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# AGILE MANUFACTURING PROTOTYPING SYSTEM (AMPS)<sup>1</sup>

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## ABSTRACT

The Agile Manufacturing Prototyping System (AMPS) is being integrated at Sandia National Laboratories. AMPS consists of state-of-the-industry flexible manufacturing hardware and software enhanced with Sandia advancements in sensor and model based control; automated programming, assembly and task planning; flexible fixturing; and automated reconfiguration technology. AMPS is focused on the agile production of complex electromechanical parts. It currently includes 7 robots (4 Adept One, 2 Adept 505, 1 Staubli RX90), conveyance equipment, and a collection of process equipment to form a flexible production line capable of assembling a wide range of electromechanical products. This system became operational in September 1995. Additional smart manufacturing processes will be integrated in the future. An automated spray cleaning workcell capable of handling alcohol and similar solvents was added in 1996 as well as parts cleaning and encapsulation equipment, automated deburring, and automated vision inspection stations. Plans for 1997 and outyears include adding manufacturing processes for the rapid prototyping of electronic components such as soldering, paste dispensing and pick-and-place hardware.

**KEYWORDS:** automated assembly, flexible manufacturing

## CONCEPT DESCRIPTION

The Agile Manufacturing Prototype System (AMPS) consists of one or more modular assembly process modules or workcells centered on robotic arms, with two conveyors in the front of the cells for work-in-progress (WIP) pallets and in the back for parts pallets. Figure 1 shows the AMPS system and Figure 2 a close-up of one assembly process module. The conveyor segments at tabletop level transport the pallets in the forward direction while the conveyor segments below operate in the opposite (return) direction. The cells are arranged in a line, with pallet elevators at each end to receive pallets from the forward (return) conveyor and lower (lift) the pallet onto the return (forward) conveyor line. The result is that both the WIP and the parts conveyor lines are infinite loops that

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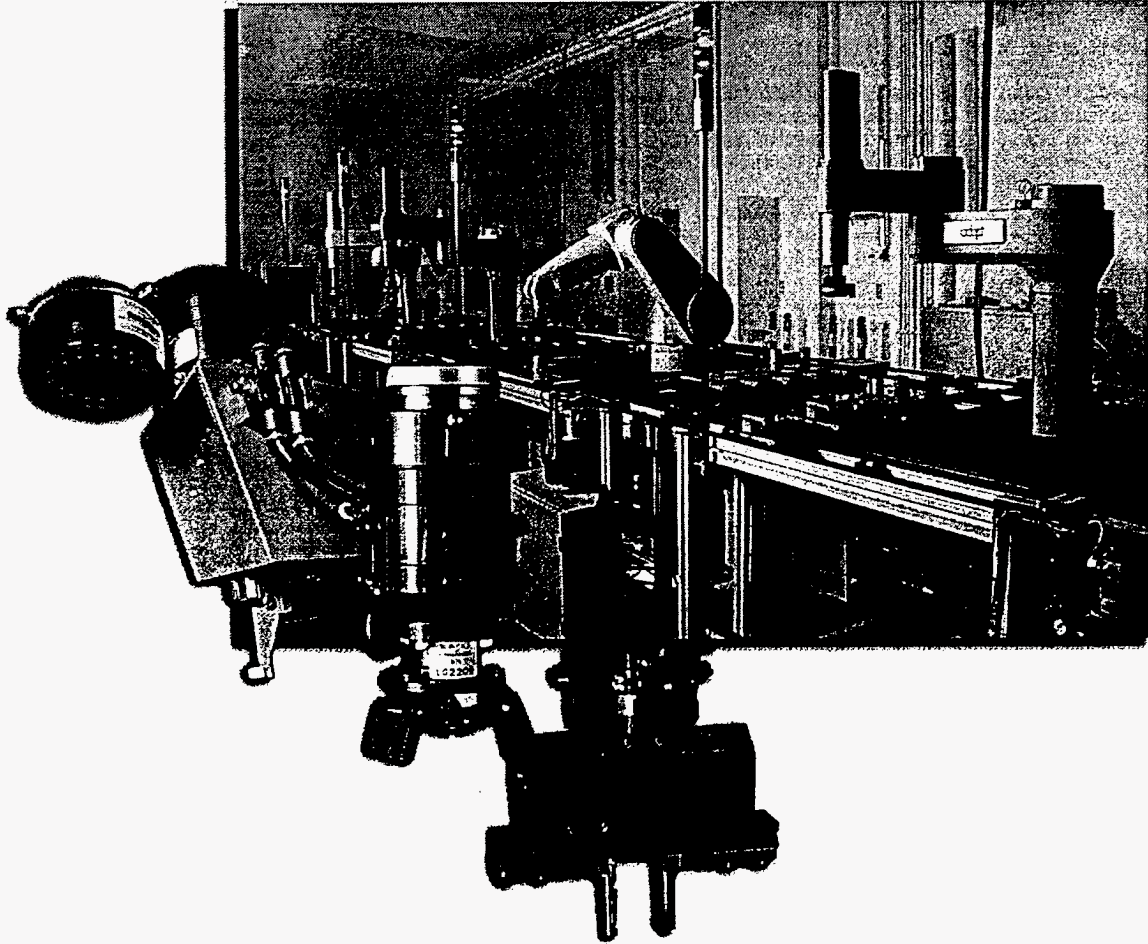
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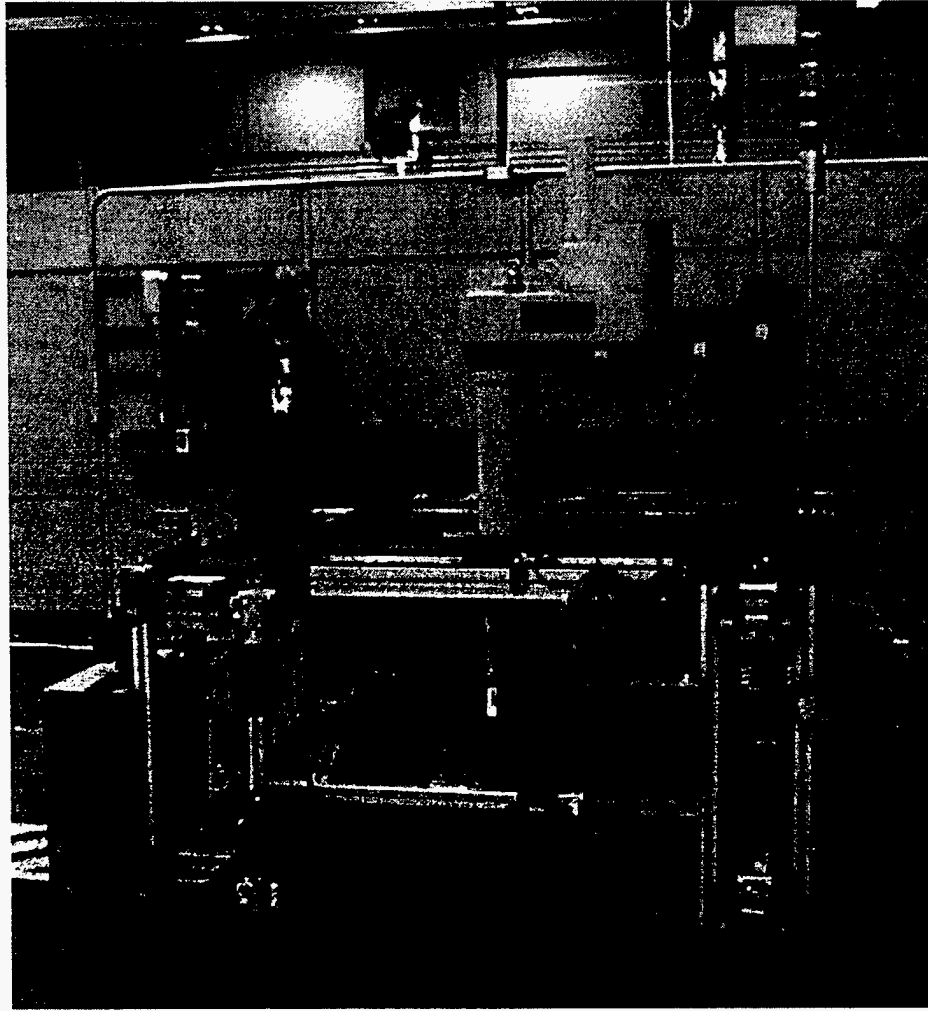
can transport a given pallet from any starting point to any destination point in the line. In addition, each cell has a WIP and a parts spur conveyor to pull pallets into the workcell



**Fig. 1.- Agile Manufacturing Prototyping System**

so that an open path is maintained along the main conveyor lines. Insertion into and removal of pallets from the main conveyor infinite loops will be accomplished by pallet input/output “jukeboxes” placed in line or beside the workcells.

From the beginning, a primary design goal for AMPS has been ease of reconfiguration. We wanted robotic workcells that would be easy to reconfigure whenever a new assembly task needed to be automated. Each workcell has been made into an autonomous unit as much as possible. Currently, AMPS consists of four cells with Adept One SCARA robots, one cell with two Adept 550 table-top SCARA arms, and one with a Stäubli RX90 6 degree-of-freedom arm. The materials handling portions of the modular workcells are commercial products supplied by Bosch Automation. The framework which supports items such as conveyors and elevators is made of extruded aluminum structural shapes. The entire structure--which may be assembled “Tinker-Toy” fashion--depends upon a traditional foundation, i.e., its stability comes from being firmly anchored to the floor, which is normally a concrete slab.



**Fig. 2.- AMPS Assembly Process Module**

Ancillary equipment, such as the robot in this case, is also bolted to the floor and alignment depends upon the stability of that floor. In the case of the AMPS workcells, it was necessary to integrate the robot into the rest of the structure in order to make it possible to move the entire assembly as a unit. This posed some interesting structural problems, chief among them the need to pick the system up in one piece without permanently deforming it or allowing elastic deformations great enough to damage any of the items that it supports. In addition, the fact that the robot was directly tied to the work-surface without the seismic mass of a concrete floor in the load path gave rise to concerns about vibration damping.

The design constraints were satisfied by the use of a base made of welded structural steel. Vibration and dynamic loads are treated by taking the weight of the robot directly to a baseplate which is lagged to a concrete floor. The balance of the structure is supported at the corners by adjustable feet that accommodate irregularities in the concrete substrate. Provision for lifting is provided by slots for forklift tines. These are arranged so that a forklift of common dimensions can engage the structure in a footprint that surrounds the center of gravity. Structural integrity is provided by struts that have the

effect of turning the entire structure into a truss during handling, and which serves to stabilize the robot support column after it is bolted to the floor. This structural concept has already been successfully demonstrated during a local move.

Each cell requires its own compressed air supply, 208VAC 3-phase 30A electrical supply, and 10BaseT ethernet cabling for its control PC and robot controller. The pair of elevators (for the WIP and parts conveyors) at each end of the conveyer line draw compressed air and 208VAC from the adjacent workcell.

Considerable thought went into designing a safety system that would allow maximum configuration flexibility. Each cell has a power distribution box that interrupts power to the conveyor motors and elevators and signals the robot controller to remove arm power whenever an Emergency Stop device is activated. This box has several receptacles available for connection of E-Stop devices. E-Stop devices can be simple red mushroom buttons as well as active devices such as light fences and pressure mat systems that provide a relay contact opening to signal an E-Stop. The power distribution box also has several relay contacts available on receptacles that can be used to signal other equipment that an E-Stop has occurred. These allow us to daisy-chain the E-Stop systems of two or more cells so that an E-Stop in one causes an E-Stop in the others. Since we anticipate some situations where it may be necessary to approach one of the workcells without E-Stopping the entire system, we have provided means for attaching local E-Stop devices directly to the robot controller E-Stop circuit so that only the nearest robot is stopped.

Each workcell is controlled by its own local computer or process module controller (PMC). The workcells can be programmed to operate autonomously, or they can be controlled or coordinated via ethernet by a supervisory computer. All the existing robot controllers have ethernet capability and could act as servers for the local control computer or for a remote client.

## **PROCESS MODULE CONTROLLER**

The process module controller (PMC) is based on a Pentium industrial personal computer (PC). The PC obtains sensor data using the S-S Technologies DeviceNet PC card and drivers. The PC reads and writes to radio frequency identification (RFID) tags using Datalogic antennas and PC card. The process module controller communicates with other controllers and supervisory computers using ethernet TCP/IP socket communication.

We selected a PC as the PMC of choice because of its open architecture, extensive availability of third party hardware and software, and low cost. Most of the capabilities needed for the PMC could be provided by the Adept MV controller we are using in several modules. However, not all process modules may contain a controller as powerful as the MV. Hence, we decided to incorporate PC based control into each module; thereby, shortening development time (and reducing development cost) because the generic module control capabilities would only be developed once for all current and future process modules.

Windows 3.1 was originally selected as the operating system (OS) for the PMC but we recently have migrated to Windows NT. The PMC has no true "real-time"

requirements; hence, we decided to use an OS that has refined development tools to expedite development. If the PMC does have true "real-time" requirements in the future we could run a small real-time OS underneath DOS and Windows to accommodate the real-time component.

Software development was carried out using C-language for custom driver development and Visual Basic for state machine control, client/server communication, and graphical diagnostics. C was chosen for driver development because it is currently the standard for such use. Visual Basic was chosen for high level software development because of the availability of large numbers of third party software components and general compatibility with all other Windows components.

Sensor input and device control is accomplished using Allen-Bradley's DeviceNet. The DeviceNet network is similar in nature to local area network technology. Each device (i.e., sensor, motor controller, manifold, digital input/output ports, etc.) connects to the DeviceNet network cable. The network cable also connects to the network controller card in the PMC. The single network cable is able to provide communication and power for all the devices on the network. This methodology greatly simplifies system wiring because all the devices use a single cable instead of running individual cables or wires for each device in the process module back to the controller. In addition, reconfiguring the module is easy because new devices need only be connected into the network cable instead of running new cables back to the controller.

The AMPS modules contain DeviceNet devices from several different suppliers including Allen-Bradley, Festo, and S-S Technologies. In general, all devices integrated into the network with little effort. The few exceptions we encountered, although frustrating, were quickly resolved by the suppliers. From our experience, DeviceNet is a new technology that has huge potential to reduce development effort and dramatically improve maintainability of control systems.

In the current mode of operation, the supervisory computer that orchestrates all the process modules, downloads the pallet number(s) or identification code(s) needed by each workcell to the workcell's PMC. The PMC then begins looking for the requested pallets by reading information from each pallet's RFID tag on the main conveyor system. If the PMC locates a requested pallet it shuttles the pallet onto a spur conveyor for use by the process module. The supervisory computer may at any time query the PMC to determine the pallets and location of pallets in the process module. Once a sufficient number/type of pallets are in the process module, the supervisory computer initiates the process module. At any time, the PMC can return pallets to the main conveyor or retrieve additional pallets based on the need of the process module.

Alternatively, the process module can be locally programmed. An operator can initiate pallet requests using the PMC's graphical user interface. Once the PMC retrieves the pallets from the main conveyor, the PMC signals the process controller to begin operation. At any time, the operator can request the PMC return the pallets to the main conveyor or retrieve additional pallets.

Ideally the process module would operate in a more autonomous fashion. The PMC could understand the raw material and finished product flow requirements and interact directly with the process controller so that the process module could operate

independently of supervisory control. If there is little variation in process for all the products in a product family and the factory only produces that product family, autonomous process modules would be a very elegant solution. As the number of products in a product family increases or becomes more diverse, the more complex the local control becomes and a hierarchical control structure begins to have significant advantages. The optimal solution is likely a hybrid of supervisory control and autonomous operation and highly dependent upon the requirements of the product line.

## SYSTEM STATUS

The AMPS implementation phase consisted of constructing the six workcells along with the elevators that allow pallets to circulate between the workcells.

Placement of electrical and pneumatic equipment was compromised due to the dimensional constraints of the welded steel substructure, the Bosch conveyors, supports (the standard Bosch legs were used), and various pallet handling mechanisms. Our solution was to use the conveyor segments as supports for all our equipment. This limits intra-cell flexibility because the conveyor elements are structural members that cannot be omitted easily. In addition, all the attachments to the conveyors complicate the task of aligning the conveyors of adjacent cells since they are stressed members of their workcell.

We have recently added a pallet input/output cell (a pallet jukebox of sorts). Its control architecture is similar to the robotic workcells except for the absence of a robot and its controller.

We have moved the AMPS system twice in the last year. The first move took a total of 75 man hours to take down a four workcell system and get it operational in its new home at a different building. The second move took a total of 59 man hours for the same 4-cell system, that move to its final home at Sandia's new Robotics Manufacturing Science and Engineering Laboratory. Both moves were accomplished with forklifts that picked up complete workcells and placed them on a flat-bed truck for transport to the new location. The man hours included preparing the workcell for the move, disconnecting electrical and pneumatic systems, reconnecting everything at the new location, and leveling the workcells and conveyers.

We have used the AMPS system to prototype the automated assembly for two Sandia components (switch tube and neutron tube), to develop a new process for composite forming, and to develop a process for fabricating targets for the Z-pinch X-ray accelerator.

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