Assembling the next electronic equipment generations

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Product roadmaps can look like largely theoretical constructs, but assembly requirements five or ten years down the line have very practical importance. Pick & place machines have a life of seven years or more, so they should be working up to 2017 or beyond. Assemblers looking to upgrade their production lines now need to look not only at today's equipment requirements but those of their next equipment generations. What will mobile phones, computers and other equipment look like in five years? That will determine their assembly requirements.

Assembling electronic equipment is – in essence – about placing the maximum number of SMD components in the minimum time, with zero defects and zero waste. So, the most important pick & place factors are the real output (which depends on the machine design, pick rate and work load balancing), product quality (accuracy and yield), and number of productive hours (influence of changeover time, maintenance, repair and assists). Products are demanding shorter development times and increasing customization. Even high-volume lines are increasingly needing high-mix production, right down to a batch size of one for testing prototypes (best done on the machine they will actually be mass produced on). With contract manufacture in particular, customers often only supply a single batch of components for prototypes, and a single defect can make the whole board useless.

Although large ICs like Ball Grid Arrays are the most obvious components on a pc board, there are often only three or four of them compared to a hundred or more chip components. So, the chip components and their interspacing largely determine packing density. Component interspacing will become even tighter and will demand improved accuracy and repeatability. Half height (and therefore particularly fragile) components are on the way, along with '0050025' chips (L x W = 0.2 x 0.1 mm), which will be a quarter of the size of today's micro-miniature 01005 types. These smaller, thinner components will likely be embedded into the pc board and underneath ICs. The real test of a machine is how well it places the smallest components – 01005 chip capacitors and resistors – and the largest ones – flip chips and ICs with large numbers of (small closely spaced) bumps. Besides tighter accuracy requirements, these need lower placement forces to prevent component cracking.

Meeting all these (often conflicting) performance requirements will place extreme demands on the placement process. Pick & place machines will have to be faster and smaller, and place components more accurately. Placement movements will need smooth and controlled movements to avoid vibration that worsens accuracy and cuts machine life. Machines should be simple for easy service, and the placement process itself needs to be 'future proof'.

Two pick & place techniques dominate the industry

Perhaps the major influence on pick & place performance is the process itself. There are two main techniques within the industry: sequential placement (turret-based, placement head with multiple component pick actions followed by multiple placement actions) and parallel placement (single-pick/single-place).

Sequential placement machines normally have one or two placement robots, each with multiple vacuum pipette placement heads. The heads rotate to pick components sequentially until all available pipette positions are taken, then all the components are placed sequentially onto the substrate. Although sequential placement machines can have more than one robot, they use multiple pick followed by multiple place. Parallel placement machines instead have multiple robots with only a few – sometimes just one – independent placement heads (Figure 1) per robot. The essential difference is that, with true parallel placement, each head handles just one component at a time.

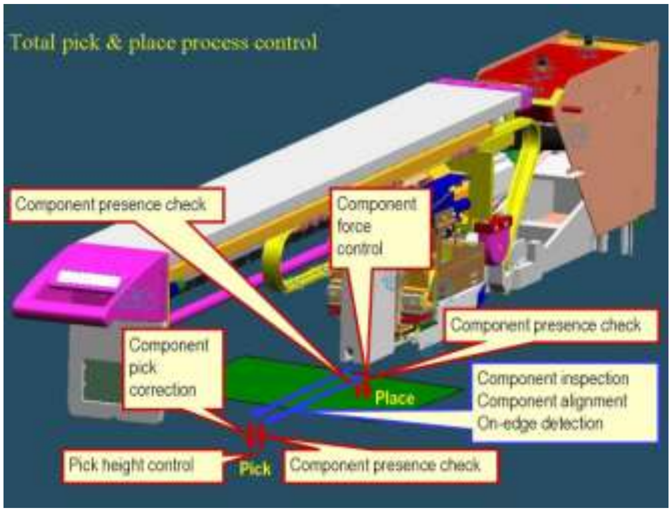

Figure 1: Unlike sequential placement (turret-based) machines, parallel placement machines pick a single component, transport it to the board, and place it.

Sequential placement inherently uses a sequence of short movements with high accelerations and decelerations. That means high forces (particularly rotational forces) acting on components even *after* they have been aligned, which degrades placement accuracy.

Parallel placement instead transports components at controlled speeds with lower acceleration/deceleration. Rotational forces are also virtually zero, with any slight rotation being compensated by components self aligning on the solder paste. There is only one x-y movement from pick to place, meaning only one acceleration and deceleration per component, and similarly there is only one controlled downwards z-movement. After acceleration the movement is linear and, apart from the vacuum force that holds the component to the nozzle, no forces are applied to the component.

Continuous component position measurement means no risk of component shift on nozzles. And every placement head has its own board alignment camera, so giving a fixed relationship between board camera and placement heads.

During each pick cycle, parallel placement machines check that a component is present, check the pick height, and correct for any misalignments in component position. During the place cycle they check that the component is still there and correctly aligned (Figure 2), place it with the appropriate force (easy because each head holds only a single component), and inspect the placed component. Importantly, parallel placement *prevents* defects to improve placement quality.

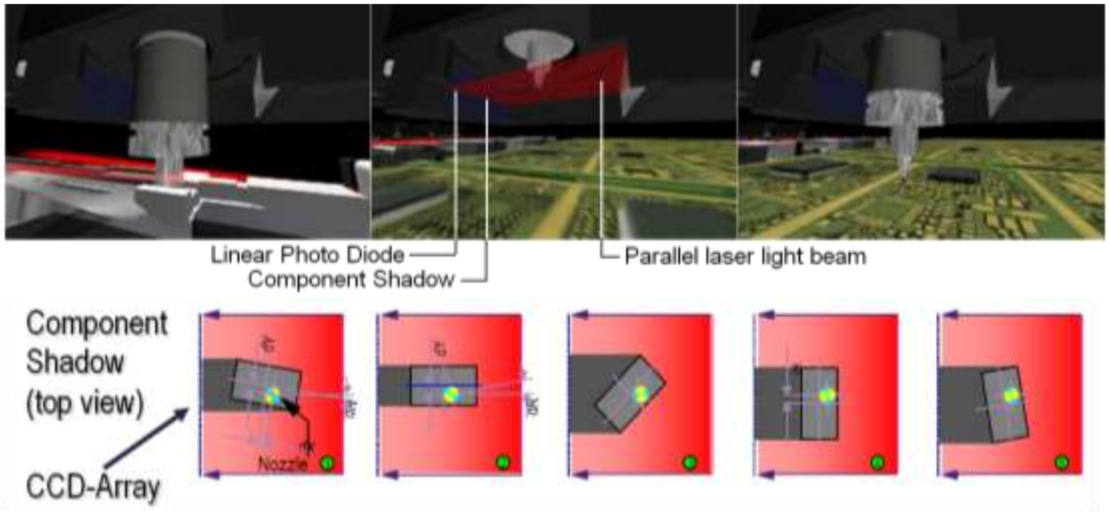

Figure 2: Chip components are aligned using a laser beam before placement, and components like QFPs and BGAs are aligned by camera to maintain accuracy.

Although improving accuracy and repeatability is a challenge whatever the equipment design, it is more difficult for sequential placement. Producing zero defects depends on reducing (for example) machine vibration, so heads must be given time to settle after any motion. Machines of both types can now place above 100,000 components per hour, but equipment assemblers should view these headline figures – even IPC 9850 rated ones – with suspicion. Actual parallel placement speeds can be higher than the IPC 9850 figures, but many sequential placement machines must be derated during use.

The Japanese Jisso industry roadmap demands over 150,000 chip components per hour by 2017. For equipment assemblers, though, placement rate per square metre of production floor is becoming the key metric. Assembléon’s AX-501 places 121,000 cph to IPC 9850 from an area of just over 6 m^2, which already matches the US-based iNEMi 2017 industry roadmap requirements.

Poor line balancing limits production predictability

It is of little use placing chip components and small ICs at very high rates, however, if the line is actually limited by placing flip chips and medium and large ICs. Line balancing is therefore key, but is difficult for sequential placement. This often needs several types of placement heads to cope with the wide variety of component sizes. The alternative is to change the nozzle but this, too, reduces the placement output. The result is a work cycle unbalance – the heads placing small components are fully loaded while those placing large components are sometimes idle for three-quarters of the time.

The individual placement heads for parallel placement machines can handle a much wider variety of component sizes and types, resulting in a much better work cycle balance and higher real output. That makes for predictable output independent of the component mix. Assembléon’s parallel placement has three types of robots. A compact robot head places chip components and small ICs. A standard robot head places chip components up to large ICs, Chip Scale Packages (CSPs) and flip chips. And most recently, a Twin Placement Robot (TPR) places a similar component range to the standard head (also accepting components from trays), but with improved high-speed placement accuracy of 25 microns.

Figure 3: AX-501 with TPR

The TPR allows Assembléon’s A-Series machines to work as chip *and* IC shooter. It takes all the major ICs (including bare dies, stacked chips, Package on Package and System in Package). Choosing the right line setup ensures that lines can work flat out without needing head changes (Figure 4). The Twin Placement Robot can place up to 16,000 large ICs per hour. With the other robots on the AX-501 simultaneously placing up to 94,000 chips that, too, is ahead of 2017 industry roadmap requirements. It even ensures lines are well balanced for pc boards with high IC count like Solid-State Drives, and Flash and DRAM modules.

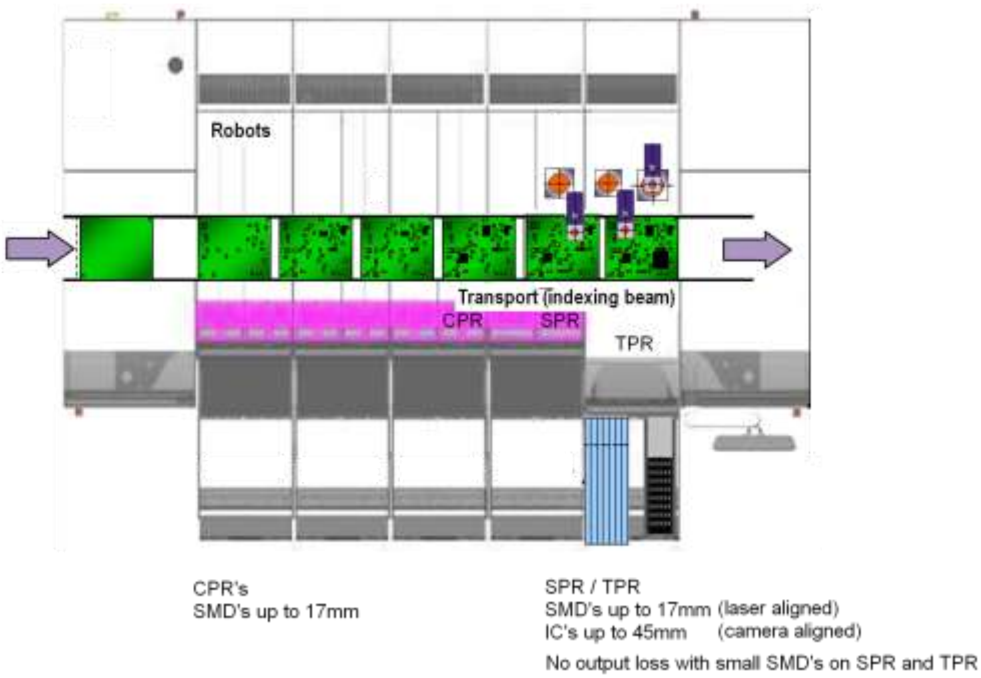

Figure 4: Assembléon's Compact, Standard and Twin Placement Robots help ensure that production is perfectly balanced without needing to change the placement head.

Look at the whole placement process

Component densities in portable equipment are now already at over 50 components/cm^2, and will rise to 80 or so over the next 10 years. To reach this, the established 0603 and 0402 chips need to be replaced by 0201 and even 01005 types in consumer and other mainstream production. However, sequential placement can still find yields problematic with 0201 chips, let alone 01005 chips. That is even true for the major drivers of new technologies and equipment assembly miniaturization – smartphone manufactures. And in that dynamic high-value market, low yields are particularly expensive.

Measuring 0.4 x 0.2 mm, 01005 chips are now regularly used in semiconductor modules or SIPs placed with only 50 microns component spacings (giving local densities of 300/cm^2). Many manufacturers see the move to 01005 as virtually impossible for mainstream production with their current equipment. There is no such problem with parallel placement, though, which achieves a single-digit dpm for both 0201 *and* 01005 chips.

Placing these components reliably demands that the *whole* assembly process can cope. When analyzing products at the end of the production line, up to three-quarters of defects can be traced back to faulty stencil printing. The problems are particularly acute on boards that combine micro-miniature components with connectors or other larger devices. Different sizes of components need different amounts of solder to give reliable connections for each of several thousand connections on a pcb.

As solder lands and the resulting screen aperture sizes become smaller and more closely spaced, new factors affect solder paste deposition. Even small process variations can affect repeatability; particularly squeegee blade angle and speed. Assembléon’s MCP screen printer has an innovative head design with variable attack angle printing, allowing it to maintain constant solder pressure independent of the stencil thickness. With board cycle time as short as 11 seconds, it is also the first stencil printer to keep up with pick & place production lines (another form of load balancing).

Another critical part of the process for 01005 chips is the tape feed. The pocket dimensions of conventional W8P2 paper tapes cannot be guaranteed, which increases the risk of mispicks and misplacements. Separating the cover tape from the paper carrier also releases a large number of paper dust particles, which can cause bad solder connections to the micro-miniature components. Reliable placement needs more recent W4P1 tapes, which are 4-mm wide on a 1-mm pitch. The tapes have stably defined pockets and are static free to reduce the risk of components being thrown out when the cover tape is pulled off. The antistatic polycarbonate tape also completely eliminates paper dust, providing a higher yield in end-product quality level.

Placement accuracy determined by component requirements

Because components tend to self align on the solder pads, today’s 40-micron placement accuracies will be more than enough to place TSOPs, FCIPs (Flip Chip in Packages), FLGAs (Fine-pitch Land Grid Arrays, CSPs and QFPs (Quad Flat Packs), even into the future (Figure 5). That will remain true even as I/Os are predicted to increase from around 3,000 to nearly 10,000 per IC over the next five years (with body sizes increasing to 50x50 mm, pitches should only need to decrease to 300 microns). Ultra-fine pitch devices like FBGAs (Fine-pitch Ball Grid Arrays), flip chips and BGAs will all need 35 micron 3-sigma accuracies. This is well within the 25 micron accuracy of Assembléon's AX-501 TPR head, which could itself drop within five years to 10 microns (achieved now in the laboratory).

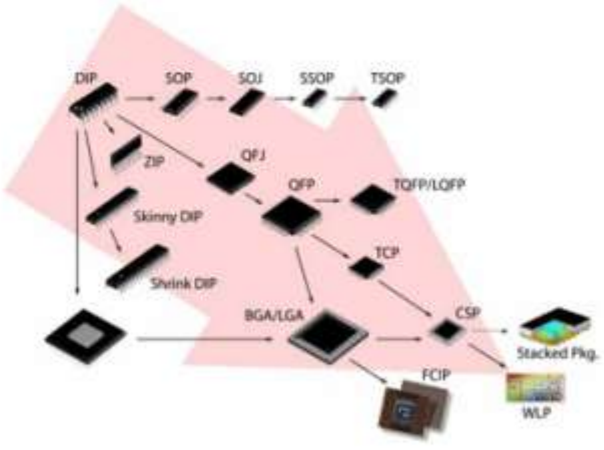

Figure 5: Pick & place machines must handle future components, particularly micro-miniature chips and fine-pitch components like Tape Carrier Packages, FCIPs, and Wafer Level Packages. Assembléon’s A-Series works with flip chips, 01005 chips and other chip components inside the FCIP, which have even tighter accuracy requirements.

Accuracies of 40 microns are also quite good enough for chip components. However, this will change when embedding chips into PCBs. The copper terminations of these passive devices will have solderless copper-to-copper contacts.
As these components will not self-align, the accuracy for placing chip components may need to be 20 microns or better.
Placement *must not* be subject to either sudden variations or to drift, so techniques like setup verification and auto calibration are needed to maintain repeatability. That is perhaps the key parameter of a production line because it also fundamentally determines cost per placement by setting the rework (which is becoming more difficult with every new equipment generation) and scrap levels for expensive populated boards. Parallel placement can have single-digit dpm (defects per million) figures. Any higher than that (and 50 dpm is common within the industry) and production yield for complex boards begins to suffer. This is the major reason why 01005 chip components have developed a reputation for being difficult to place.

Reliable placement will be even more difficult for ‘0050025’ (0.2 x 0.1 mm) chips, and the half-height components that are predicted to be embedded into PCBs, or even underneath ICs. These will be even more fragile, so will need lower and controlled placement forces to prevent cracking – even down to 0.5 N. Impact force is determined by head velocity at impact, the mass of the head and the head contact stiffness. Parallel placement heads have lower masses, and it is easier to reduce the velocity of the nozzle in the ‘safe zone’ before placement to eliminate impact force. A closed loop system ensures that the static placement force is built up to the correct value before letting go of the component. Roadmap placement forces are predicted to reduce to 0.5 to 1N Newton (they are currently 1.5 N on the AX-501 and 0.9 N for the AX-201 and these can be field upgraded in the future).

Productive hours

All these factors combine to determine a machine’s life-cycle cost of placement. Machine reliability is also key, and parallel placement has the advantage of simplicity. Sequential placement typically needs 100 cycles per robot for a 4x12-fold revolver head, compared with around 40 for an equivalent parallel placement head (8 robots in parallel). That means less wear, and longer life and longer MTBF (Mean Time Between Failures).

The actual output for equipment manufacturers is the product of the component placement rate, the yield and number of productive machine hours (Figure 6). Parallel placement heads are smaller, lighter and less complicated than for sequential placement. The controlled low impact and static forces of each placement also make for low wear on nozzles, which can easily last for years. So, maintenance and repair is simpler, and annual scheduled maintenance, for equipment placing above 100k cph, takes only around 50 hours. Sequential placement machines usually do not allow off-line repair, have longer calibration procedures, and higher MTTR (Mean Time To Repair).

Besides needing constant attention, sequential placement machines typically need 300 hours of scheduled maintenance annually. That means 10 more lost days of production a year.

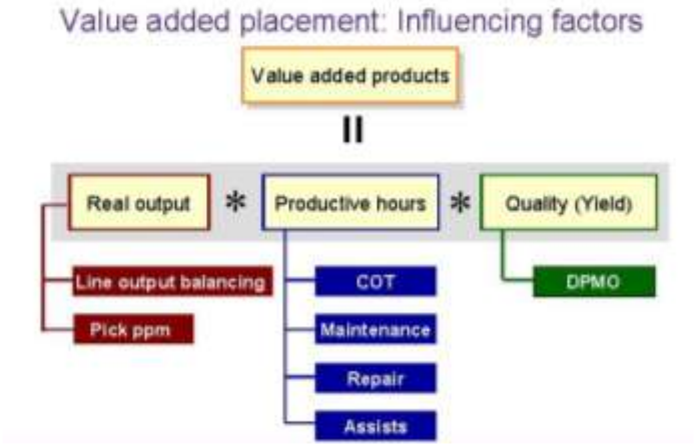

Figure 6: The overall cost of placement is a combination of output, productive hours and yield.

Factors like these will become even more important to the profitability of equipment assemblers as components and component pitches continue to shrink. And different applications have their own special requirements. Safety critical equipment like automotive, computer systems/servers, and communication infrastructure will need even lower dpm levels to maintain yields as system complexities and component numbers increase. Communications, computer and consumer (3C) devices are all continuing to move to higher mix and smaller batch sizes. These will increasingly need plug-and-play operation for faster New Product Introductions that don't need extra operator training.

And a final requirement that is increasing in importance is for high-volume, high-mix manufacturing, where software must cover the total line automation process. Factory software can generally deal with high-volume/low-mix or low-volume/high-mix, but has not yet been perfected for mass production lines of mobile phones and similar equipment that must often change.

Lines can now be instantaneously changed when assembling members of the same product family. Contract manufacturers though, in particular, need reduced feeder changeover times and improved product scheduling to ensure that production continues at 100% of maximum speed for 100% of the time. For high volumes, performance monitoring, component supply, warehousing connections and setup verification systems need to be particularly advanced for minimum costs.

Software needs to integrate with companies' Enterprise Resource Planning systems to keep component inventory stock levels low, even when placing at top speeds. It needs to integrate with warehouse equipment to provide new reels to the line at the right time so the operator can splice them on time to keep production uninterrupted.

All that will need open software to tie together all a manufacturer's separate Manufacturing Execution Systems into a single, perfectly integrated process.