

DESIGN OF A ROBOTIC WORKSTATION FOR COMPONENT INSERTION

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The characteristics of electronics manufacture have changed: instead of high volumes of the same product, the trend is toward much smaller volumes of many varieties of similar products. In this environment, the ideal assembly machine would be capable of virtually limitless adaptability. Using robotic technology, AT&T at Merrimack Valley has undertaken a project to design such a machine for printed-wiring-board assembly. This paper describes the configuration of the resulting workstation for component insertion on the automated in-line manufacturing system.

Introduction

Electronics manufacture has changed from a business turning out high volumes of the same product to one generating much smaller volumes of many similar products. The manufacturing engineer must not only respond to this change but must also continue to improve manufacturing quality, consistency, and costs. In this environment, the ideal electronic assembly machine would be capable of virtually limitless adaptability. Through computer integration of design and assembly equipment, it is possible to transfer electronically design data from a computer-aided design (CAD) system to the shop floor. The challenge, then, is to design an assembly machine that can use design data to assemble any of a large variety of products with no human intervention or downtime.

Significant progress toward this ideal has been made since 1984 at the Merrimack Valley Works. Engineers there have been actively involved in the development of a robotic workstation for printed-wiring-board component insertion. During this time, similar development efforts have focused on this application of robotic technology at many other AT&T locations as well.

Initially, Merrimack Valley engineers concentrated on through-hole insertion of "nonstandard" components—that is, components that cannot be inserted by commercial automatic insertion machines. This work has been expanded to include standard components in cases when there are not enough parts per board to justify the setup time required

for high-speed insertion machines. Experience resulting from this early through-hole insertion work has also been helpful with application development efforts to place surface-mounted components with similar robotic manipulators.

The AIM Line

Workstation development at Merrimack Valley is part of a larger project to implement an automated in-line manufacturing (AIM) process to assemble digital terminal circuit boards. The AIM line at Merrimack Valley is one of the most automated circuit-board assembly processes within AT&T. The assembly portion of the process is separated into six workcells, as illustrated in Figure 1, each with an AT&T 3B2 computer as a local host. All of the computers are tied into an AT&T 3B20 mainframe computer, on which the manufacturing process control system (MPCS) operates. This constitutes the information and process control architecture of the assembly portion of the AIM line.

Product flows through each workcell in panelized form, that is, in a standard panel size that contains one or two circuit boards. Panelization eliminates mechanical changes when circuit-board sizes are changed. A bar-coded serial number is applied to each circuit board on a panel at the beginning of the assembly process to permit product tracking and data collection through the assembly and test processes.

Currently, circuit boards for both the D4 and D5 transmission systems are assembled on the AIM line—approximately 60 different codes. Lot sizes vary from a minimum of 23 circuit packs to as many as 1000.

Workcell Description

The robotic workstations discussed in this paper are part of the in-line insertion, inspection, and repair workcell. The components of this workcell and their interconnections are illustrated in Figure 2.

After high-speed insertion of standard components, circuit boards are passed sequentially down a palletless conveyor line through an inspection station, manual and robotic assembly stations, a second inspection station, and, if necessary, a repair station. The workcell

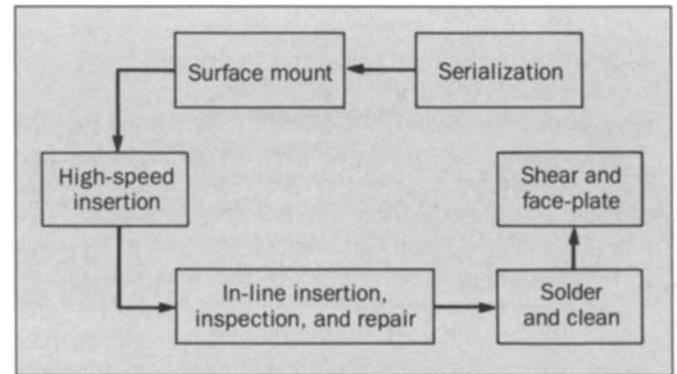


Figure 1. Automated in-line manufacturing (AIM) system workcell functions and sequence.

conveyor is actually made up of 23 individual modules, each 5 feet long. Three belts on each module operate as a non-synchronous buffer-stop-buffer system, resulting in a pull assembly process. In other words, work is “pulled” into the next station only when that station is ready to receive the work and perform the required operation. Each station in the in-line insertion, inspection, and repair workcell operates independently of other stations in the cell.

No lead clinching is done on-line at the present time. Snap-in forms on some component leads are used when required, although for the most part proper board handling is relied on to prevent components from falling out.

After assembly is complete, all boards are conveyed through the line-scan automated inspection station developed by the AT&T Engineering Research Center/Manufacturing Development Center (ERC/MDC). If a defect is identified, or a previous assembly defect is logged against the board’s serial number, the board is routed through the real-time repair loop. After the board has passed inspection, it is moved directly into the wave-soldering workcell.

Currently, seven robotic workstations are installed along the conveyor line (Figure 3), and an additional station is scheduled for installation. The robotic workstations on the line insert 13 different families of parts, as illustrated in Figure 4. The board component population determines

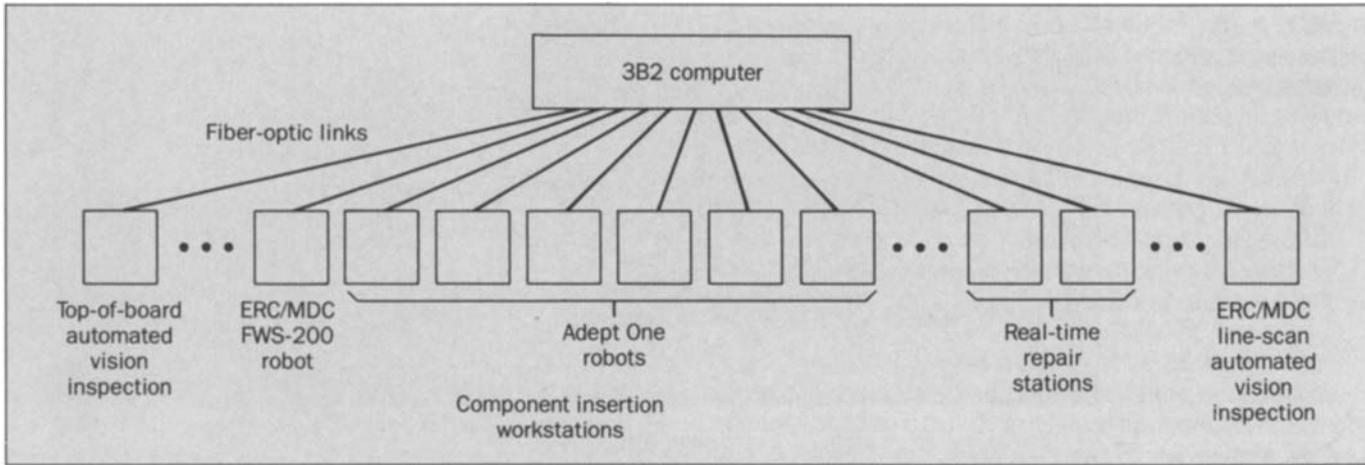


Figure 2. Components and interconnections of the in-line insertion, inspection, and repair workcell.



Figure 3. Workstations in the automated in-line manufacturing system at Merrimack Valley.

the number of robotic stations needed for assembly. The mixes of component types require various levels of robotic and manual activity: anywhere from zero to all seven robot stations and from zero to eight manual stations.

Workstation Description

The components of each workstation and their interconnection are illustrated in Figure 5. Each workstation consists of:

- One robot
- One to four parts-preparation and presentation feeders
- One conveyor section
- End-of-arm tooling.

The robot used on six of the seven workstations is the Adept One™ system (trademark of Adept Technology Inc.). This robot (Figure 6), was selected after specification data on more than a dozen commercially available robot arms were compared. It was found to offer the best combination of speed, shape and size of work envelope, repeatability, accuracy, software features, and cost for the needs of the particular workstation design. The remaining workstation uses a manipulator developed by the AT&T ERC/MDC, called the FWS-200.¹ This robot is being used on the AIM line to evaluate its performance in a factory environment. Although different manipulators are used in the workstations on-line, the basic station integration and operation is the same.

Figure 4. Parts inserted by robotic workstations.

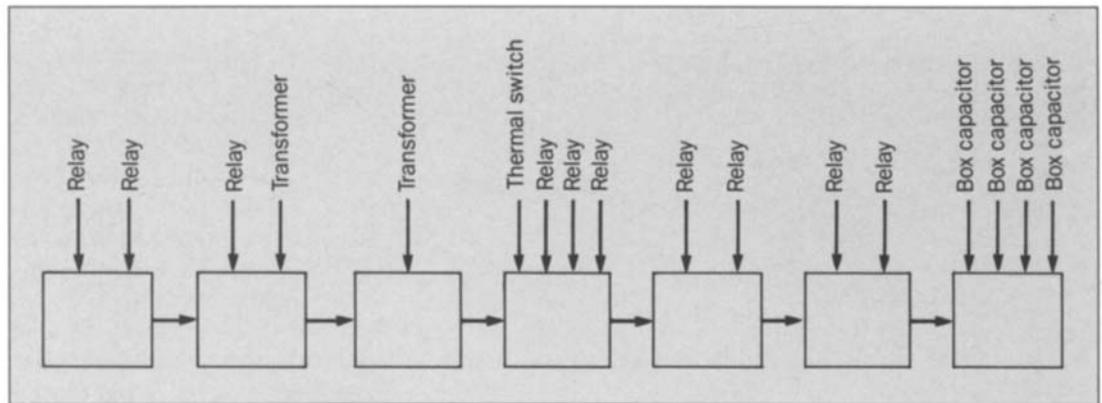
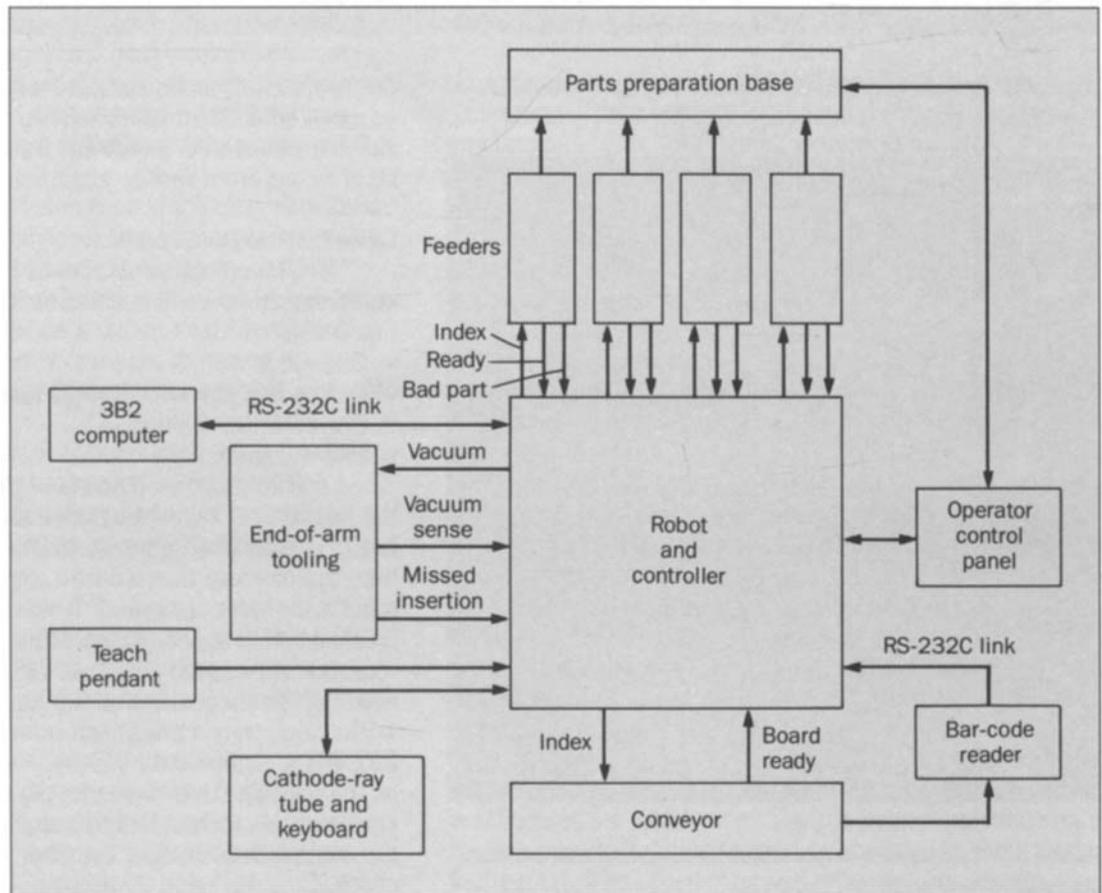


Figure 5. Organization of a robotic workstation.



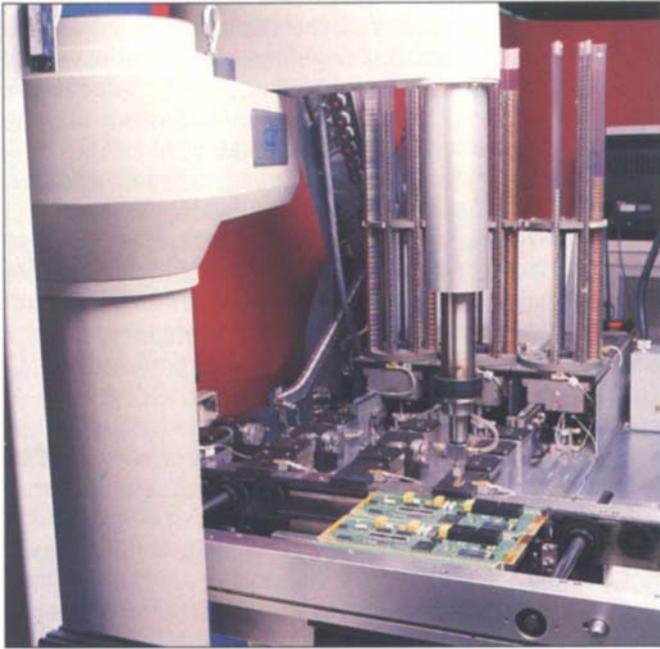


Figure 6. Robot manipulator at a parts-insertion workstation.

The parts preparation and presentation feeders were designed by engineers in the Merrimack Valley Machine Design Department. All nonstandard components are packaged by the suppliers in tubes, to be fed from one of two basic types of feeders, the rack or the turret. The type of feeder is determined by component shape and orientation in the tube. Components are singled out to a walking-beam mechanism, which transfers parts through lead-cutting, lead-straightening, and lead-verification operations and on to the lead-locating nest for robot pickup.

The feeders are located on a base that contains control electronics for up to four feeders. Each feeder is controlled by a single-board computer and is interfaced to the robot via three digital signals. The feeder indicates to the robot when a part is ready for pickup and whether the part is insertable or not. The robot, after clearing the feeder, tells it to index the next component to the pickup nest. The feeders are set on dowel pins for quick and accurate positioning and are interchangeable between positions

on a base as well as from base to base.

Each workstation in the cell contains one conveyor module. Spare sections were purchased at the beginning of the project to allow off-line integration. Workstations were assembled and demonstrated in the Merrimack Valley Machine Construction shop and installed in the AIM shop with no line downtime. Each station can be set to stop the board for an operation or to pass the board through without stopping it. Boards requiring assembly are positioned over an elevator mechanism in the center of the station. The mechanism lifts the board slightly and uses tooling holes in the circuit-board panel to locate the panel. Two digital signals interface the conveyor to the workstation—one to signal the robot that the board is ready for assembly and the other to signal the conveyor to index the board to the next station.

Simple end-of-arm tooling was also designed by Merrimack Valley engineers for five of the workstations. The tooling allows for an interchangeable vacuum nozzle and calibration sensor and has proved quite versatile. The use of vacuum nozzles to pick up components offers several advantages. The nozzles:

1. Require little or no clearance between components
2. Eliminate body-to-lead location tolerance problems
3. Are simple to design and maintain
4. Can handle a wide variety of parts.

Compliance in the end-of-arm tooling prevents forcing the components on the board; such forcing often causes components not secured to the board to bounce out. Compliance also provides a means to sense whether the insertion attempt is successful. With straight leads, a properly positioned component will not require any force to insert. When a misinsertion occurs, a small force in the upward direction is used to move the vacuum tool upward. A flag on the end-of-arm tool breaks a photoelectric-cell beam, indicating that the leads did not go through the board. The tooling design works well with a spiral search pattern, which the robot uses if the part fails to fall in on the first attempt.

Vacuum cannot, however, handle all parts. For example, parts with irregular or very small top surfaces require a mechanical gripper. One station on the AIM line uses a servo gripper to insert box-type capacitors. The

gripper has its own controller and programming language and communicates with the robot through a combination of digital input/output and RS232C serial input/output.

Workstation Operation

All workstations are set up and monitored by a machine operator. Experience has indicated that one operator can manage up to five workstations at a time. The operator interfaces on all the workstations provide the same information, although they differ somewhat in their physical design. The Adept robots are operated by means of a cathode-ray tube (CRT) and keyboard. Through the keyboard, the operator informs the station of the code to be assembled, the components in the feeders, and the configuration of the feeders. On the new FWS-200, this information is conveyed through a touch screen on either side of the controller. The touch screen interface has proven very reliable and preferable to the keyboard.

Parts feeders are operated through a control panel, accessible from the front or back of the station. The panel has on/off, reset, and manual index buttons for each of the four possible feeders on a base. In addition, the panel has indicator lights for a feeder jam and for low-on-parts and out-of-parts conditions for each of the feeders.

Once the station is running, operator attention is required to keep the feeders loaded with parts, clear any feeder jams, and generally monitor the workstation performance. The robot inserts parts in order based on feeder availability. Each component insertion is attempted once, using a spiral search pattern if necessary. If the component fails to fall in, the miss is logged into a data file and the part is placed in a reject box, but the insertion is not attempted again. The component will be placed in the board at the repair station down the line before soldering. Components in the reject box are inspected, tested if necessary, and used to stock the repair station.

Design Objectives

The two principal design objectives that led to the configuration of the current systems were modularity and flexibility. These attributes were considered key in optimizing system performance and allowing for future implementation of technical developments. Modularity was designed into the workstation by separating the control of

components and by keeping the communication between them simple. As a result, none of the component brands is essential to the station design.

For example, even after an in-depth study of commercial robots to select the best one available for the application, a new and better robot became available after the first station had been built and installed. Because of the system's modular design, it was possible to switch to the new robot, which was more reliable and faster, with very little additional design effort.

Moreover, the modular workstation design has allowed Merrimack Valley to participate in performance studies of robots developed by the ERC/MDC. Feeders and a conveyor section were supplied to the ERC/MDC as standard workstation components, interfaced to the ERC/MDC manipulator, and then installed as a system in the AIM line.

Workstation flexibility proved to be an important factor in the ability to adapt to a changing product design. Not only are individual codes of the product family changing (components removed, added, and moved) but entirely new product families have been added to the AIM line. The changing product mix has not been a problem because of the high degree of flexibility of the workstation realized through:

- Interchangeability of feeders
- Using a workspace calibration sensor
- Software development.

Typically in robotic workstation design, the challenge is to utilize fully the robot's flexibility without outrageous hard-tooling expense. The major design challenge in the Merrimack Valley workstation for component insertion was in the component feeder part of the system. Flexibility was achieved by making feeders interchangeable, connectorized, and doweled in position for quick changes in line configuration. It has been possible to shift feeders among stations, allowing maximum usage of each station, without slowing the line by putting in too many components at any one station.

Another major factor in determining workstation flexibility is the calibration routine. The vacuum nozzle can be replaced with an infrared reflective sensor that the robot uses to scan for the edges of the component presentation nest on each feeder. These points are used to set up

a reference frame for each nest. Edges of a "golden" board positioned on the conveyor tooling pins are found in the same manner, and a frame is set up for the board with the origin at the circuit-board datum.

The benefits of this simple and quick calibration routine have been significant. First, identifying the location of the circuit-board datum, which is not physically located on the circuit board, facilitates the use of raw CAD data as received from the drafting system. Secondly, the calibration routine eliminates the need for an operator or engineer to teach precise pickup and placement points, using the robot's teach pendant. Teaching precise points by moving the robot around with a teach pendant is a tedious, time-consuming task. Compounding this effort by multiple robot workstations in a workcell renders the job unreasonable. Since it often requires that the teacher move into the robot's work envelope to better see its position, the job also requires great caution. By eliminating the need to teach precise points, the calibration routine has greatly improved the workstations' utility on the factory floor.

The program software of each of the six Adept robots on-line is identical, which also helps to maximize the stations' flexibility. The software requires the operator to set up the feeder configuration and input circuit-board code information. The program then references a CAD database on the local 3B2 computer or, if that link fails, reads the information from its own system disk. The robot searches the CAD file to find a match between what is available in the feeders and what is required to assemble the board.

Each CAD file contains an x,y location of the component center relative to the board datum, a component orientation (given as 0, 1, 2, or 3), and the reference designator (such as R13 or K2). An additional file, created by Engineering, contains other required data such as component height, part orientation in feeder, and required robot wrist orientation to pick up the part. With this information, along with board and feeder position, the robot can assemble any product.

The FWS-200 runs a user program modeled after the one running on the Adept units but in a different language, MRL. Similarities in the language and use of the same CAD and engineering data structures minimize the

problem of having two different kinds of robots on the same line.

Design Constraints

Lack of experience with robots resulted in some design objectives that proved to be constraints rather than necessities. For example, there was concern regarding how reliable the robot would be in a manufacturing environment over the life of the installation. Therefore, it was decided that it should be possible to operate the station manually in case the robot failed. A human operator could perform the task by picking up components from the same feeders the robot used. In the event of a robot failure, an operator could occupy a robotic station, allowing the line to continue in operation.

For this reason, the robot and feeders were arranged about the conveyor in such a way that the station could be manually operated without removing the robot. Experience so far has shown, however, that in most instances it is a feeder that fails in the workstation, not the robot. Thus, the objective proved unnecessary and constraining since the feeders could have been better arranged for maintenance accessibility and more feeders could have been made accessible to the robot if the station were designed for automatic operation only.

A better approach, in retrospect, would have been to provide extra manual stations, while more fully utilizing the robot's work envelope with more than four feeders. This way, feeders could have been moved around in case of a robot failure and manual stations could have been used in case of feeder failures. Because of the higher feeder-to-robot ratio, fewer robot stations would be needed so that the additional manual stations would not have increased the overall length of the line.

Conclusions

The application of robotic technology to component insertion tasks is expected to improve quality, increase test yields, and maintain flexibility while reducing direct labor costs. The main barriers to realizing these goals are:

- Insertion reliability
- Workstation cost
- Utility on factory floor.

The insertion reliability that should be expected with a robotic insertion workstation was virtually unknown before the first station was installed in the AIM line. A number of variables affect the frequency with which a robot is able to successfully insert a component on the first try. These factors include component lead location and board location tolerances, robot repeatability, and robot accuracy. Although approaches such as retry and search patterns can be used to improve insertion reliability, both have a negative impact the insertion cycle.

On the basis of data collected from the installed stations, insertion reliability at each station is approximately 99 percent. This assumes that a search pattern is used if the part misses the holes at first, but no retry if the part still does not go in. Some components have been more difficult to insert than others, depending on the shape of the leads, shape of the component body, and the lead-to-hole clearance. The goal for insertion reliability of 99.9 percent is being pursued through better component design, component packaging, board layout, and improved end-of-arm tooling.

At the outset of the project, a target cost was set for a workstation that could operate as efficiently as an operator performing the same task. The goal was to design the station with as much flexibility as this cost would allow. For a workstation to handle even close to the variety of work an operator does on the line, numerous and/or very flexible parts feeders are required. These increase the overall workstation cost.

Cost reduction effort, then, has focused on the feeder design. Working with component vendors, we have made progress in improving component quality with respect to insertability. This has facilitated the elimination of the walking-beam part of the feeder design. Components can still be straightened, when necessary, by having the robot place the component in an active lead-straightening nest. It is believed that, without sacrificing insertion reliability, the simplified version of the feeders could be used to present components to the robot. This would result in a four-feeder robot station for less than the original target cost. A side benefit of the development work has been a faster average cycle time, from four components in 16 seconds to eight in 16 seconds.

Finally, it has been demonstrated that multiple workstations can be operated easily by a single machine operator. Simplifying the feeders has affected the amount of attention the stations require by reducing minor maintenance problems. Generally speaking, the workstations have been well received by the machine operators on the AIM line.

In conclusion, the use of a robot workstation as a flexible component insertion machine is both feasible and attractive. Much has been learned from the design, integration, and installation of the workstations on the AIM line. Although the design of a new station would look very different from those currently installed, the stations on line continue to assemble boards and allow further exploration of the capabilities of robotic technology and the effects of improved product design, component design, and component packaging. Further, an even more flexible station with, for example, 50 feeders accessible to a robot arm is certainly technically possible and potentially economically advantageous.

Acknowledgments

As is the case with most successful projects, the development and implementation of the robotic systems described were the result of the cooperative effort of many engineers and organizations. The vision of N. R. Brunelle in initiating the AIM line concept at Merrimack Valley, the innovative feeder design by W. A. Fyfe, A. H. Killam, and K. Hoang, the leadership and patience of W. C. Lawrence, and H. C. Wilbur's tireless work in building parts feeders are gratefully acknowledged.

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