

# An Automated Cable Assembly Machine

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A hand-built cable purchased from an outside vendor, and used in large quantities at the Denver Works to assemble AT&T private branch exchange (PBX) systems, did not meet quality, shipping, and cost expectations. Therefore, Denver engineers began in-house automated production of this cable, using robotics and custom-designed automation. This paper describes the configuration and operation of an automated cable assembly machine composed of six major workstations that, when operating simultaneously and sequentially, completes one cable assembly every 30 seconds. Restocking the machine with piece parts is the only manual intervention required.

## Introduction

Producing cable assemblies used for high-volume manufacturing traditionally has been a labor-intensive operation. When these operations have been moved to outside vendors to save money, the engineer often has been faced with unacceptable quality, high inventory, and erratic shipping schedules. AT&T's Denver Works engineers have been involved in using automated cable manufacturing facilities to solve these problems, and to reduce product cost.

Figure 1 shows the product targeted for automation. The cable assembly consists of fifty strands of 26 American wire gauge (AWG) solid wire looped through a ferrite core. The assemblies are used to terminate the taping wire pairs from the carrier backplane to the rear cabinet panel on AT&T PBX systems. The ferrite core is included to reduce electromagnetic interference (EMI) emissions from the cabling. At one end, the wires terminate at a 50-contact insulation-displacement ribbon connector, i.e., an electrical connector with a molded plastic "ribbon" that provides retention and separation for two rows of leaf contacts. At the other end are two insulation-displacement grid connectors that mate with .025 inch square pins spaced .125 inches apart. The assembly is about 8 inches long.

Development of the cable machine began in February 1987. Some early studies with model stations supported the feasibility of the project. The machine, shown in Fig-

ure 2, was constructed and partially developed in an engineering laboratory, and was moved to the manufacturing shop in August 1988. The machine was fully developed and operational in February 1989.

## Machine Description

Figure 3 is a schematic representation of the automated cable assembly machine. It is composed of customized stations and mechanisms designed at the Denver Works, as well as commercially purchased parts including a robot, air cylinders, controllers, motors, and drivers.

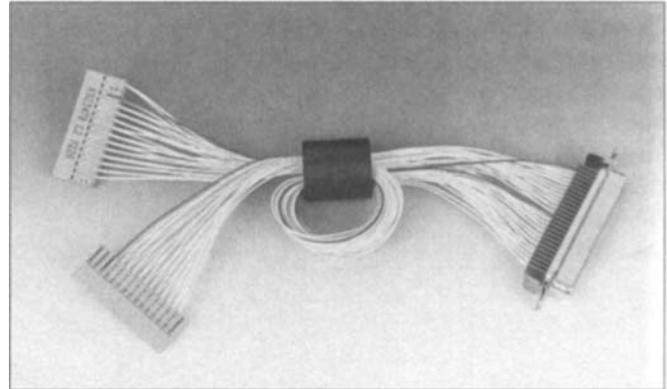
The machine's basic operations are wire pulling, cable taping, connectorization, and wire identification. The robot and other fixtures and handling devices supplement these basic operations.

## Control System Description

The control system, shown as a block diagram in Figure 4, includes the controller purchased to operate the Adept® robot; an AT&T PC6300 personal computer to control stepping motors and provide the operator interface; a large digital input/output (I/O) bus addition to the robot controller; several programmable indexers to control motor movements; modules to interface sensors to the I/O structure; air valves that allow I/O signaling to be converted to a mechanical operation; and RS-232 interfaces between the PC6300 and the cable machine.

**Panel 1. Terms and Acronyms in This Paper**

AWG — American wire gauge, a means to specify wire diameter  
EMI — electromagnetic interference  
I/O — computer input/output bus  
indexer — electronic control unit that provides a computer interface to activate a stepping motor  
mandrel — shaft or bar, the end of which is inserted into a workpiece to hold it during processing  
PBX — Private Branch Exchange, local telephone switching system  
ribbon connector — electrical connector with a molded plastic “ribbon” that provides retention and separation for two rows of leaf contacts  
RS-232 — computer serial interface  
stepping motor — multiphase motor that rotates a fixed number of degrees as its phases are activated in sequence  
vibratory feeder bowl — mechanism driven by low level vibration that causes parts to ascend an inclined spiral on the outside of a bowl-shaped container



**Figure 1. The cable assembly targeted for automation. It consists of fifty strands of 26 American wire gauge (AWG) solid wire looped through a ferrite core. It connects leads from the carrier backplane to the rear cabinet panel on AT&T PBX systems.**

The software driving the process is written in V+® in the robot controller and QuickBASIC® in the PC6300. (Adept and V+ are trademarks of Adept Technology, Inc.; QuickBASIC is a trademark of Microsoft Corporation.) The software simultaneously drives each process and synchronizes all processes.

Special interface and communications techniques keep the controllers synchronized to achieve cycle times under 30 seconds per assembly. In critical timing areas, the communication is via hardware I/O handshakes (i.e., signals transmitted over a communications network that connect the two parties). In areas where timing is not critical, the communications is via RS-232 interfaces.

The Adept robot controls the machine's major functions, with software that takes full advantage of V+'s capability of allowing multiple process control programs to run independently yet synchronized.

The PC6300 controls the stepping motors at the connectorization and identification stations, coordinating with the Adept controller that moves assemblies through

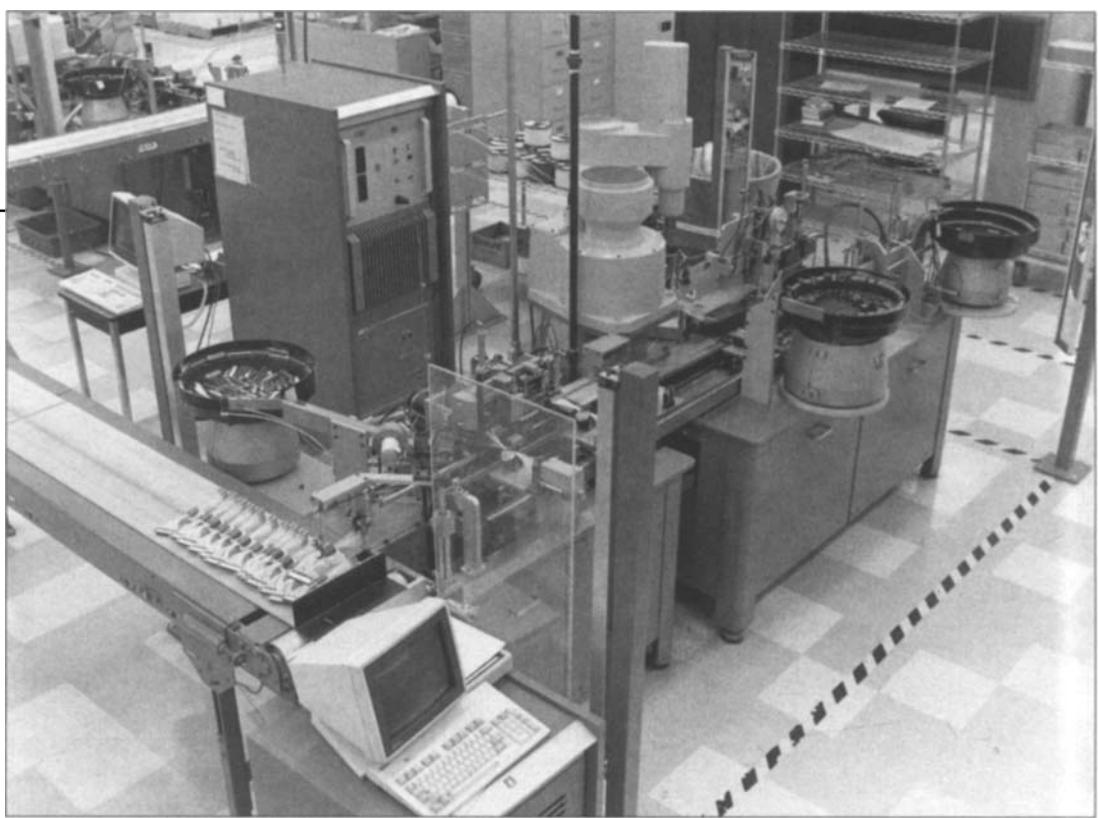
these stations and controls the air cylinders that do the combing and insert the wires into the ribbon connector. The stepping motor indexers have internal processors running software downloaded from the PC6300. Special techniques allow connectorization within the stepping motor indexers while the identify-and-collate process is controlled by the PC6300. These techniques include using the PC6300's interrupt capabilities, and hardware handshakes among the controllers, the stepping motor indexers, and the Adept controller.

The software for each station includes checks to ensure that incomplete or incorrect assemblies are not allowed to proceed further. Where possible, automatic error correction is performed.

The process' complexity requires that the operator be informed about the cause of any stoppage. Information from the Adept controller or PC6300 is displayed and interpreted onscreen for operator action. That is, the operator receives a suggested course of corrective action, including the steps to restart automatic operations. All operator responses are via the PC6300's function keys. To ensure operator safety if an error condition occurs, all processes in both controllers must be stopped before the operator takes action.

Operator, maintenance personnel, and visitor safety is further ensured by a light curtain around the machine. If anyone enters the protected area, the light curtain detects them and interrupts the processors to

**Figure 2. The automated cable assembly machine that was developed for AT&T's Denver Works and made fully operational in February 1989.**



halt machine operations. The machine can be restarted without losing the product being made at the time.

#### **Machine Operation**

The wires that make the assembly come on spools loaded onto a rack. This setup allows the wires to be pulled from the spools without tangling or twisting.

The machine simultaneously pulls 26 wires from the spools, measures them to length, and straightens them. The wires from the rack are threaded through a heating chamber, and then through a wire straightener. The heater softens the insulation to remove the plastic's tendency to remain coiled. The straightener uses an array of curved tubes to straighten the wires. After straightening, the wires are laced through a clamp mechanism that holds them during pulling. A wire spacing block holds the wires in alignment with the contacts of the grid connector. The puller mechanism is an air cylinder that draws the straightener, clamps, and spacing block forward to meet the grid connector.

The grid connector vibratory feeder bowl has forced air blow-off devices to ensure that the connectors feed flat and one layer deep. A sensor looks for the proper connector orientation. An air blast returns any improperly oriented connectors to the bottom of the bowl. The bowl feeds the grid connectors into a track that guides them to an escapement and holding mechanism. This mechanism picks one connector at a time and positions it so the wires from the wire puller can be placed into the connector by insertion blades at the

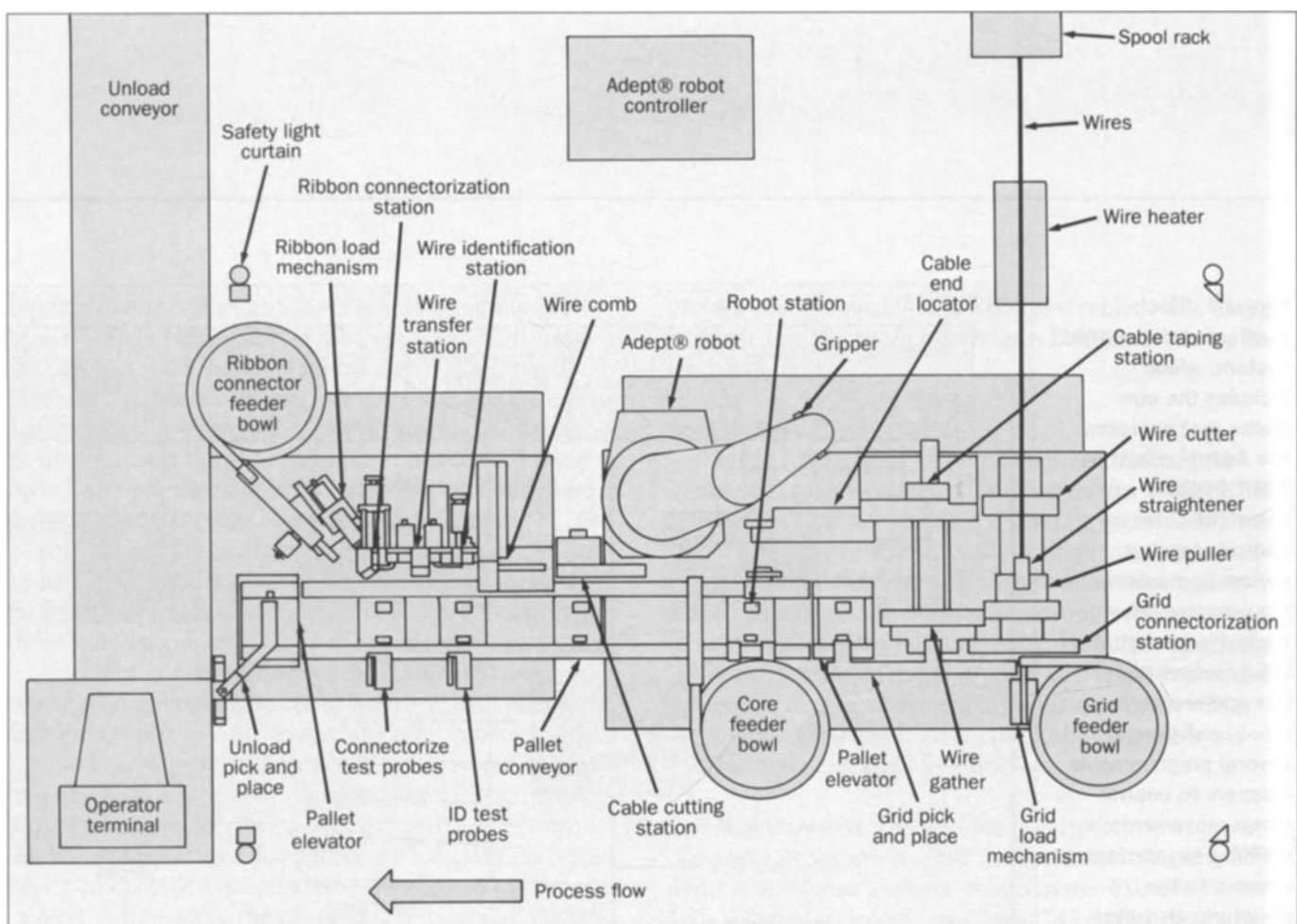
grid connectorization station.

A servo motor moves a pair of insertion blades to each pair location on the connector. The blades, operated by air cylinders, insert the wires into the connectors' insulation displacement contacts.

The final assembly requires 25 pairs of wires, allocating these pairs on the two grid connectors places: 13 wire pairs on the first, and 12 wire pairs on the second connector. This is accomplished by not terminating the top pair of wires on the second connector. After the wires for one connector have been inserted, and the wire puller has returned to its home position, the wires are cut to a predetermined length.

The grid assemblies are moved from the grid connectorization station by a pick-and-place mechanism equipped with two stop points that allow two grids to be placed in adjacent holding slots at the taping station. After both connectors are present, the wires are gathered by a mechanism that moves away from the connectors toward the free ends of the wires, forming a small compact bundle near the wire ends. The taping mechanism pulls a preset length of tape from a roll, cuts it, and transfers it to the wire bundle via a vacuum holding plate. A spinning cavity is opened and placed over the tape and the end of the wire bundle. The cavity is closed and spun, wrapping the tape onto the wire bundle. Taping allows the wire bundle to be threaded through the hole in the ferrite core.

The same pick-and-place mechanism that moved the grid assemblies from connectorization to taping also



moves them from taping to a pallet loading position. The assemblies will move through the remainder of the machine on small pallets.

A pallet containing one partially processed assembly is transferred to the robot station. The robot gets one ferrite core at a time from the end of a feeder track filled by a vibratory feeder bowl. A free end clamp locates the end of the wire bundle so the robot can feed the core over the bundle to a holding position on the pallet. Mechanisms under the pallet close the core clamp holding it in place. The free end clamp reestablishes the wire bundle end location. The robot picks up the free end of the wire bundle, inserts it into the core, and pushes the wire bundle a small distance into the core. Mechanisms on the pallet, activated from beneath, keep the bundle from backing out of the core when the robot moves back to get a new grip. After several pushes, the wire end protrudes through the core. The robot grasps this end, pulls the wires, and forms the correct size loop through the ferrite core. The taped end is no longer needed, and is removed at a cable cutting station.

The pallet with the partial assembly is now transferred to the combing position, where the combing action arranges the bundle of wires in a single-file queue. Mechanisms press the bundle and rub the wires with a

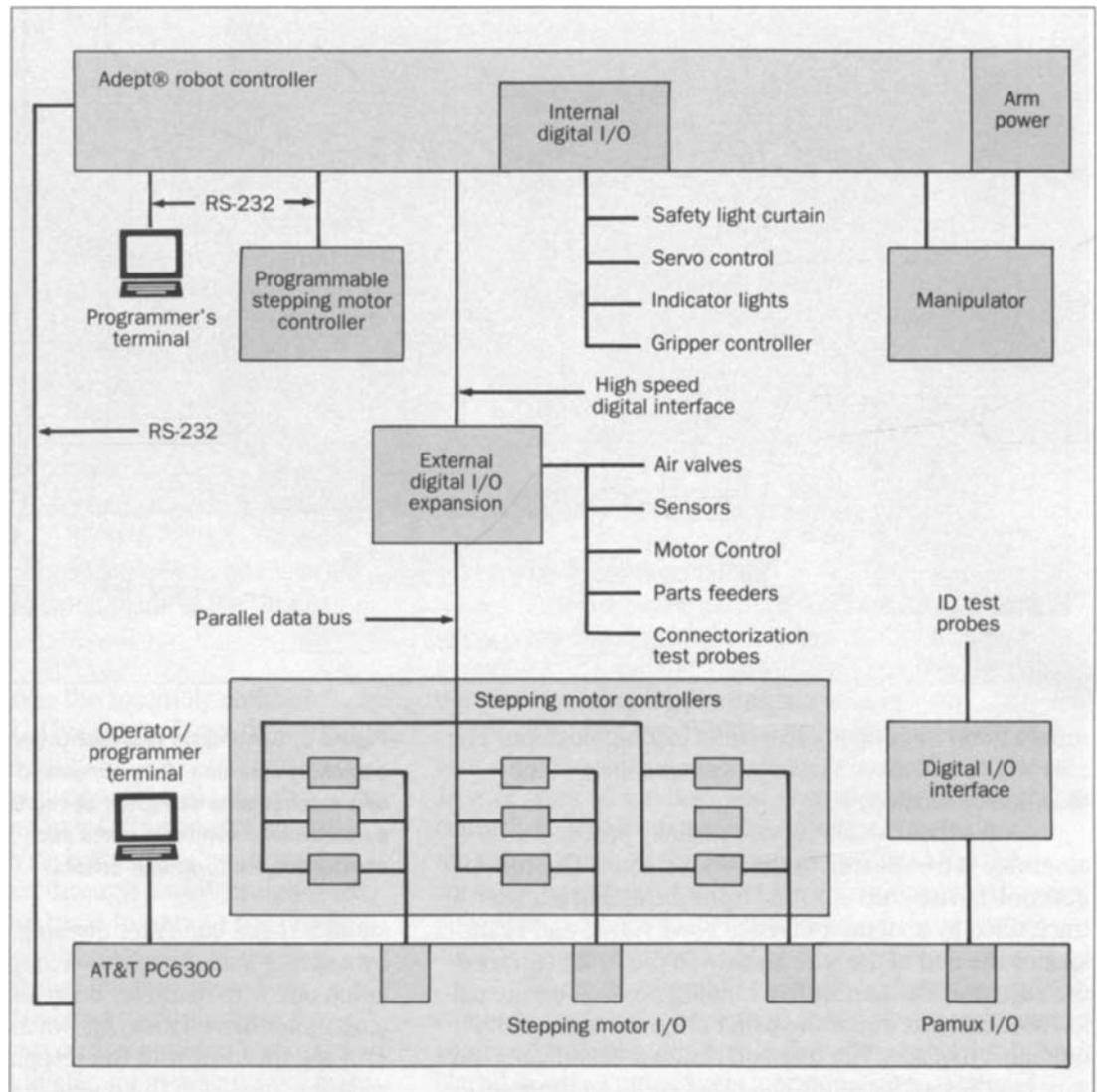
**Figure 3. Schematic representation of the automated cable assembly machine. It is composed of customized stations and mechanisms designed at the Denver Works, as well as commercially available parts such as a robot, air cylinders, controllers, motors, and drivers.**

smooth metal bar. After queuing, the wires are pushed by a spring-loaded rod into a long slot that ends in a notch one wire diameter deep on the periphery of a stepping motor-driven disk, known as the *wire pick disk*. Turning this disk with the stepping motor removes one wire at a time from the queue. Each wire is moved to a position where a sharpened blade pierces the insulation. This sharpened blade is part of a continuity test circuit that allows the wire in contact with the blade to be identified through test probes that contact the grid connectors.

After a wire has been identified, one of two racks containing notches for each wire is moved so the notch for its location is aligned with an exit slot from the wire pick disk. When the disk moves to the exit slot location, a spring-loaded ejector pushes the wire out of the pick disk into the notch in the rack. These rack notches are filled with wires in the correct sequence for termination in the ribbon connector.

The identification racks move the sorted wires to

**Figure 4. Block diagram of the control system, which includes the controller that operates the Adept® robot; an AT&T PC6300 personal computer to control stepping motors and provide the operator interface; a large digital input/output (I/O) bus addition on the robot controller; several programmable indexers to control motor movements; modules to interface sensors to the I/O structure; air valves that allow I/O signaling to be converted to a mechanical operation; and RS-232 interfaces.**



a transfer station where they can be unloaded. They then return to the identification station to begin work on the next assembly while the connectorization racks retrieve wires from the transfer station to complete the assembly.

Ribbon connectors are provided to a feed chute by a vibratory feeder that removes all but two alignments of the connectors being fed. A detector in the feed chute determines if the connector is in the correct orientation. A stepping motor-driven turntable inverts connectors fed with the incorrect orientation. Correctly oriented connectors pass through the turntable without inversion. The connector is now located in a nest that, when activated by

an air cylinder, positions it in front of a mandrel that captures and accurately locates the connector. (A *mandrel* is a shaft or bar, the end of which is inserted into a workpiece to hold it during processing.) The mandrel containing the connector is moved into the wire insertion area. Each contact location on the connector is aligned with a wire guide slot by a stepping motor driving the mandrel.

The connectorization racks advance to the connectorization station, where they bring each wire pair to the unload slots in sequence. A spring loaded ejector pushes each wire out of its rack and into a notch in a wire pick wheel. The wheels are then turned by a

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stepping motor that pulls the wires into the guide slots aligned with contact pairs on the connector. The insertion blades are activated by air cylinders that force them through these slots. Cutters, working with the insertion blades, trim the wires to the correct length just before the blades insert the wires into the connector. The discarded wire pieces include the damaged sections of wire pierced during the wire identification process.

The grid connectors are electrically probed during connectorization to verify the insertion process. This combined verification and identification process provides a fully tested product.

After connectorization, the completed assembly moves to an unloading position, where a small pick-and-place device places it on an accumulation conveyor.

The pallets that hold the assemblies are moved from one station to another on power-and-free conveyors. These conveyors are chains with extended rollers on which the pallets ride. The pallets are halted at each station by an extended pin-stop, and are allowed to move to the next station when the pin-stop is retracted. Each station has a sensor to determine if a pallet is present.

Elevators at both ends of the conveyor raise or lower a pallet from the work conveyor to the return conveyor under the stations.

### Results

The original, manually produced version of the cable assembly was unacceptable. The new, automated assembly method provides a uniform, high-quality product at half the cost of the manually built version. Because production takes place in the Denver Works, inventory and its associated costs are reduced.

The low cost of this cable made it attractive for use in new AT&T PBX systems. This increased usage drove production volumes beyond the design capability of one machine. Additional production capability was provided by a second machine that was installed in May 1990. The cables' continued use suggests that both machines are satisfying their users' needs. Each machine currently produces 3,500 assemblies per week, with a

proven weekly capability of 5,000 assemblies. The assemblies are also exported for systems built in Australia, Ireland, and Italy.

### Conclusion

In future designs of complex automation, the increased cost associated with using motion controls with feedback versus no feedback should be evaluated. Those with feedback provide potential savings from improved process yields. Machine controllers need information about critical processes obtained through different types of sensors. Carefully defining critical processes and what could cause failures in these processes leads to proper initial design of control system information needs. Using automation for other high volume cable assemblies is feasible and economically attractive.

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