LIGHTGUIDE APPARATUS TECHNOLOGY AND AUTOMATION

AT&T TECHNICAL JOURNAL

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Marketing lightguide apparatus products is becoming a very dynamic and competitive business. As new products are introduced to the marketplace, they must be introduced quickly and at low cost. In addition, sufficient quantities must be produced to satisfy any initial demands and thereby establish and maintain a customer base. This article examines how the development of a prototype flexible automation work cell for new lightguide connectors accomplished this goal. The article also evaluates the future potential for a completely automated product line using flexible automation as a basic building block.

Developing the Prototype

Recently, several new lightguide connectors were introduced. While initial production was performed manually, a prototype flexible automation work cell was quickly introduced to handle a portion of the assembly operations until production facilities were implemented. Flexible automation has made possible early order placement because product design refinements can be handled more easily in flexible automation as opposed to fixed or hard automation.

Flexible automation has a significant cost advantage over manual assembly and definite advantages over hard automation. These advantages include:

1. Robot precision that allows quality assembly of products with less than 0.001-in clearance between mating parts.
2. Assembly times that are almost twice as fast as manual methods with minimal operator attention.
3. One simple end effector (parallel jaw gripper) that can handle all the parts and pallets of parts as well.

Other major advantages of flexible automation include the short lead time from concept to introduction, the ease of accommodating process and product changes, and the ease of adjusting production capacity to meet our market needs.

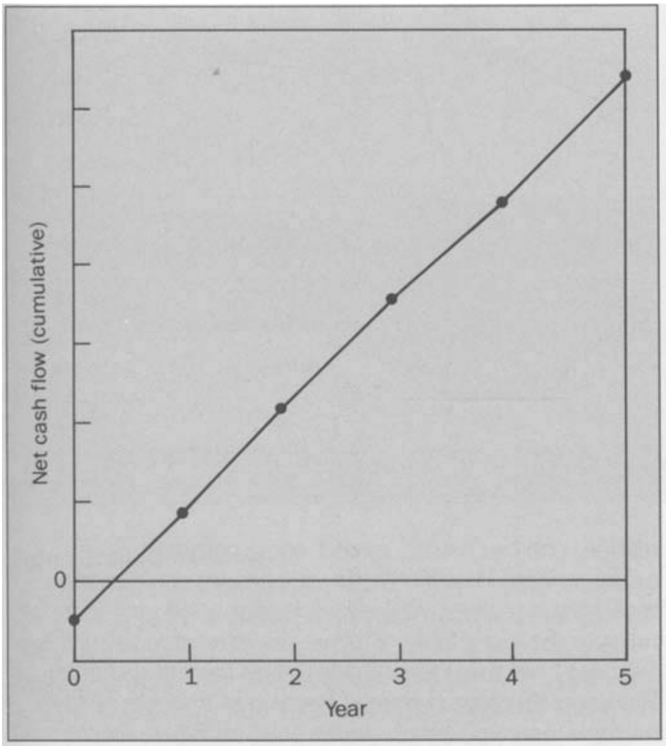


Figure 1. Cash flow advantage for flexible automation versus manual assembly.

Flexible Automation

In an evaluation of how to most effectively manufacture our new lightguide connectors, manual assembly was compared with both flexible and hard automation. Seven parameters were considered in this evaluation and are listed below:

1. Manufacture at low cost.
2. Provide high-quality product.
3. Begin with automated production facilities.
4. Match production capacity to demand.
5. Minimize effect of product design changes.
6. Consider retooling costs for new products.
7. Select robot and work cell configuration.

Each parameter was considered in detail in the overall decision-making process. However, for cost justification, only the traditional factors were assigned monetary values. The other advantages were considered intangible assets.

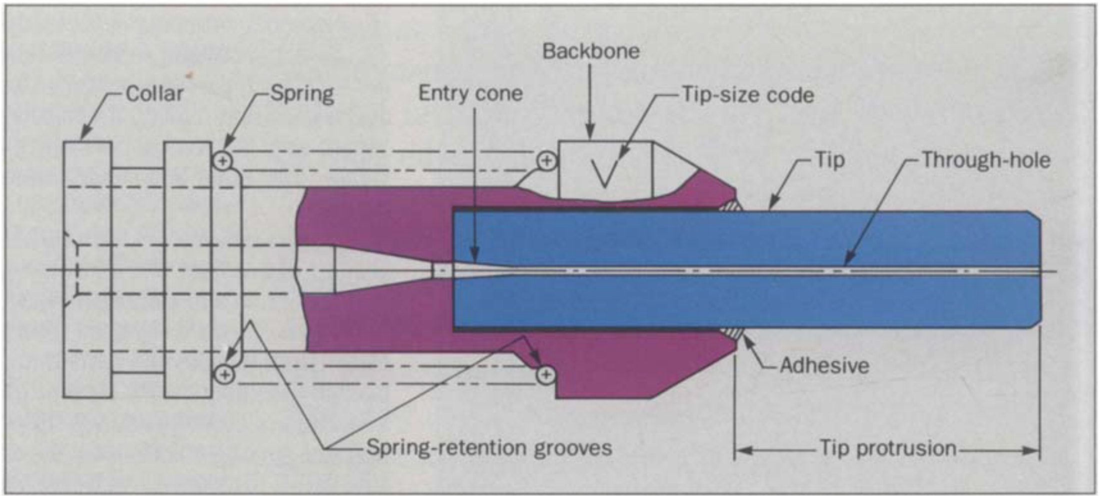
Manufacture at Low Cost. Manufacturing the new product at low cost was a prime consideration. Traditional cost reduction and cumulative discounted cash flow (CDCF) methods were used to evaluate return on investment. Both flexible and hard automation were compared to manual assembly. Labor savings and capital investment, as a function of our projected program, were the variables used for savings calculations. Figure 1 shows a typical cumulative discounted cash flow for one of our assemblies. The cost analysis indicated the manual method to be the most costly by far.

In comparing flexible with hard automation, our program gave flexible automation an edge. A hard automation machine would cost more than flexible automation and would have much idle time. With the small cost advantage of flexible as opposed to hard automation and with some intangible advantages from other parameters factored in, the choice of flexible automation was clear cut. For our application, the cost of the completed work cells ranged between two and two and one-half times the cost of the robot.

Provide High-Quality Product. It is important to ensure reliability and repeatability when evaluating and fixturing the robot and work cell. Sensors were included to ensure that parts are present and that assemblies pass the most common failure modes. The sensors are monitored by software that identifies problem areas for the operator. Product quality would be similarly monitored for either hard or flexible automation. Actual results of our experience are discussed later.

Begin with Automated Production Facilities. In the past, having automated facilities at the beginning of the product life cycle has been difficult. With hard automation, the

Figure 2. Rotary splice plug detail identification.



design must be fixed before designing and building machinery. Otherwise, considerable cost and delay are involved in adapting the machine to incorporate product design changes. This problem occurred in one stage of the process that is discussed later. Flexible automation is more easily adapted to changes in the process or product design. Changes can often be handled with software modifications and/or minimal hardware changes.

Match Production Capacity to Demand. Throughout the product life cycle, production capacity must be adjusted to meet demand. The flexible automation work cell is totally self-contained. All it needs is to be placed on the shop floor and connected to air and electrical power. In our experience with the robot mounted on a work table, few points, if any, have to be retaught after installation. Work cells can be added or removed as needed. When adding work cells, four to six months lead time is needed for fabrication and installation. If product demand declines, work cells can be easily removed and retooled for another product.

Minimize Effect of Product Design Changes. Product design changes often require tooling changes. In manual assembly, this is usually simple. With hard automation, however, it can be very difficult and costly. In flexible automation, one can usually expect some software modifications. Possible hardware changes could include modifying a gripper, replacing a feeder bowl, or adding fixtures to the work table. Changes as extensive as replacing a feeder bowl may require one to two days of downtime. However, this cost is a small fraction of the cost of a new machine. In some cases, a new bowl or fixture can be added to the work table while leaving the existing one in place. A four-by-five-foot work table was used in work cells with space still available for additional fixtures.

Consider Retooling Costs for New Products. As the product matures and the demand begins to decline, work cells can be removed from service and retooled for a new product. In the worst-case scenario, only the robot, which is typically one-third to one-half of the cost of the work cell, can be reused. More realistically, the robot would be reused to manufacture a work table and some of the same fixturing would result in a significant savings in the cost of retooling the work cell.

Select Robot and Work Cell Configuration. Flexible automation, as applied in lightguide connector assembly, is a single-cell robot mounted on a work table with supporting work table and supporting feeders, fixtures, etc. Some of

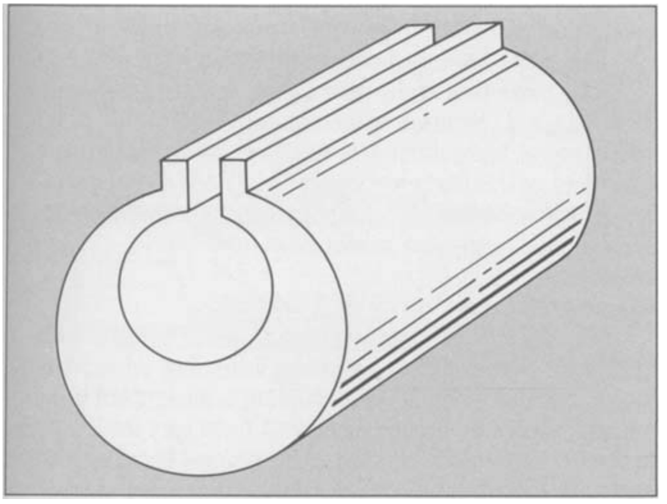


Figure 3. MMS coupling.

the work cells have conveyors to move the product from one cell to another. The robot controller is used as the master controller for the work cell and the teach pendant is used as the main interface or control panel for the operator. Several robots were evaluated and the Adeptone™ robot, from Adept Technologies Inc., was selected. The following parameters were considered assets to this particular application.

Speed. Because our work cells are single robot units and there are no time-consuming steps in the process, the speed of the robot has a major influence on the work cell.

Reliability. The Adeptone robot is a new robot with little history, but its design was simple, clean, and of SCARA (selectively compliant articulated robotic arm) configuration. In addition, company personnel were experienced in the robotic field.

Flexibility. This robot had a large work envelope capable of handling all current and expected future applications.

Repeatability. Our application required very good repeatability because of precise measurements during the processing.

Controller. With a single cell robot concept, the robot controller should control the complete work cell. VAL II is a very powerful programming language and the controller had more than enough input/output (I/O) ports and RS232 lines. Also, the teach pendant can be used as the main control panel for the robot. The only controls added were emergency stop buttons to provide stop capability on all sides of the work cell. For additional safety of the personnel working near the robot, a polycarbonate shield was mounted around the periphery of the work table enclosing the robot. Two doors on the work table have safety interlocks to prevent the robot from moving while the door is open. For convenience and to minimize down time, the feeder bowls were located outside of the safety shield so parts could be added during processing.

Product Description

The three new products in our line are the multimode mechanical splice, rotary mechanical splice and the ST™ connector. The first two are almost identical and the third has some similarities to these. A more detailed look at each connector follows.

Multimode Mechanical Splice (MMS). The multimode splice consists of two plugs and a coupling. The plug is made up of four components. A glass tip is bonded in the end of a plastic backbone using an adhesive. A compression spring and plastic collar slip over the other end of the backbone. The ends of the spring snap into grooves on the backbone and collar to hold the plug assembly together (Figure 2). The coupling, as shown in Figure 3, is a one-piece molded sleeve and requires no assembly.

Rotary Mechanical Splice (RMS). This splice consists of two plugs similar to the MMS but with a different coupling. RMS plugs are assembled in the same manner as MMS plugs and contain the same components (Figure 2). The difference between the two products results from the way in which they are used. Tip diameters of rotary splice plugs must be matched to assure the desired performance

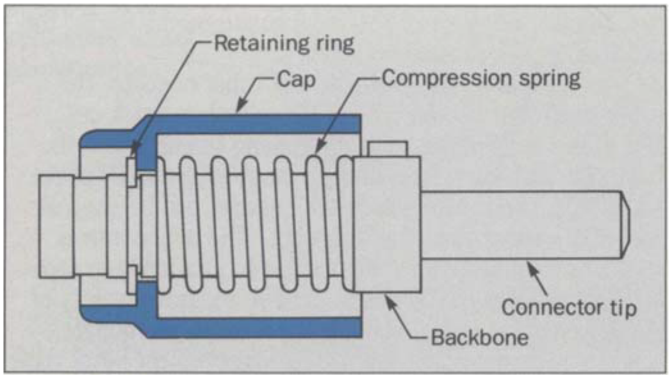


Figure 4. ST™ connector coupling.

level of the splice. Therefore, the diameter of each glass tip must be measured and the backbone marked to indicate the size of the tip. Finished plugs are placed into one of several bins according to tip size. A discussion of the coupling is not included here.

ST Connector. This connector consists of two different plugs and a coupling. The tip and backbone of the ST connector plug are similar in size and shape to those used in the MMS and RMS plugs. (Although these parts are made of different materials and have slightly different dimensions, the same feeders will handle all three products.) The plug assembly is completed with a cap and spring (different from the above products) held on the backbone with a retaining ring (Figure 4). The coupling consists of three parts: a die-cast housing, a molded sleeve, and a molded retainer to hold the sleeve in the housing (Figure 5).

These three products are well suited for automated assembly. Simple motions are required to assemble the parts. In addition, the assembly process can be subdivided into steps handled by simple fixturing. The similarity between parts allows the use of common fixtures and feeders. The assembly process is very short, requires very little skill, and quickly becomes very repetitive and dull.

The individual components also were designed for automated assembly. Their major attributes are:

1. The parts are small with precisely defined shapes.
2. The parts have tight tolerances, adequate clearances, and good chamfers where required.
3. Straight line insertion is required for all parts.
4. Most of the parts are easily fed. They do not nest, tangle, or shingle and are shaped such that they can be handled easily in a feeder bowl.

Assembly Process

The plug assembly process can be broken down into three phases: tip-to-backbone assembly, adhesive curing, and final assembly. The coupling is assembled in a separate process. Figure 6 shows a flowchart for the plug assembly process. While there are several separate processes, they have been arranged to optimize use of labor and provide for future total integration. A description of the process steps follows:

Tip/Backbone Assembly. One type of robotic work cell performs the tip-to-backbone assembly for all three plugs. (The automated-versus-manual assembly time ratio is about 7:4.)

Backbone retrieval. The first step is to retrieve a backbone from a feeder bowl and place it in a holding station.

Tip retrieval and orientation. A tip is retrieved from the feeder station and inserted into the end-orientation check station. Here the part is checked for the proper polarity. If it is not correct, a signal is sent to the robot to transfer the tip to a station that switches the exposed end using a rotary actuator and gripper.

Apply adhesive. The robot advances the tip to the adhesive application station. Here a simple adhesive applicator (simulated manual method) is used to apply two drops of adhesive 180° apart.

The tip is transferred to the backbone holding station and inserted into the backbone in a manner that evenly distributes the adhesive around the inside of the backbone. This subassembly is then placed tip up in a pallet. When the pallet is full, the robot replaces the full pallet with an

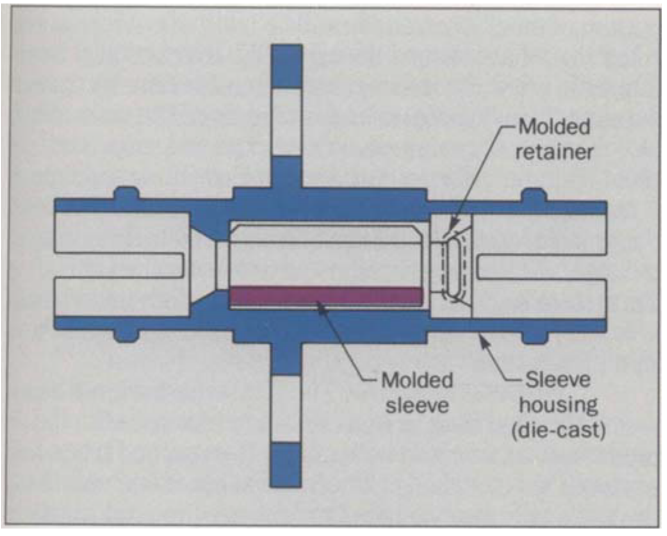


Figure 5. ST™ coupling.

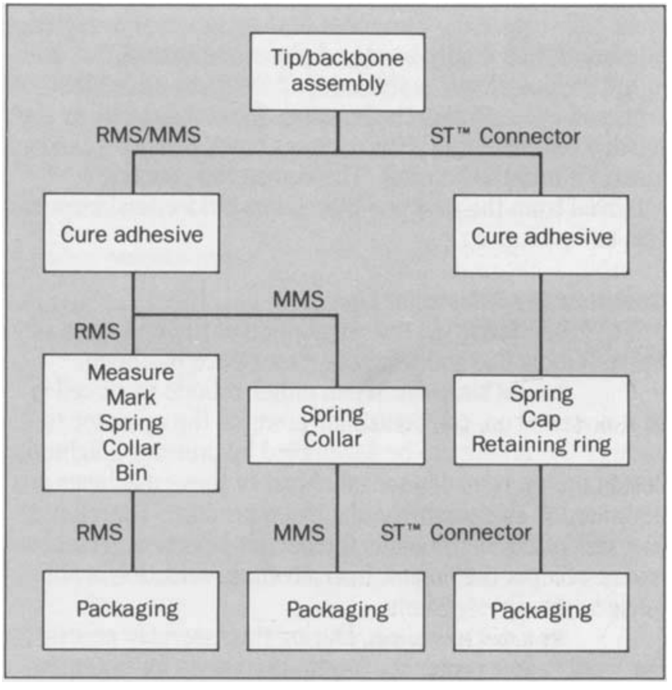


Figure 6. Process flow chart.

empty pallet and resumes the assembly of parts. Full pallets may be placed in either a rack to be removed manually or on a conveyor.

Adhesive Cure. At this point the product takes different paths through the assembly process depending on whether it is an ST connector plug or the RMS and MMS type. RMS and MMS plug pallets are placed on a conveyor and carried through an adhesive curing oven to a second type of robotic work cell for completion. Adhesive cure and final assembly for an ST connector plug were being handled manually at the time of this writing.

RMS and MMS Final Assembly. The second type of robotic work cell completes the assembly of the MMS and RMS plugs. The robot removes full pallets of cured parts from the oven conveyer and places the pallet in a workstation. (This work cell completes the assembly about five times faster than a human operator.)

Tip measurement. Each part is removed from the pallet, rotated to point the tip down, and the tip is measured in a laser micrometer. The result is transmitted to the robot controller. The controller analyzes this information and determines the action to take next.

Diameter identification. The part moves to the marking station and the controller signals an ink jet printer to mark the proper tip size code on the backbone.

Install spring and collar. The subassembly is placed in a rotary actuator that carries it to a spring feeder while the robot retrieves an oriented collar from a feeder bowl. The robot pushes and rotates the collar down onto the backbone to compress the spring and snap it into the grooves on the collar and backbone (Figure 2). The completed assembly is placed in a bin that corresponds to its marking to await final inspection and packing.

ST Connector Coupling Assembly. The ST connector coupling assembly has also been automated using a robotic work cell (Figure 5). The robot first retrieves an oriented housing from a feeder bowl and places it in a nest. An oriented molded sleeve is retrieved from a second feeder bowl and inserted into the housing. The robot picks up the molded retainer from a third feeder bowl, orients it, and inserts it into the housing. The completed coupling is removed from the nest and placed in a bin for final inspection and packaging.

Operation of the Assembly Line

The following is a description of the operation of our assembly line and what our experience has been.

Product Selection. When either robotic work cell is first powered up, the controller prompts the operator to identify the product to be assembled by pressing a lighted button on the control pendant. Most of these machines are dedicated to the assembly of a given product. Therefore, that product is identified as the default selection. The controller accepts the default if an alternate selection is not made within five seconds.

Work Cell Monitoring. During the assembly process, the work cells monitor the key workstations for potential problems. Optical sensors provide input from the parts feeders. If a part is not available when the robot is ready to pick it up, the robot waits two seconds for a part to become available. Then, it moves to a safe location, turns on an audible alarm for three seconds, and turns on a light that flashes until the problem is removed. A message is displayed on the pendant to assist the operator in diagnosing and correcting the problem.

Proximity sensors keep track of the pallet locations. By monitoring these sensors, the robot knows where to pick up an empty pallet when the loading station is empty, and where to place full pallets. If there are no empty pallets available or if there is no room for the full pallet, the robot moves to a safe position, signals the operator, and displays a message.

Sensors are also used to determine whether parts are present when they should not be. If the RMS and MMS spring and/or collar do not snap into place properly, a portion of the plug assembly will be left in the workstation when the robot removes the assembly. If a portion of the assembly is left, the robot returns, removes the parts, and deposits them in a container for salvaging. The controller also monitors the safety shield openings and suspends robot operation when a door is opened at the wrong time. A message will be displayed on the pendant that identifies the problem area. The pendant can be used to determine the status of the program currently running, the state of the system flags, or production statistics. This information is available to the operator by selecting the appropriately identified button.

Production Experience. The prototype work cell was put on the shop floor in April 1985 and replaced with the production version in October 1985. The second type of work cell was installed in December of the same year. As the work cells were installed and released to production, manual assembly operations were discontinued. However, some of the old facilities have been retained for emergency situations. Yields from the prototype work cell were greater than 95 percent. The most frequent failure mode was dropped parts due to worn grippers. New grippers were designed to minimize wear and assure proper handling of the part.

The gripper design was improved for the production machines, but further improvements are needed. The most common failure on the new work cells was the sensor used to verify that parts are present. This sensor required frequent adjustments to keep the machine running. It has been replaced with a more reliable type of sensor. Another problem area was the tip orientation detector. The new work cells had difficulty positioning the tip at the same vertical point on the electricator each time. The problem was solved by pushing the tip against a fixed object and allowing the tip to slide inside the gripper. This provides the repeatable vertical position required for reliable results.

Product Quality Control. Product quality is monitored both by the work cells and by an operator. The primary test performed by the robot is a through hole test on the tip/backbone assembly. This is to ensure that the fiber can be inserted in the plug. The new work cells have incorporated a light test into the design that checks for a clear hole through the part. The machine operators monitor product quality from all the machines on a sampling basis (comprising the largest portion of their assignment). Additional inspections are performed by other groups.

The transition from partly manual to automated production has shown product quality to either improve or remain at the same level depending on the specific operations. With proper monitoring of the production process, product quality is very consistent with very high yields.

Future Automation

One of our future automation goals is the automation of the packaging of the finished products as they come out of the final assembly work cells. An automatic bagging machine, currently used to package products, can be interfaced to the robot controller for packaging. Parts require packaging either individually or in multiples and in certain situations require placement in a cushioned container. Sizable savings are anticipated with the automation of the packaging operation. However, methods of automatically packaging products that must be cushioned have yet to be identified. A second goal will be to integrate the complete system with a computer to control the work cells including the packaging and boxing for shipment. This concept means complete control from order entry to shipping labels, including machine and process monitoring. Such a system is commonly referred to as a *computer integrated manufacturing system.*

Acknowledgment

The authors wish to acknowledge P. S. Nelson and W. D. Granger of AT&T Technologies, Inc. in Atlanta for their contribution to the automation effort for this product line.

(Manuscript received February 19, 1986)