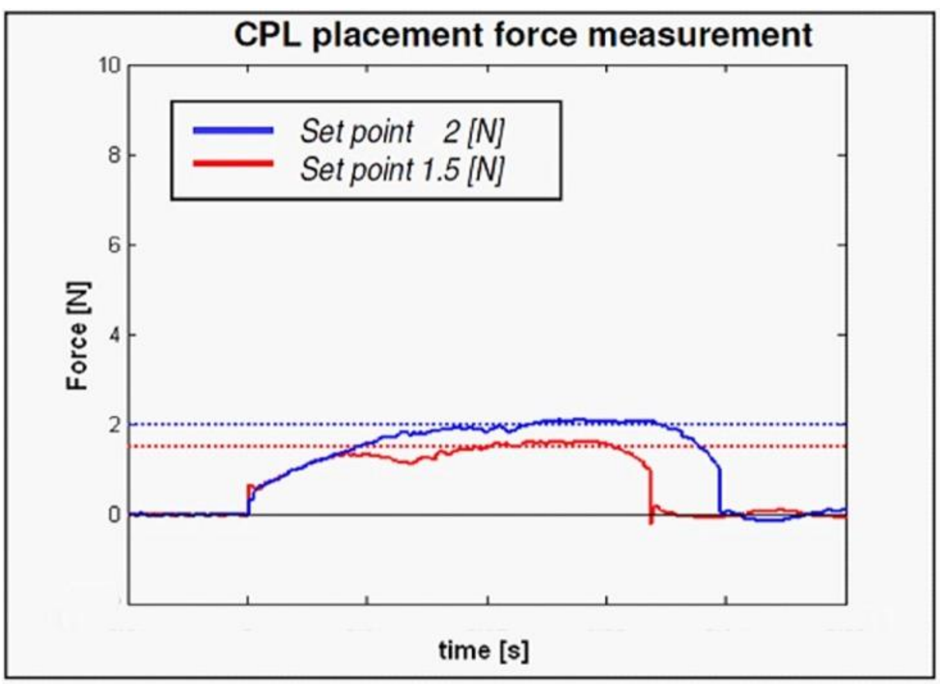

Figure 8: A-Series closed-loop active placement force control system diagram.

Normal placement
During the first part of a placement action, the Z-axis of the placement head moves downwards at high speed. When it arrives at the 'search zone', the speed is reduced to the search speed (Figure 9). Then the downward motion continues until contact with the board is detected.

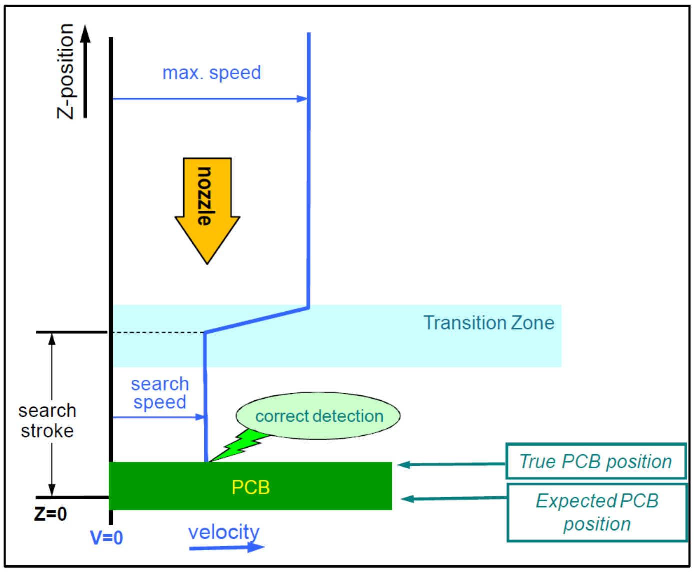

Figure 6: Correct detection of contact with the PCB

Figure 9: Correct detection of contact with the PCB.

The advanced collision detection mechanism filters out any false collision signals but will always make sure a component is placed, even if the board was lower than expected (e.g. negative warp). Additionally, throughout its lifetime it will record all placements and alert the operator if behavior may influence placement quality – a requirement when board quality is critical. And finally, the advanced collision detection mechanism records a surface map of the PCB, allowing all subsequent placements to be made at higher speed by reducing the search area, even with 3d mounting.

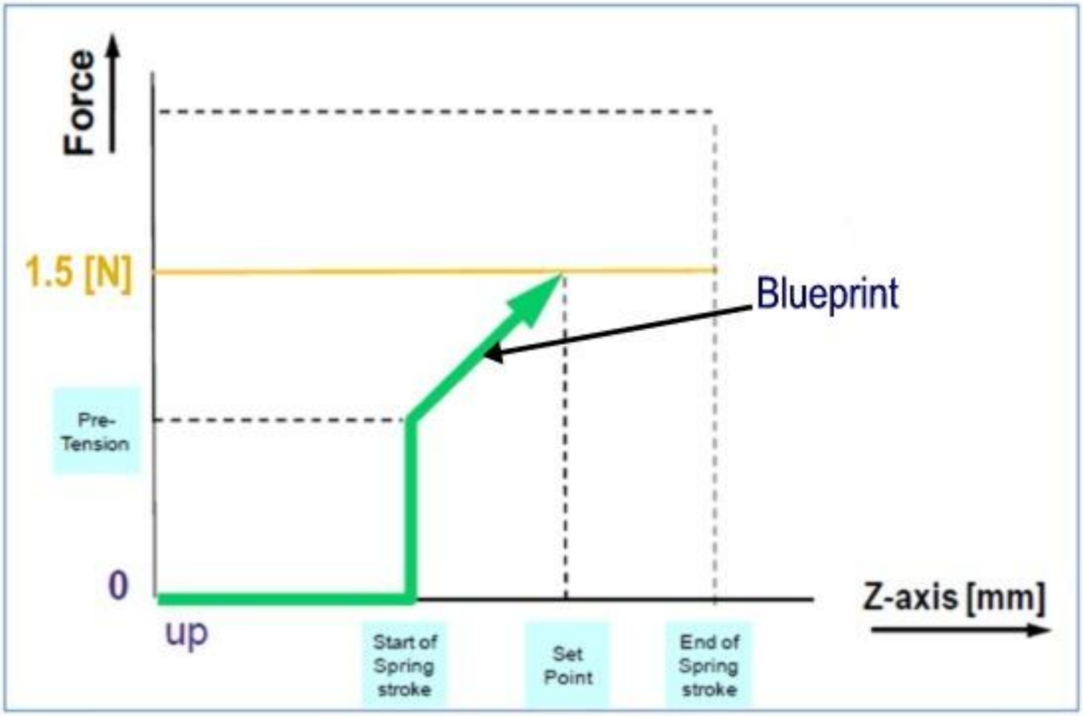

Figure 10: Comparing placement against a blueprint value.

For reliably low and stable placement forces, Assembléon's pick & place process not only measures the force using the real-time and closed loop placement mechanism, but also compares it against a blueprint value – a placement profile description (Figure 10). Also, when the nozzle rises, the velocity is high enough to break the contact between nozzle tip and component to prevent components from being retained on the nozzle. Monitoring systems check whether the component has been detached from the nozzle tip immediately after placement. This quality check filters out any behavior that does not meet the blueprint value and warns the operator in time, avoiding possible costly board reworks throughout the machine's lifetime.

Placement force control test

To ensure high quality and reliability of the placement force, measurements are taken in a "worst case" scenario. Measurements are performed on a rigid aluminum substrate (Figure 11). The force sensor was bolted on the board and components were directly picked and placed onto the piezo electric sensor at default search and collision speed, identical to real production speed. Components are not placed on tape or, as in a real production process, on paste as these act as a shock absorber.

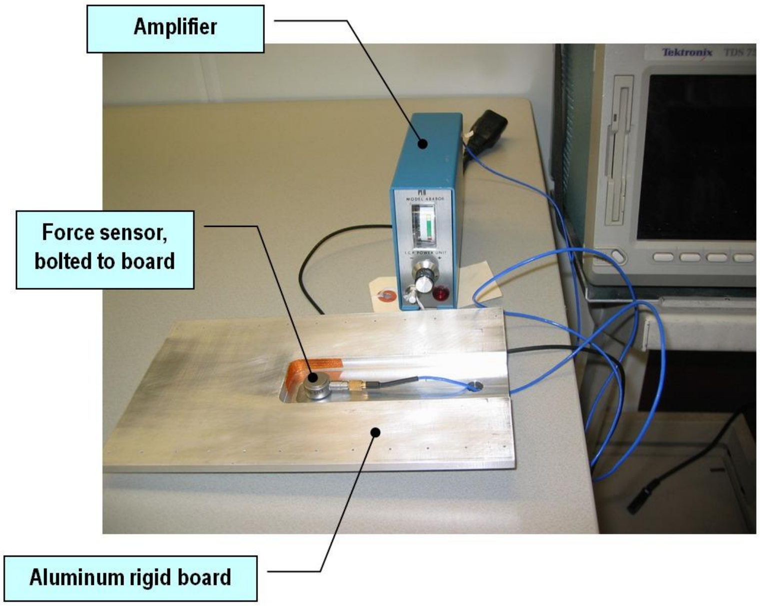

Figure 11: Measurements were performed on a rigid aluminum substrate to test the placement force control system.

The unique A-Series parallel placement design achieves high output speeds with slower moving multiple parallel robots. These all have just one placement head with one nozzle, making it possible to optimize and control each and every component pick and placement. Components can be picked and placed with any impact force and with well controlled dwell forces without any effect (or compromise) on machine output.

One test used the same nozzle on several placement heads and placement robots to check for repeatability. The test confirmed that the A-Series placement force control system achieves very accurate, stable - and repeatable - placement force. Since the nozzle tip has a lifetime of 20 million picks, the quality of contact for one nozzle remains perfect for a production period close to 3 years (Figure 12)**.**

0 Picks

20million picks/place

Figure 12 Shape of nozzle tip new and after 20 million pick and place actions

<u>Placement accuracy</u>

Component interspacing is key for 01005 components. For 80 μm component interspacing, for example, minimum accuracy must be 40 μm even excluding rotational offset. The SMT roadmap indicates that 01005 interspacings will be 60 μm (and possibly even less in future). Accuracy is therefore essential.

Pick & place suppliers normally define accuracy to IPC-9850 standards, which defines repeatability as the machine accuracy. However, that does not represent the true pick & place performance in a real production environment (repeatability gives the deviation at one location only**).** Typically, the accuracy of pick & place equipment is influenced by:

- Movement of boards through the machine
- Measurement of the board fiducials or artwork
- Measurement of the component
- Placement of the component.

Each step introduces a number of variables that influence the accuracy. Each variable will contribute an error that affects the mean offset of the variation from the mean. Assembléon conforms to the IPC-9850 characterization rules for accuracy:

- Repeatability for X, Y and Rz deviations, defined at the center of the component
- CpK 1.33 specification limits for X, Y, and Rz
- This specification limit consists of:
    - The mean, or average value representing the systematic errors (e.g. calibration residues)
    - Repeatability, related to incidental errors that occur in the pick & place process, specified at 4-sigma level.

Based on the criteria above, the AX achieves the accuracy of 50 µm @ 4-sigma and 40 µm @ 3-sigma, including rotation.

Testing the A-Series 01005 process in practice
A test placed 72 01005 components between another 72 previously placed, with interspacings of 50 µm. The board was thus processed twice by the machine, with the second batch of components being picked from a different reel and placed by a different robot. The components were perfectly placed, with no defects (Figure 13).

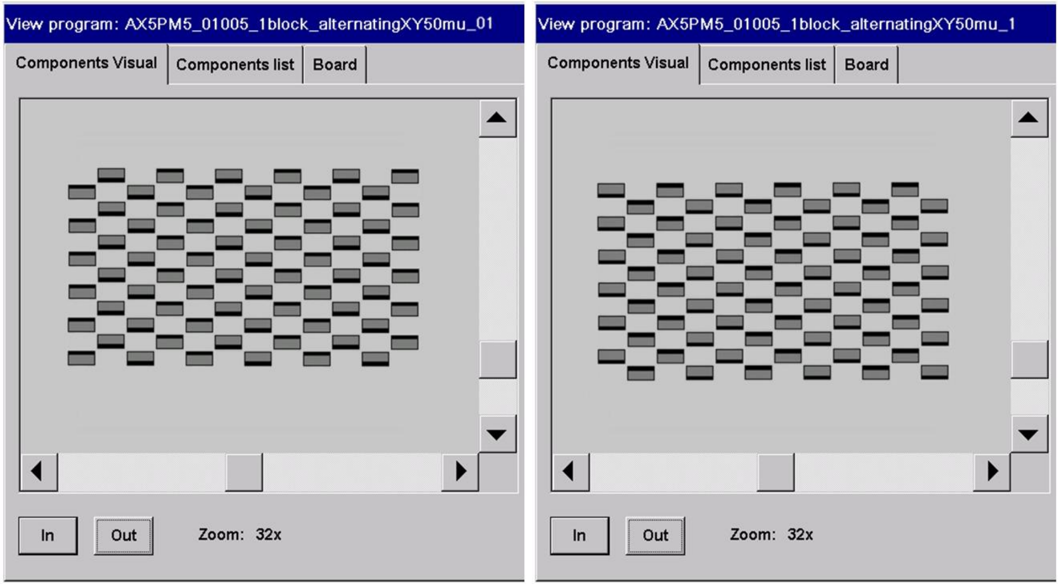

Figure 13: One batch of 01005 components was placed (left), with a second batch placed between the first, picked from a different reel and using a different robot (right).

Recent tests on a newly delivered AX-501 system at a large contract manufacturer ran 12 boards with 01005 resistors and capacitors, with 1152 placements per board. The components were placed in eight 12 x 12 grids, each at 0°, 90°, 180° or 270° and 50 µm or 100 µm interspacings (Figure 14).

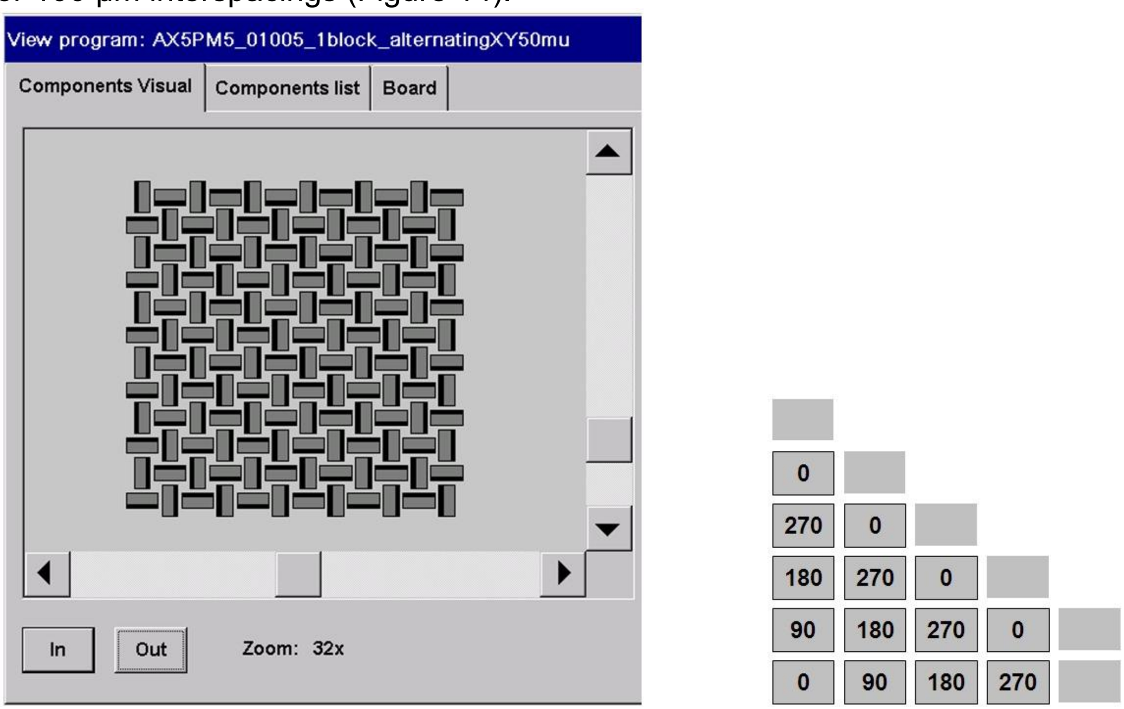

Figure 14: 12x12grid of 01005 placements at 50 micron with alternating angles.

After each three boards were completed, the operator stopped the machine, unloaded the reels, reloaded the reels on a different feeder and started the machine again. After the full 12 boards, all components were correctly picked and placed without any defects. The same test was performed on an older AX-501 machine (which was already at the customer site and from a pre-01005 era, equipped with the latest software but with no change in hardware). Again, there were no pick or place defects (0 PPM), demonstrating that Assembléon's basic pick and place process has been reliable and future proof for some years.

Challenges will remain and issues must be resolved in each process including components, carrier tape material, solder paste, screen-printing, reflow and inspection. These need technical and process innovations, but also close communication with customers and material suppliers. Minimizing defects across the whole production process in this way can give whole-line defects of <30 defects per million. That can mean a difference of tens of thousands of US$ per line per year.