# Going Beyond - ACHIEVING HIGH Accuracy Placement in a Volume Application

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**ABSTRACT**
The constant drive by designers to create more functionally unique products has challenged the assembly community for some time. As a result, many processes have been developed under the "Necessity is the Mother of Invention" rule. For EMS providers to develop unique adaptations to their processes, they must work closely with their suppliers of equipment and materials. Some requirements even push the scope of assembly outside typical boundaries demanding truly creative solutions.

Flip Chip applications are a good example of this technology. Instances whereby placement tolerances push the limits of conventional SMT equipment, but volumes and specialization preclude the use of stand alone die bonding equipment are becoming more common.

In order to match the true requirements of the process to the capability of the machine, a determination of factors affecting the accuracy must be made. Specified placement tolerances are vague and may not apply in all instances as stated.

The process development does not end with getting the devices placed, but extends into determining an adequate metrology for verification of the placement accuracy. Applications where the placement tolerance is less than 25 microns create new challenges for measurement. Additionally, imaging of these devices may prove to be the most challenging piece of the development.

The application covered in this paper involves the placement of 2 Flip Chip devices end to end with tolerances of ± 10 microns. The body of the discussion will cover the challenges of the application and how these were addressed through the partnership of the EMS and equipment manufacturer. Details will be given on the technical solutions for imaging, movement, tooling and measurement as well as final process data.

Keywords: Flip Chip, placement, accuracy, measurement

**PROCESS REQUIREMENTS**
The requirements placed on the positional accuracy were due in part to 2 factors. One, all subsequent processes rely upon the position of the die in reference to a fiducial on the substrate. Secondly, the capability of the artwork on the substrate was inaccurate enough to place the tighter requirement on the location of the die, impacting the total stackup the least.

Due to capital expenditure concerns, volume production and shortened learning curves, it was decided to perform the initial development on an existing piece of placement equipment, a Universal Instruments GSMxs™ machine. This machine has a specified placement accuracy of ±18 microns at 6 sigma. See Figure 1.

**Figure 1 - GSMxs die placement system using Variable Reluctance Linear Motors**

In addition to the placement, verification of the placement also needed to be performed. Per the customer, all devices manufactured were to be measured, approximately 1000 per week. In this specific instance, no features were placed on the topside of the device for measurement reference. Typical placement tolerances would have allowed the use of die edge averaging and line intersections, but this proved entirely inadequate as will be discussed later.

**PLACEMENT DEVELOPMENT**

As with all development activities of this type, getting past the specifications and looking into the contributing factors is the primary issue. This is where working with an existing supplier can be advantageous. Much of the technical push/pull is eliminated and the facts come to the forefront.

Universal Instruments manufactures various assembly machines capable of die placement. However, an accuracy level beyond standard die placement accuracy was needed in this particular case, due to application-driven requirements. The machine chosen to investigate feasibility was our linear motor machine. The linear motor machine has a specified accuracy of +/- 18 microns (6sigma). At the base of the system lies the Variable Reluctance Motor (VRM) drive system. This technology eliminates thermal shifts, thereby providing superior stability and reliability. The positioning system offers 1micron encoder resolution, dual-drive registration and complete closed loop feedback. See Figure X for a brief description of the technology

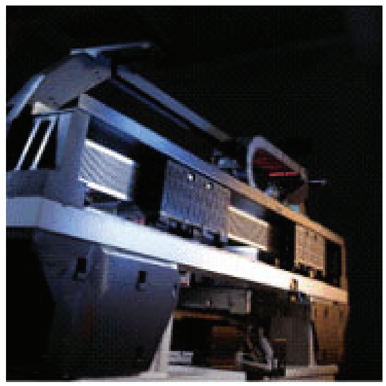

**Figure 2 - Detailed view of Variable Reluctance Motor system. Head Mounting Assembly and linear scales.**

**MACHINE VERSUS PROCESS CAPABILITY**

The traditional technique used by equipment suppliers to measure accuracy consists of placing perfectly etched glass slugs on perfectly etched glass boards, the manufacturers objective is to measure the inherent capability of the machine, eliminating all external sources of error, such as those coming from the process and from the product. High-accuracy die placement machines are normally single-spindle systems, with specified accuracy between 14 microns and 24 microns at 6sigma. The placement machine, consisting of a more complex 4-spindle system, has a specified accuracy +/- 18 microns at +/- 6sigma. On such a system, standard deviations are calculated per spindle. Data is then pooled for all spindles and the overall standard deviation is calculated for X, Y and Theta. Coordinate Measuring Machines (CMM) with less than 0.5micron variability are used to qualify such systems.

The challenge in this case was to develop a product-specific system with a "real" accuracy of +/- 10 microns at 6sigma, beyond the specified accuracy of single-spindle die placement machines. To achieve this level of accuracy, application-focused testing was conducted and a unique machine configuration capable of achieving such accuracy was established. Finally, a specific mode of operation was developed.

**DETAILED SYSTEM DESCRIPTION**

Although the positioning system is critical to obtain high accuracy, the overall accuracy greatly depends on the concerted performance of subs-systems. Contribution from the placement head, the vision system, the application-specific tooling and the contribution of the process itself must be taken into consideration. In addition, variability from one system to another was considered here since results were to be ported from a test machine in the supplier's engineering facility to a system already in place at one of Plexus' factory. Furthermore, the performance needs to be repeatable on future systems.

*Pressure-Enhanced Head*

In an application where the spatial distance between devices is critical the elimination of spindle-to-spindle variability is a necessity. Therefore one of four available spindles of a "high accuracy, pressure-enhanced head" is used in an effort to eliminate mean variation associated to spindle offsets. In addition dies are presented in a pre-orient fashion to the camera recognition system. The pre-orientation minimizes any small error in placement associated with errors in calibration. As a result, a standard deviation of 1.5 microns was obtained.

Die in this application were large and thin and accuracy loss was shown to occur with standard nozzles. Application-based nozzles were therefore developed to constrain die planarity during vision inspection and placement. Nozzle adapters, used as the interface for automated nozzle change, were replaced with higher-precision nozzle adapters to ensure repeatability of planarity after nozzle removal or replacement.

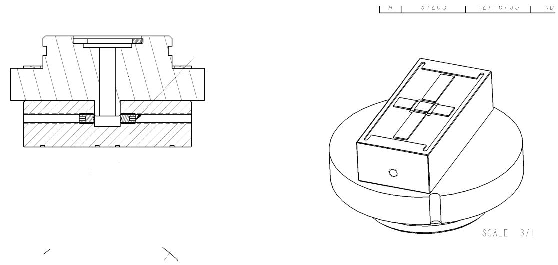


**Figure 3 - ProE image of nozzle assembly**

**Vision/Camera System**
Because of its large field-of-view and high pixel-to-feature ratio, a 12micron/pixel camera system was chosen for component imaging. This novel digital system offers mega-pixel capability and a field of view up to 12mm. In addition, component feature contrast was optimized by using a three axes illumination scheme. The 3-axes can be independently fired or used in a concerted fashion.

Die registration was performed by imaging the active features, as per the alignment criteria of the process. In addition, Universal's "vector correlation vision array algorithm" is used to identify, sort and calculate the position of specific targets.

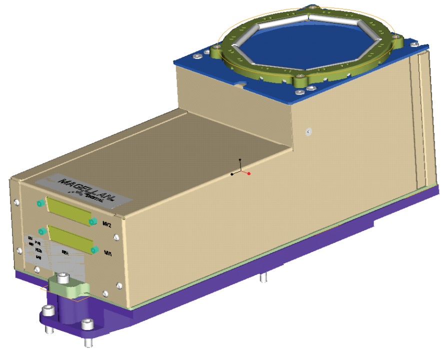

**Figure 4 - Digital upward-looking camera assembly**

**Board Handling**
Key elements and methods of material handling within the assembly area such as support, stability and constraint establish key links between machine and process. In addition, the challenge of high accuracy assembly comes from various "process-driven" sources, as equally important as the aforementioned component tooling. The system needs to accommodate or maintain compatibility with all loading/unloading, upstream and downstream process steps, all the while providing the critical constraints essential to a successful assembly process. In the case at hand, the substrate is transported within a process-specific carrier and transfers using traditional transfer belt systems. The substrate is not captivated within the carrier, enabling simple separation during assembly and post assembly processes. As part of the die placement operation, the product carrier moves into the assembly area, where it is first roughly located using mechanical registration. The product is thus properly pre-positioned in the application tooling area. The carrier is then lifted off the transfer belts, the substrate is released from the carrier and clamping occurs in a pre-defined area of the substrate to a rigid top plate. The Pick and Place assembly occurs, the process reverses and the carrier transfers downstream.

For support, stability and constraint, the application tooling area incorporates critical handling design elements. Firstly, an under-board support assembly appropriately named a "Precision Lifter Assembly" is mounted in the placement area, anchored to the machine base. This assembly is a box-like construction containing a base plate, 4-Point levelers, a lift mechanism, a pusher system and a top plate. The base plate locates the assembly within the machine space. The levelers allow for planarity setup between substrate and spindle. Lift mechanism is the foundation for tooling and product separation.

The top plate tooling establishes a reference, as well as repeatable image and mounting planes, critical for high-accuracy assembly. The speed of separation and engagement are all controlled through the lift element.

As per design, the lifter assembly and all application tooling were to be outfitted and tested on one machine and then subsequently transferred to another machine in the field, pegged to be the production tool. The setup, installation and verification procedures were performed by Universal field personnel alongside Plexus' maintenance and operations crew. Performance results between the two systems were found to be comparable and the system was released for customer builds.

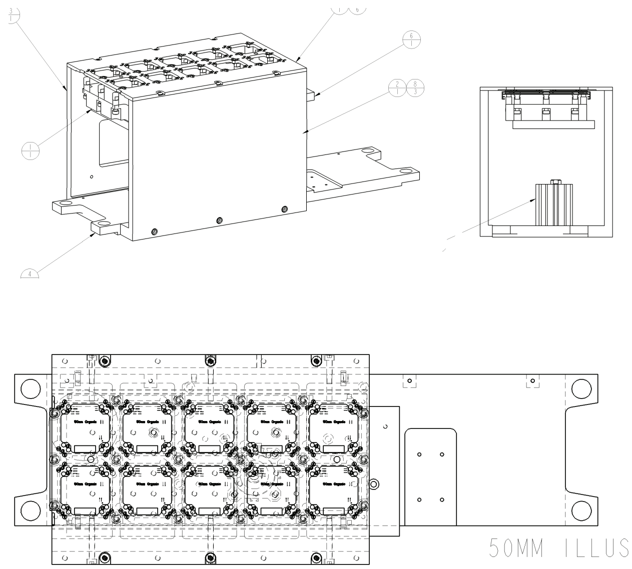


**Figure 5 - ProE drawings of application-specific tooling**

**MEASUREMENT DEVELOPMENT**

Initially, averaging several measurements along the cut edges of the die was proposed but found to be grossly inaccurate due to chips and variation of the diced edge to the critical features on the I/O side. See Figure 6.


**Figure 6**

Secondly, a process of characterizing each individual die through measurement of the error of a feature on the attachment side of the die to the die edge was used. The error was then subtracted out of the data as measured in the primary method mentioned previously. The graph on Figure X on Page 5 shows the measurement error from several lots of die measured from a feature on the I/O side to the cut edge.

The fiducial on the substrate was applied during the thick film application process and positional accuracy was verified at approximately 2 microns. Processes performed after the die placement also utilize this fiducial. This placed specific artwork accuracy requirements on the substrate manufacturer that decreased the allowable tolerance for die placement.

The fiducial on the active side of the die went through several iterations before settling on a feature at the intersection of two streets. This feature is used on three corners of the die, to give X, Y, and Theta measurements.

As no feature was possible on the topside of the die, alternative measurement techniques had to be evaluated. One such technique was to focus a light source between the die and substrate. Then using a digital camera fitted with a 900-1100nm wavelength filter, the feature could be imaged. However the combination of image resolution and magnification could not be matched sufficiently to make accurate measurements. See Figure 7. This also created additional issues trying to calculate distances between features identified with separate acquisition sources.

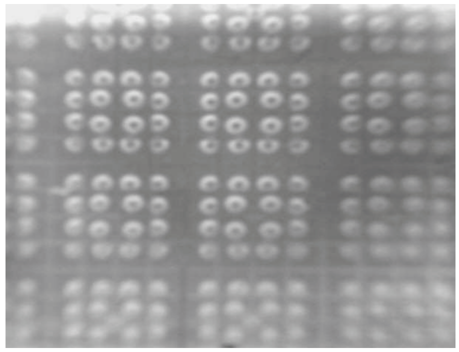

**Figure 7**

In many conversations the idea of using Infrared inspection was discussed but not seriously pursued. It was only after all mainstream avenues were exhausted that it was determined to examine it further. Identification and rudimentary evaluation of potential partners lead to the involvement of a company that manufactures and sells a family of infrared inspection systems primarily as bond inspection systems for MEMs and SOI wafers.

Initial evaluation of the system revealed a superior imaging capability, suggesting that micron level measurements could be made and utilized to monitor the placement processes. Alignment features on the active side of the die are clearly visible viewed from the back side (thru) of the die. See Figure 8.

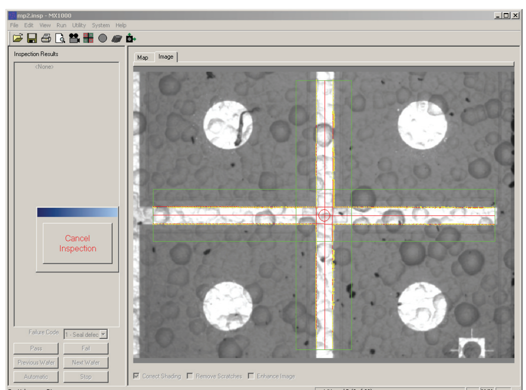


**Figure 8**

This work culminated in the delivery of a process solution capable of placing Flip Chip die onto substrates with a total error well within the specified tolerance ± 10 microns. Post bonding placement is measured using an infrared inspection system with XY accuracy of 0.5 microns and 3 sigma repeatability of 1.5 microns (the GR&R for ±10 microns is less than 15%).

**PROCESS RESULTS**

As with every process development, the end results are what matters. In cases where you are technology limited, and more so in the metrology portion, the results are neither predictable nor initially trusted. With the initial results showing a Gauge of 2% and accuracy of the system at 1.5 and 1.7 um for X and Y coordinate respectively, the latter was eliminated.

The results for this process ultimately lie in the accuracy and repeatability of the placement of the flip chip devices. All subsequent processes rely upon this. Measurements were set up for X and Y positioning at 3 corners of each device. The positions and devices were identified independently to reduce any imposed error and aid defect root cause efforts.

All measurements, 6 per substrate over 1700 devices sampled for this test, fell between Cpk 1.32 and 1.41. The majority of the remaining variation has been identified as being contributed by the assembly tooling. See Figure 9. This tooling was simply designed and made from less precise materials than now needed. Phase II development includes elimination of this systemic variation.

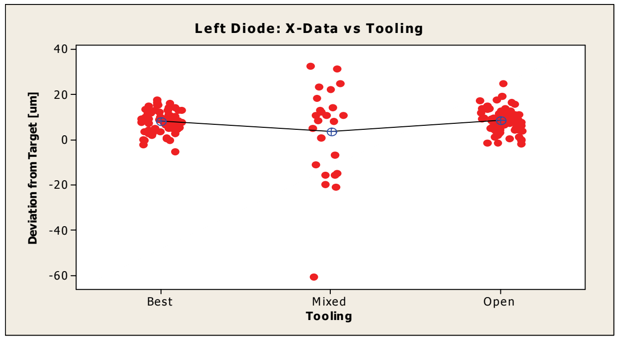


**Figure 9**

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