Accurate Alignment of Laminate Materials Using Sensor-Based Robot Techniques

Andrew E. Brennemann∇, Robert Hammer§, Ralph L. Hollis‡, and William V. Jecusco II

Manufacturing Research department
IBM Research Division
Thomas J. Watson Research Center
Yorktown Heights, NY 10598 USA

Abstract

Assembly accuracies of 0.05-0.1 mm, needed for electronic product manufacture, are attainable with current automated manufacturing equipment. Aggressive electronic system designs will require manufacturing accuracies in the range of 0.005-0.01 mm.

A system and strategy is described here to fabricate circuit boards requiring alignment accuracies of 7.5 μm using existing automation equipment with enhancements and typical manufacturing line fixtures.

The system, configured as a pilot workcell, consisted of an IBM 7576 coarse positioning robot, a fine positioning manipulator, an optical sensing system and a unique bracing method to reduce environmental disturbances.

The strategy was to use a coarse/fine placement technique with sensing to align, stack and bond individual test laminates with patterns of 100 μm holes. The results showed that pairs of holes were consistently aligned to 2-5 μm which surpasses the 7.5 μm manufacturing requirement.

I. Introduction

Computers use integrated circuits mounted and interconnected on circuit boards by means of printed circuit wiring with wiring widths and spacings in the range of 0.1 to 0.2 mm. Many circuit boards are multi-laminate structures with one or more internal wiring patterns interconnected vertically through contact holes to adjacent laminates. Traditionally the laminates are aligned with a mechanical pin-in-slot method where each laminate has either drilled or punched alignment holes referenced to the wiring pattern on the laminate. The laminates are aligned and stacked by placing the alignment holes of each layer over a set of guide pins so that the layers are physically constrained to the pins. The stack is bonded to form a rigid structure to support circuit components. This method is sufficiently accurate in present manufacturing to satisfy the hole alignment accuracy.

Newer high density circuit designs require manufacturing accuracies better than 0.1 mm with interplane hole registrations of 7.5 μm. or better. Lamination thickness's for the newer designs are in the range of 0.05 to 0.1 mm. The pin-in-slot method is not suitable for alignment as 1) it could cause deformation of the laminate and thus require the holes to be slightly larger than the pins, 2) the pins must be spaced very accurately and 3) pin spacing would be a function of temperature. The accumulated tolerances from these factors would easily exceed 0.025 mm.

This paper describes a system that accurately aligns and stacks laminates for circuit board fabrication with contact hole registrations of 7.5 μm or better using standard manufacturing assembly machines and parts feeders.

A sensor-based robotic system pilot workcell was developed to demonstrate a technique to accurately align and stack thin laminates at production line rates. The system

∇Retired, 4 Morningside Court, Ossining, NY, 10562
§Now at VATELL Corp, P. O. Box 66, Christiansburg, VA 24073
‡Now at Carnegie Mellon University, Pittsburgh, PA, 15213

1050-4729/94 $03.00

consists of an IBM 7576 robot coarse positioning manipulator, CM, with a fine positioning manipulator, FP, [1, 2] fastened to its tooling end. An optical sensing system, feeder stations and an IBM PC-AT industrial computer complete the system. The CM moves the FP to locations in a 0.5 m x 1 m x 2 m work envelope with 0.1 mm accuracy.

The FP is a precision air-bearing supported planar manipulator with a programmable fine motion range of ±1.000 mm the x, y plane and ±1.75° about the z axis. It can be programmed to move 0.03 μm with 0.3μm resolution and repeatability in both axes. Small rotations of 0.0003° can be commanded about the θ_z axis. A frequency response of 50 Hz. is attainable with no load on the device. The FP is the critical component of the aligner system as it provides the precision fine motions for the alignment process as well as a calibrator for the optical sensing units. Thus the CM/FP combination with endpoint optical sensing enhances the positioning capability of the system. A program actuated vacuum chuck attached to the FP takes laminates from the feeder station to the alignment and stacking area. The coarse/fine positioning strategy [3] with endpoint sensing allows inaccurate equipment to be used in the workcell for typical assembly [4].

The optical sensors locate a set of fiducials in each laminate and registers their coordinates to the alignment system. The fiducials are part of the wiring pattern lithography and are accurately referenced to it. The fiducials are the virtual guide pin equivalent of the pin-in-slot method.

Vibrations occur at the unrestrained end of the CM with amplitudes about 10 μm in the frequency range of 1-50 Hz, typical of environmental noise. Various means of bracing to reduce vibration are described by Book [5]. A unique bracing system used in this system is shown in Figure 2 consisting of two mechanical grounds or "V" blocks. The lower block braces the FP, the upper the CM during an alignment operation.

II. Laminate details

Test laminates are 0.05 mm thick molybdenum sheets with dimensions shown in Figure 1. A photolithographically generated hole and fiducial pattern is formed on the laminate. An array of 100 μm diameter holes spaced on 200 μm centers is placed at the laminate center to represent a wiring pattern with the 750 μm diameter hole fiducials formed outside the pattern boundary. The holes and fiducials are opened in the material by a double sided etching processes.

Fiducial considerations

Fiducials are accurately formed and positioned as part of the wiring pattern photolithographic artwork. The fiducial shape and spacing are design options but must be accurately reproduced between laminates to insure minimum dimensional variation between pairs. An image of the fiducial, formed by back lighting the laminate, is focused on a position sensing detector, PSD. The image centroid is computed from the detector output and stored as the laminate location. Centroid coordinates obtained from subsequent laminates are aligned to those of the first laminate.

Laminate dimensions

The laminates and feeder station are designed to meet two requirements:

1. The centroid of the fiducials coincides with the centroid of the outer dimensions within ordinary manufacturing tolerances of about 250 μm.
2. Laminates can be randomly placed in a feeder station and have the centroids of the laminates remain within about 500 μm of each other.

Meeting these requirements ensures that the fiducials and the FM movements are in the view of the optical sensor when a laminate is placed at the alignment site.
The feeder station shown schematically in Figure 2 is designed to constrain the laminate supply to a square area of dimensions 226.854 mm with tolerances of -0.00 mm, +0.02 mm on a side. Details of the laminate dimensions and fiducial locations are shown in Figure 1.

III. Aligner system

Experimental hardware

The experimental hardware arranged as a pilot workcell is shown in Figure 2. Major components are the feeder station, an IBM 7576 robot for coarse motions, CM, the fine positioner, FP, an optical sensing system and the alignment/assembly station. A vacuum chuck attached to the FP transports laminates from the feeder station to the alignment station. A second vacuum chuck at the alignment/assembly station secures a stacked laminates after alignment. A transport mechanism moves the

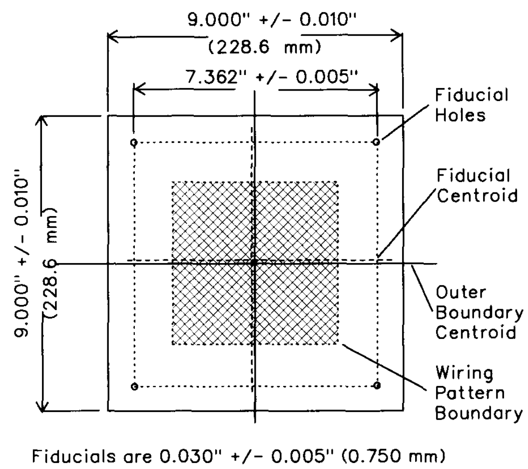


Figure 1. The test vehicle is a thin metal laminate with 750 μm diameter hole fiducials accurately registered to the wiring pattern. The centroid of the fiducials is registered to the laminate edge centroid within a tolerance of 250 μm..

illuminator into the alignment site to project the fiducial images on the optical sensor and is later removed when the optical sensing is complete. Mechanical grounds for both the FP and the CM, alignment process and its function described below.

Alignment process

A simplified drawing of the pilot workcell aligner system is shown in Figure 3 and the procedure to align and bond two laminates is described below. The CM picks up a laminate from the feeder station and transports it to the alignment site beneath the optical sensors. The FP is pushed into a mechanical "V" groove grounding block just prior to the grounding of the CM robot with its block. Light reflected from two 45° mirrors, passes through the fiducials to produce an image on the optical sensors. The centroid of the fiducial image is computed from the sensor output and stored as a reference for all subsequent laminates of the stack. The laminate is lowered, transferred and secured with a vacuum chuck at the aligner/assembly station without disturbing laminate position. The location of a second laminate is determined using the same sequence. Fine x, y, θ motions are made by the FP using an iterative process to minimize the error between the first and second laminate locations. The second laminate is lowered and glued to the first laminate to complete a bonded pair. Subsequent laminates are aligned and glued in the same way to form a multi-layer stack. The stack is later processed to form a rigid circuit board for circuit assembly.

Optical sensor

Each optical sensor consists of a set of microscope lenses to focus the fiducial image on a position sensing detector, PSD. The image generates two sets of currents from which the x, y coordinates of its centroid are derived with analog-to-digital conversion circuits. Faster data acquisition is obtained with this technique as there is no image processing required.

IV. System performance measurements

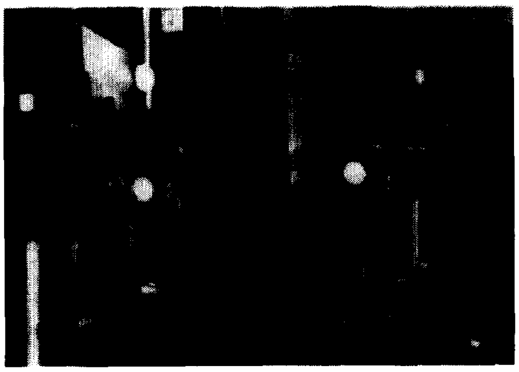
System registration accuracy is a function of electrical noise, mechanical vibrations and repeatability of mechanical positioning. Each source was isolated and classified as

- Random noise sources
  1. analog to digital converter noise
  2. optical detector and circuit noise
  3. mechanical vibrations seen by optical sensor
  4. FP electrical noise
- mechanical repeatability
  1. illuminator transport repeatability
  2. robot z-axis repeatability

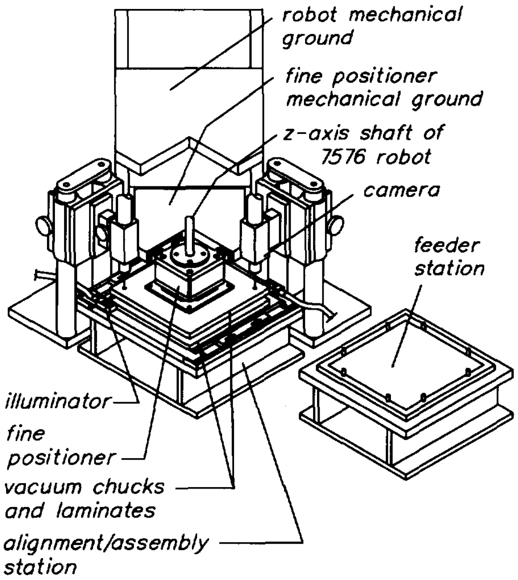
The sources are shown as a diagram of interconnected boxes in Figure 4. Measurements of output voltages were made on each source to observe the distributions. The 3σ values were obtained and converted to equivalent dimensional errors at the end of the 7576 robot. These values were placed at their respective sources shown schematically in Figure 4.

Combined effect of error contributors

An estimate of the sum of the three major un-correlated contributors to alignment error *i.e.,* random noise (vibration, converter noise), illuminator stage repeatability and z-axis repeatability, was made by taking the square root of the sum of their squares, where $N_r = 1.2\ \mu m$, $N_{op} = 0.65\ \mu m$, and $N_z = 2.3\ \mu m$. Thus the total uncertainty is,



(a)



(b)

Figure 2. Aligner/Stacker Hardware. (a) photograph of the aligner system, (b) schematic drawing of the aligner system (a).

$$N_t = \sqrt{N_r^2 + N_{op}^2 + N_z^2} = 2.7 \ \mu m.$$

V. Registration results

The alignment process described relies on good repeatability and is particularly important in two areas of the stacking.

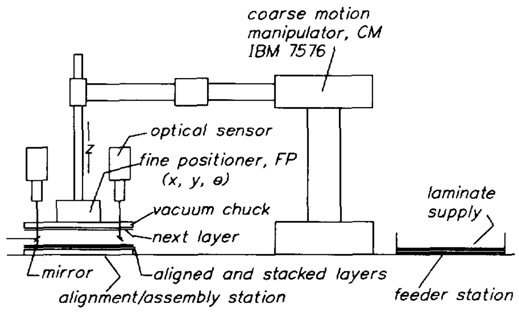


Figure 3. Laminate Aligner/Stacker System Concept. A coarse-fine positioning strategy is used to accurately align and stack laminates with an IBM 7576 robot, a fine positioner and optical sensing.

- lowering of a laminate from the sensor area to the bottom most vacuum holder
- preventing translation or rotation or "squirm" of a laminate when contacting the bottom most laminate.

Two tests were performed, one to characterize system repeatability at the stacking station and the second to measure the misalignment of two holes on a bonded pair.

Laminate placement repeatability

System repeatability was measured using a single alignment sequence consisting of picking up a laminate at the feeder and aligning its fiducials to an artificial target at the sensor site. The laminate was lowered to make contact with the vacuum holder at the stacking area and the fiducial locations were remeasured. The laminate was placed back into the feeder station and the cycle repeated. All the system uncertainties are included in the test cycle including randomly replacing the laminate into the feeder. A short term repeatability test was done for 24 alignment cycles with the results shown in Figure 5.
The radial errors are smaller than 2 μm and are well within the 7.5 μm specification. Ideally all the misalignment values should be less than 1.0 μm which is the threshold of the iterative alignment algorithm. However the laminate is lowered to the stacking area by the z axis from the sensor site. The laminate position is not monitored during this excursion and a misalignment error is attributed to this motion.

A long term repeatability test was run for 1500 cycles over a 26 hour period. The results were similar to the

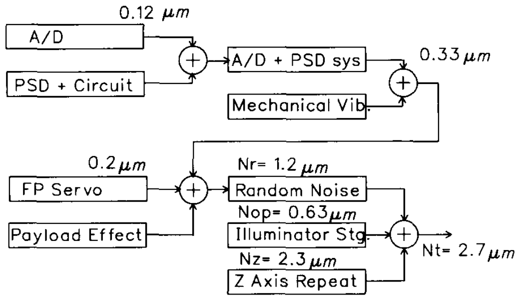


Figure 4. Alignment error contributors. The total alignment error is the vector sum of the individual noise parameters. All the 3σ values were obtained from distributions measured at each noise contribution source.

short term repeatability test. Most of the misalignment errors were within 1 μm and 98% less than 2.5 μm [6].

Laminate registration accuracy

Pairs of laminates with the geometry shown in Figure 1 were aligned, stacked and bonded. A scanning electron micrograph of two 100 μm holes with 2.7 μm misalignment is shown in Figure 6 at a view normal to the surface. From similar SEM images taken of other aligned and bonded laminate pairs it is estimated that the alignment capability of the system to be in the range of 2.8 to 5 μm.

Conclusions

We have demonstrated a technique to improve the accuracy of performing a manufacturing assembly task by a factor of ten better than existing automated assembly processes. Accuracy improvement was achieved by enhancing the positioning ability of an existing robot controlled workcell by adding to the workcell a fine positioning manipulator, optical sensing and mechanical bracing. The task was accomplished by using a coarse/fine positioning strategy with sensing to accurately align, place and stack laminates for fabricating circuit boards. The mechanical bracing system was shown to reduce environmental disturbances to a negligible level in the overall placement error summation. Another factor in achieving improved accuracy was the short time repeatability of the mechanical motions involved in the alignment procedure. The largest contributing repeatability error from the CM was appreciably smaller than

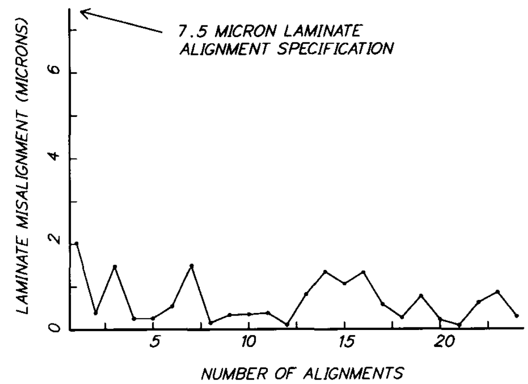


Figure 5. Short term repeatability experiment. The alignment errors for 24 placements are less than 2.0 μm overall and well under the 7.5 μm specification.

the specified alignment tolerance of 7.5 μm. It is concluded from this work that the strategy applied to this task could be used to improve other manufacturing systems to perform accurate assembly tasks.

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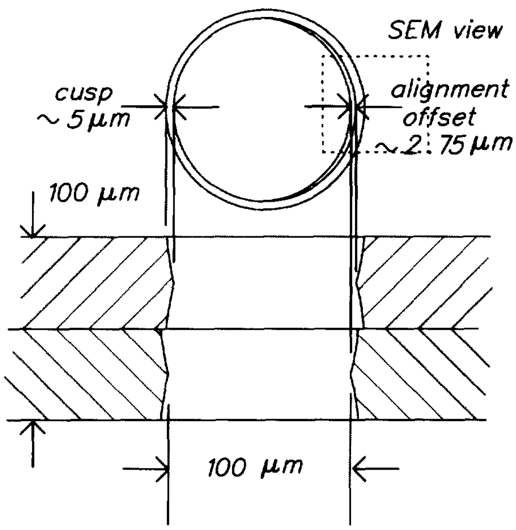
(a)



(b)

Figure 6. A pair of aligned 100 μm holes. (a) micro-photograph of an SEM view along the vertical axis of an aligned pair. The alignment offset appears as a small dark arc with a white horizontal line at the center of the view. (b) cross section of the pair of aligned holes. The cusps of the holes are formed as result of the double-sided etching process, one is seen as a broad white arc in (a).

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