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PROGRAMMABLE CONTROLLERS

by

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I. INTRODUCTION

As defined by D. K. Anand (1), "A simple control system is merely a device which allows a human operator to control the flow of energy to a machine or process in such a manner as to achieve the desired performance".

Although World War II marks the beginning of the development of mathematical automatic feedback control theory by Bode and Wiener and others, the actual use of feedback control systems greatly preceeds this event. There are a number of examples that readily come to mind.

EARLY CONTROL DEVICES

Perhaps the first example in the history of mankind is the control of the volume flow rate of a fluid, accomplished by the Alexandrian Greek Ktesibios in the 3rd century B.C. The device is illustrated in Figure 1.

The purpose of this simple feedback control system is to correct large fluctuations or disturbances in the supply pressure. If some large and unforeseen increase in supply pressure occurs, the inlet flow rate will increase causing a difference between inlet and outlet flow rate. This will ultimately cause the float to rise and restrict the inlet flow area. As the inlet flow rate is decreased, the system tends towards stability and reaches stability when the inlet flow rate equals the outlet flow rate. The system comes to

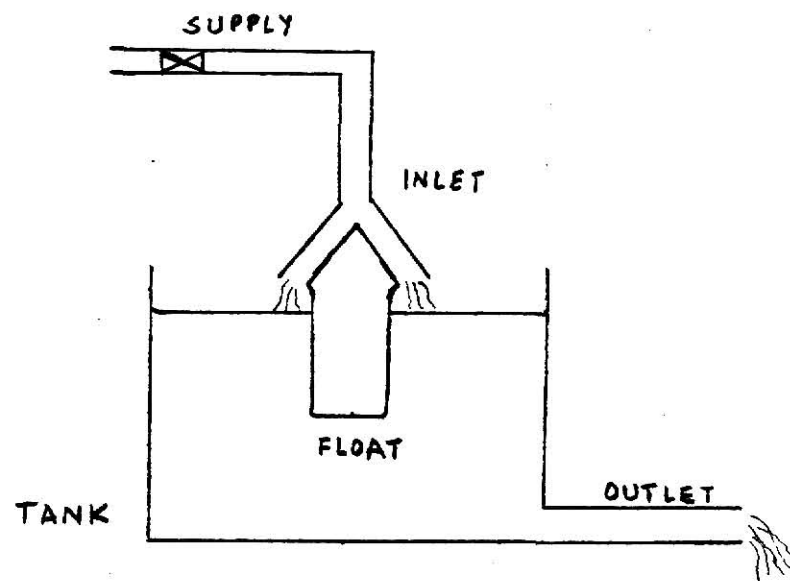


Figure 1. An Early Control Device

equilibrium with a slightly increased head in the regulator tank and since the output flow rate is proportional to this head, with a slightly increased outlet flow rate.

The invention of the thermostat by the seventeenth century Dutchman Cornelis Drebbel led to the development of feedback temperature control systems. A simple device, the thermostat is used to control the temperature in every artificially heated or cooled space.

Analogous to thermostats for temperature control systems, the first device for speed control systems was the centrifugal pendulum or the flyball governor as it is called in modern applications.

It was invented by James Watt in the year 1788. He incorporated a similar feedback loop on his steam engine to control an otherwise uncontrolled variation in the power output caused by variations in fuel combustion process and by environmental disturbances which affected the steam temperature and pressure. The governor is still used in modern applications with modern prime movers and other devices of sophisticated design.

Cams are used in internal combustion engines to time the opening and closing of inlet and outlet valves. Oven knobs, gyroscopes and autopilots are among other innumerable control devices in use today.

INDUSTRIAL CONTROL LOGIC AND DEVICES

Till the late 1960s, there was little choice but to use electromechanical relays for industrial control logic. They use the ladder diagram notation and are of the 300 or 600 volts, 10 amps, machine tool type.

In fact, the industrial control relay has been performing admirably. The multipole structure and changeable contacts provide flexibility and economy, maintenance men understand them and are comfortable with them, and life is up in the hundreds of thousands of operations. Also, relays are invulnerable to electrical noise. An arc welder can be placed next to a relay and it will still carry out its operations smoothly.

But there are several deficiencies inherent in the relay systems. They are bulky, prone to "hard-to-locate" intermittent failures and have a finite life due to the excessive wear and tear of the contacts. Relay panels are difficult to modify or re-program as may be required during testing. A major change in the machine operating requirements usually means the original panel must be scrapped. This is because documentation is difficult in relay systems. There is no way to "read" panel wiring other than the tedious and error prone procedure of ringing it out point by point. Construction time - mounting and wiring - is long and expensive. Another obvious drawback is that communication with a host computer for data acquisition or

supervisory control is impossible.

Over the years, other forms of industrial relay logic have been tried. Reed relays and reed logic modules were tried and discarded. In reed relays, which are of the size of usual resistors, two extremely thin metal wires enclosed in a plastic cover come in contact upon application of a magnetic field force. Low voltage, enclosed relays did not do well either, and more recently manufacturers have developed variations of the machine tool relay. In one such variation, heavy duty reeds have replaced the contacts; in another, contacts have been enclosed to protect them from contamination. There is also a family of solid-state relays that replace electromechanical relays on a one to one basis. Till recently, the conventional machine tool relay has been the major form of industrial relay logic.

In the early 1960s, the first discrete-component solid-state industrial logic modules were developed. Immediately following their entry into the market, it was forecast that the solid-state relays would take over the market from the industrial control relay. High speed, reliability and ability to perform complex operations were the positive features of these new solid-state relays. Although at the time of introduction they were more expensive than the electromechanical relays, it was hoped that with greater technological experience in solid-state devices, cost would not be a factor. But accompanying problems more than

overcame the potential advantages.

First, Boolean algebra had to be used in logic design whereas almost all electrical control designers were only familiar with relay ladder logic. Second, maintenance men were not familiar with solid-state equipment and troubleshooting from logic diagrams was difficult.

Further, the early solid-state units were sensitive to interference and electrical noise encountered on the plant floor - their place of work. The unreliability of input devices, particularly limit switches, meant overall system unreliability even though the logic system itself might be totally reliable. Also, since they were still hard-wired systems like relay logic systems, they were also considerably difficult to modify.

Improvements in hard-wired solid-state logic have increased their application - mostly in complex systems difficult to mechanize with relay logic. But inspite of that, they have failed to capture a significant portion of the market. Recently, some manufacturers have developed lines of electric current based, solid-state logic modules which use ladder diagram logic so designers can develop a system in the same manner as used with electromechanical relays. With the addition of the logic modules, lower cost, and noise immunity achieved through the use of integrated circuits and isolation, solid-state relays have gained wider acceptance.

PROGRAMMABLE CONTROLLERS (PCs)

Simply, PCs are general purpose microprocessor controls that accept inputs, evaluate them and generate appropriate outputs to control machines or processes.

As defined by Ron Ortscheid (6), "a PC is a device that controls the various aspects and motions of a machine over a predetermined program to accomplish a repetitive cycle".

More specifically, according to NEMA (National Electrical Manufacturing Association) standards, a PC is a digitally operating electronic apparatus that uses a programmable memory for the internal storage of instructions that implement specific functions such as logic, sequence, timing, counting and arithmetic to control machines and processes.

The first PC was developed at Modicon Inc., currently a division of Gould Inc., to avoid the problems in logic control previously outlined. Modicon was incorporated in October, 1968, by a small group of farsighted innovators and investors. Their special creation - a solid state electronics box - is now known as the programmable controller.

The fledgling company began operations in April, 1969, made its first customer demonstration in November and delivered its first PC to the Hydra-Matic division of General Motors in March, 1970. This was to help reduce the

manufacturing costs caused by tedious, time consuming and expensive rewiring or scrapping of existing relay panels, during annual model changeovers.

As can be expected, early PCs had many limitations. They were difficult to program and required the use of computers and unfamiliar terminology. They performed the basic on-off functions and their reliability was somewhat questionable. Also they were functionally large and costly, and thus were only considered for applications in systems, equivalent to about 150 relays and up.

Naturally, with the passage of time and the rapid advancement of technology, improvements came and today's PCs are infinitely more capable of performing various tasks that could not be envisioned in the beginning. These and other aspects will be discussed in the subsequent chapters. Chapter Two deals with PCs in general - their components, functioning and characteristics. Chapter Three covers applications. Chapter Four makes a comparative study of some of the hundred or more models available on the market today. Chapter Five discusses the topic of PC versus the microcomputer. Chapter Six looks at the current and future trends in PCs.

II. THE PROGRAMMABLE CONTROLLER

The PC was introduced in the last chapter and will be discussed in greater detail here.

The PC has come a long way since its inception in the late 1960s. Table 1 provides a brief insight into how the PC has developed over the years.

COMPONENTS

The components of a PC and their configuration are illustrated in Figure 2.

As shown in Figure 2, all programmable controllers contain a central processing unit (CPU), memory (the established program), power supply, input / output (I/O) modules and a programming device (for programming, editing and troubleshooting).

The CPU receives instructions from the memory together with the feedback on the status of the input and output devices. It processes these signals, such as the on or off status of a particular input or output device and generates commands to the output devices, such as energizing or de-energizing the output device designated in the instruction, by means of the output modules.

The process or machine input elements transmit status signals to the input modules which, in turn, generate logic

TABLE 1 : DEVELOPMENT OF THE PC OVER THE YEARS

YEAR	EVENT
1968	Design of PCs developed for General Motors Corp. to eliminate costly scrapping of assembly line relays during model changeovers.
1969	First PCs manufactured for automotive industry as electronic equivalent of relays.
1971	First application of PCs outside the automotive industry.
1973	Introduction of smart PCs for arithmetic operations, printer control, data transfer, matrix operations, CRT interface etc.
1975	Introduction of analog PID (proportional, integral, derivative) control which made possible the accessing of thermocouples, pressure sensors etc.
1976	First use of PCs in hierarchical configurations as part of integrated manufacturing systems.
1977	Introduction of very small PCs based on microprocessor technology.
1978	PCs gain wide acceptance and sales approach \$80 million.

TABLE 1 (cont.)

YEAR	EVENT
1982	Wide range of product offerings for a wide variety of chores. Sales approach \$500 million mark. Expected growth rate of 20%.

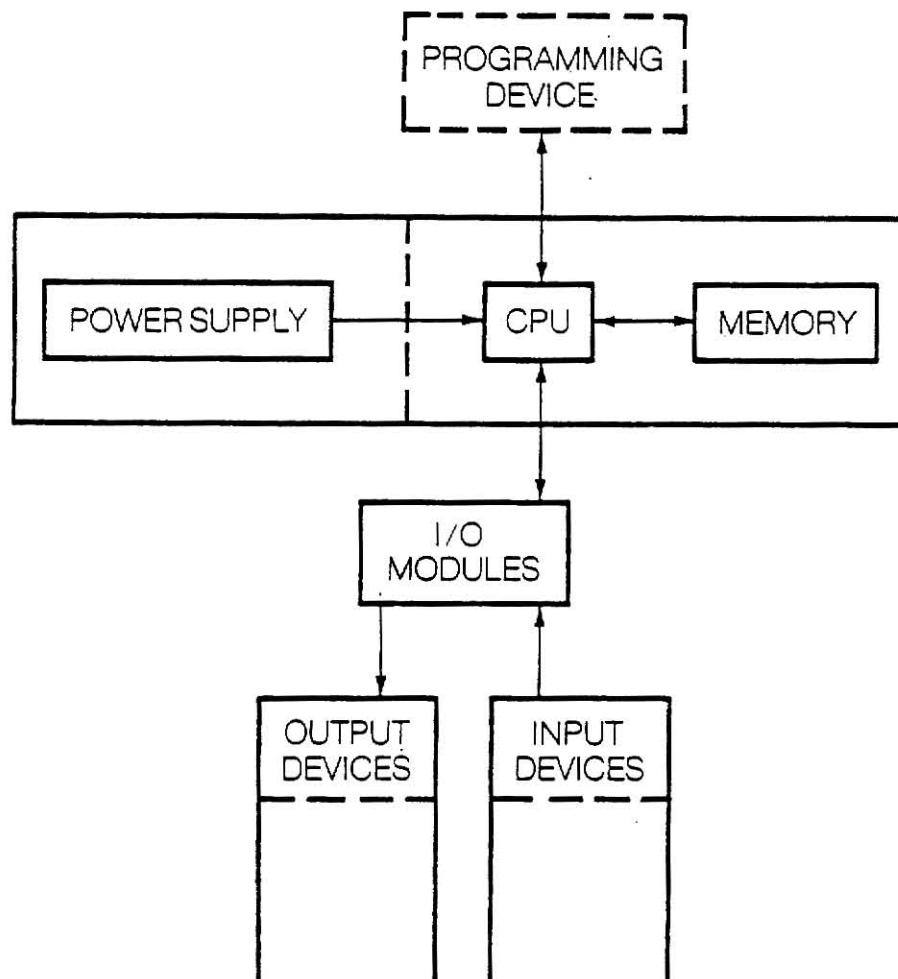


Figure 2. Components of a PC

signals for use by the CPU. In this way, the CPU monitors input elements such as pushbuttons, selector switches, limit switches, pressure switches, proximity switches, relay contacts, thermostats etc.

Devices such as relay coils, solenoid valves, indicator lamps, motor starters, clutches, brakes and indicator lights are typical output devices to be controlled.

The controller scans the instruction set continuously in "top-down" fashion at very high speeds and each time makes the appropriate changes on each output device based on the detected status of the inputs and the logic of the control program.

The memory, used to store the program, is perhaps the most important part of the controller since loss of memory or an error in memory can cause the control system to stop functioning.

Currently, there are several types of memory in use for various applications. Some of the more prevalently used types include the following.

1. Read / Write (R/W)
2. Programmable Read Only Memory (PROM)
3. Erasable Programmable Read Only Memory (EPROM)

Semi-conductor random access memory (CMOS) is the latest type of memory to be used and is quite popular in today's controllers. In this type of memory, each cell is made up

of flip-flops. This makes it a volatile memory and memory is completely lost if power fails or is turned off. To overcome this problem a battery is provided to support the memory in case of power loss.

Since in each cycle a controller sequences through all of the instructions in order, scan time depends on the number of words required to hold the program and on the memory speed. This varies from three to seven milliseconds per thousand words of memory. In small controllers holding only 256 words of memory, this can be as low as one millisecond.

In addition to the memory scan period, time is required to sense an input change and cause an output to change state. This delay, between the time the input changes and the time this change is reflected as a logic state switch to the controller, may be as high as 15 to 20 milliseconds in controllers that employ a noise filter in each input module. It may be as low as 1 to 2 milliseconds in some others. Similarly, output change in response to an internal logic state change can be delayed for periods ranging from 1 to 10 milliseconds.

Therefore the period between external input change and external output change is the sum of the input delay, controller scan time, and output delay. For thousand words of memory this period can vary from 5 to about 35 milliseconds. PC designers are attempting to reduce this time.

Most controllers are available in a wide range of input and output options which can handle all required levels of a.c. (alternating current) and d.c. (direct current). Input and output capabilities vary widely between various controllers - from 32 inputs and outputs in any combination to 5000 inputs and 5000 outputs. Generally all of them are modular so that the user can closely specify the required number of inputs and outputs. In most cases the basic I/O capacity can be expanded by adding more I/Os.

In addition to isolation and filters to prevent input or output interferences from entering the system, PCs are also designed to withstand power line disturbances, stray electrical fields and other shopfloor interferences. Normally the units are conservatively designed so as not to require artificial cooling.

Since their inception more than a decade ago, PCs have enjoyed outstanding success. They have been embraced by a wide variety of industries and serve as an essential part of many diverse automated industrial systems.

The growth and popularity of the PC have been fueled by a rapid advancement of technology that has provided PC users with an increasing array of useful and sophisticated control functions. Although the capabilities of PCs have expanded substantially over the years, PCs have retained the characteristics that made them so popular in the beginning.

ADVANTAGES AND DISADVANTAGES OF PCs

There are a number of reasons that make PCs attractive.

- * The PC is programmed in a simple language directly related to the application. The language used is the relay ladder logic.

In fact, relay ladder logic programming language was largely responsible for the initial success of the PC. Since PCs were originally intended to replace relay panels, the use of relay ladder logic greatly facilitated this change. It was a language well understood by control engineers, technicians, electricians and other operating personnel.

The highly pictorial nature of the language also helps in this regard. And most importantly, knowledge of computer software techniques was not required of the user. Therefore it could be programmed and maintained by the existing plant personnel.

- * PCs are easy and quick to reprogram. A major product changeover of the type that occurs in the automobile industry once each year, if not more, would necessitate extensive rewiring of relay panels to implement new control schemes. The complexity of this undertaking is such that it is less expensive to scrap old relay panels and build new ones than to

modify existing ones. The PC's modular configuration and programmability allows the logic system to be configured late in the design cycle when the machine or process operating procedure has been substantially finalized. Program changes can be easily made during testing, in case of a change in the machine requirement or if the entire operating procedure is changed.

- * The PC is a computer that is designed to be rugged enough to operate reliably in the harsh industrial environments (0 - 60 degree C ambient temperature and upto 95% humidity) without error or damage to internal electronics.
- * The PC's modularity permits a system sized exactly to the customers' needs. Most controllers can be expanded in the future without altering the basic system structure.
- * The relatively small size of a PC permits mounting on the machine itself thereby saving expensive floor space that was required to hold the cabinets for a large relay control system.
- * Communication is possible with computers and other PCs, making it possible for a PC to be a part of a huge control system network.

- * In PCs there is no wear of components as there is with electromechanical relays because of its total solid-state construction. This provides reliability and long life.
- * In case of failure, troubleshooting is as simple as checking a row of LEDs or pushing a few buttons, in most cases. Often a PC can aid maintenance personnel with its self-diagnostic capability. Also repair can usually be accomplished in a matter of seconds by replacing a faulty module with a spare.

Other beneficial features and characteristics of PCs include ease of operation, economic competitiveness with alternate control technologies, availability of advanced programming functions and high speed operation.

However all of this is not to say that PCs are the manufacturing world's panacea for production related problems. They definitely are not.

First, PCs lend themselves mostly to relatively low speed manufacturing processes. For example, PCs generally can not keep pace with a high speed bottling operation where the bottles rush by faster than the eye can see. This is because it takes at least 20 milliseconds for a PC to respond to an input change. If the input signals come at a rate faster than that, it is unable to carry out the required functions.

Yet another drawback of PCs as opposed to electromechanical relay systems is that no moving part can be seen. For those who have an inherent distrust of computer electronics, this is not very reassuring.

A general comparison of electromechanical relays and PCs is shown in Table 2.

RELAY LADDER LOGIC - THE PROGRAMMING FORMAT

The programming format that is discussed below is with reference to the Modicon 484 programmable controller, equipped with 1K of RAM.

The processor is programmed from a program panel (CRT) with a special keyboard shown in Figure 3.

The basic element of programming is the relay contact which is either normally open or normally closed. These when connected in parallel or series form a ladder diagram (see Figure 4).

The diagram allows upto ten elements of the program in each horizontal rung of the ladder diagram. Up to seven of these rungs can be combined into a network of relay contacts and other programming elements (timers, counters, etc.). Each network can have upto seven coils placed at the extreme right of the network.

TABLE 2 : COMPARISON OF ELECTROMECHANICAL RELAYS AND PCs

CRITERION	ELECTROMECHANICAL RELAYS	PCs	

Ease of			
Modification	VERY LOW	VERY HIGH	
Reliability	LOW	HIGH	
Life	HIGH	VERY HIGH	
Size	BULKY	COMPACT	
Trouble-			
shooting	VERY DIFFICULT	VERY EASY	
Maintenance	EASY	VERY EASY	
Communication *	NIL	GOOD	
Initial Cost	LOW	VERY HIGH	
Documentation	VERY DIFFICULT	VERY EASY	

* Here communication refers to the ability to communicate with other PCs or minicomputers.

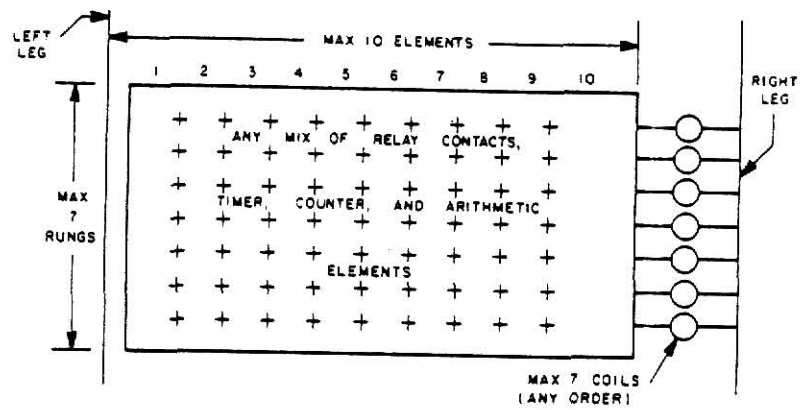


Figure 4. Multi-Node Program Format

The network becomes one basic parameter of the ladder diagram; it is defined as a group of program elements comprising from one to seven rungs, each with upto ten elements, that are connected. The quantity of networks or logic elements that can be entered depend upon the memory size and the complexity of the network.

Each contact has a four digit reference number that controls the power flow of this contact. Within a network, power flow is allowed only from left to right or vertically (up and down); it is never allowed from right to left. When properly displayed on the CRT screen, power flow is indicated for all relay contacts by intensifying those contacts that are passing power from left towards the right.

Once a program has been entered, it can be monitored and modified from the CRT. The former is done by illuminating the "current" path brighter than the remainder of the circuit, and the latter is done by placing the cursor on the device to be altered and then making the change from the keyboard.

All input signals, that is all pushbuttons and limit switches, must have a number corresponding to the number of the module to which they are connected. The same is true for all output signals, which are connected to external relays or starters.

A simple example is shown below to illustrate how a programmable controller is programmed.

Problem - To design a stop-start motor control circuit with the start button (normally open) connected to I/O module 1001 and stop button (normally closed) connected to module 1002. The output signal is module 0049, which is connected to a motor starter.

The actual electrical circuit for the design is shown in Figure 5a.

The circuit shown in Figure 5a is programmed on the CRT as shown in Figure 5b.

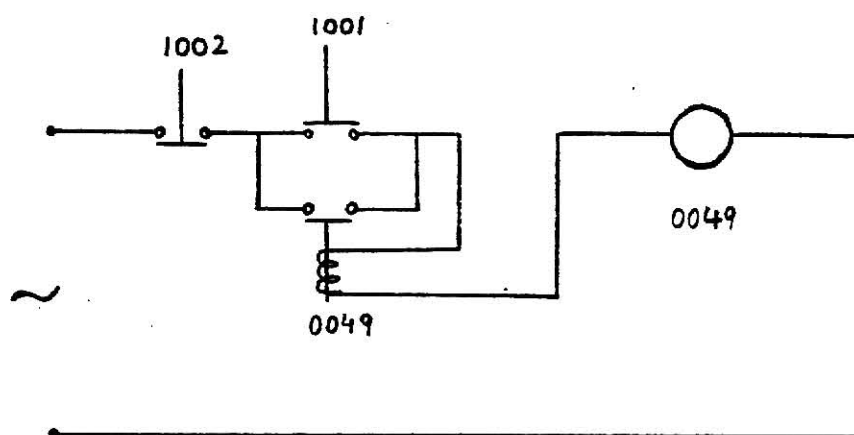


Figure 5a. A Stop-Start Motor Control Circuit

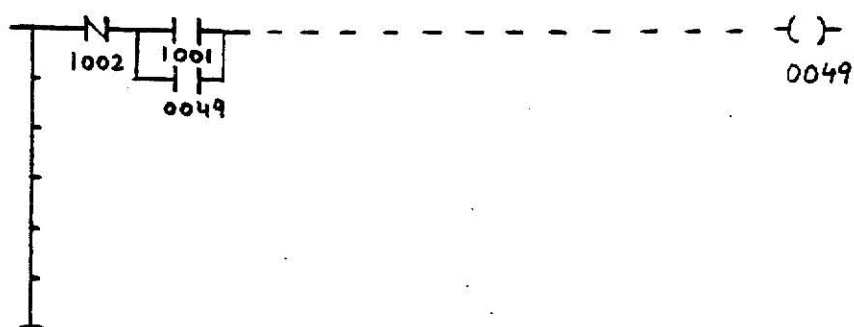


Figure 5b. An Equivalent Circuit on the CRT

III. APPLICATIONS OF PCs

The PC has come a long way since its inception about 12 years ago. The rapid development of the device has taken it to the fore amongst the logic controllers of today's industry.

Before the introduction of PCs, automated production equipment at the plant was controlled by hard-wired relay panels. Consequently, the early design of PCs was such that the PCs could be looked on almost purely as relay-replacers. The initial applications included the control of transfer machines, assembly machines, test and inspection equipment. And since the programmable controller concept came from the automotive industry, initial applications were primarily for machinery control in automotive companies, automotive parts suppliers and other machinery using manufacturing companies.

Most plants did not use programmable controllers in large numbers until a few years ago. However, as machine suppliers and plant production management gained confidence in the PC's ability and reliability, the number of PCs on the plant floor has increased dramatically.

The basic PC is a true general-purpose control tool and can handle any on-off logic control problem. So applications spread rapidly to such areas as batch process control, remote compressor station startup and shutdown, weighing and batching systems and, in fact to any

application where a reasonable amount of sequential and combinational control logic was required. The number of applications of PCs grew exponentially as the capabilities of PCs expanded from basic on-off switching functions to such sophisticated functions as counting, timing, arithmetic and interunit communications.

A list containing all PC applications would be very long. A small list containing the typical applications (though the term "typical applications" with respect to PCs is fast losing its meaning) is shown below.

TYPICAL APPLICATIONS

- Transfer machines
- Inspection and testing machines
- Weighing systems
- Chemical batch processing
- Sorting and classification
- Film coating processes
- Polymer blending and handling
- Water and waste treatment
- High speed counting
- Stacker cranes
- Foundry molding machines
- Textile processing
- Energy management
- Glass processing

Blow molding machines
Conveyors
Environmental monitoring

A brief description of a few of these typical applications follows.

DISCRETE PARTS MANUFACTURING

The PC is ideally suited for controlling high volume discrete parts manufacturing operations. In fact, this was one of the functions the PC was first designed to perform.

In discrete metal parts manufacturing, individual parts are produced by a sequence of machining operations. In transfer lines, these operations are usually performed by individual machining stations connected with automated material handling equipment. A large part of the control function is devoted to co-ordinating material handling, machining, and other operations. That is, the programmable controller is given the responsibility of ensuring that manufacturing operations occur in a particular sequence and at the proper time.

SUPERVISING MACHINE SEQUENCING

The primary role of PCs on the transfer lines is to act as a control supervisor. The PCs ensure, for example, that parts are all in proper position before machining operations

are initiated, and that all operations are completed before parts are indexed to the next station.

In this application, the programmable controllers are not directly involved in closed-loop control of manufacturing operations. Rather, PCs tell the various manufacturing subsystems when to perform their operations. This type of control is easily accomplished using simple relay ladder logic programs and discrete input/output signals. It is an excellent example of the PC's relay replacement capability.

MOTION CONTROL

A programmable motion controller is best described as a solid-state device that accurately and efficiently controls the movement of machinery or equipment in complex industrial processes.

Just a few years ago motion control was considered the exclusive province of numerical control (NC) equipment and computers. Because the computer can calculate speed and direction and continuously revise position commands based on sensed deviations from a program, there appeared to be no efficient, cost effective substitute for such a system.

For complex three to five axis, continuous path contouring, the computer is still the leader. But for single-axis, point-to-point control, as is required for most straight machining, robot handling and robot assembly

applications, programmable motion controllers are gaining wide acceptance.

The motion commands, which are programmed in a familiar language, save the user considerable time in setup procedure, since all the stops and limits are programmed, not set by hand. This results in a smooth flow from one command to the next.

PEEN STRAIGHTENING

Brittle cast iron camshafts are peen straightened for use in a 2.5 litre auto engine at the Pontiac Motor Division of General Motors, in Pontiac, Michigan. An automatic straightening system uses a programmable controller to handle all the functions. Formerly, straightening was primarily a manual operation.

Camshafts are rotated, gauged and peened, two at a time, at a rate of 220 parts per hour per machine. A transducer senses the bend of the camshaft while an encoder coupled to the drive rotates the shafts to determine the radial orientation of the part.

The PC signals a series of specially modified air hammers at each station to deliver a series of pulsed blows in bursts to the low side of the part, opposite the high point of the bend. The operation makes the part more stable for later machining and grinding.

STEERING KNUCKLE MACHINING

PCs have solved a complicated material handling problem on a high volume conveyor and transfer system in which steering knuckles are produced for General Motors.

More than a mile long, the conveyor is similar to a railroad with spur lines to the various machining operations. The spur lines provide a parts bank to assure a steady flow of parts. When filled, the system diverts the excess back to the main conveyor or to a storage loop until needed.

Three different size knuckles are machined, in three separate operations, and the number and size of knuckles produced change daily according to production quotas.

Before a knuckle is diverted to a machine, the PC reads the card on the pallet to determine if the machining operation is being done in the correct sequence. If all the lines are filled to capacity, the PC will shut down the machining operation until space is available. The PC reviews the carriers on the entire system to determine the relative age of all parts and attempts to use the oldest parts first.

ENERGY CONTROL

A PC is providing control and monitoring capabilities for Saint Mary's Health Center, St. Louis, Missouri., in an effort to control energy costs.

After installation of the controller, the hospital's energy usage has decreased by as much as 18%. It now has diagnostic reporting stations on every piece of mechanical equipment - life support or HVAC (heating, ventilation and air conditioning).

The security system consists of ultrasonic motion detectors in hallways that would normally be unoccupied at certain times. If a detector is triggered by an intruder, an alarm in the security office alerts security personnel. A printer in the security office also generates a printout of location and time of occurrence.

The PC controls and monitors HVAC equipment, exhaust fans, chillwater pumps, heating pumps, water storage pumps, compressors and motion detectors for security.

About half of the total usage of the controller is for control while the other half utilizes the controller's monitoring capabilities. There are many devices throughout the hospital that are not directly controlled by the PC, but are continually monitored by it. One example is the monitoring of vacuum pumps in the operating rooms. There are a number of dual sets of these pumps, with one of the

two pumps on-line at a time. If a pump fails, the second pump is brought on-line and an alarm message is generated on the printer in the maintenance room.

The controller's capabilities have the alarm message printed, stating which pump has failed, its location, possible solutions to the problem and the date and time of failure.

CONTROLLING WELDING ROBOTS

The following is paraphrased from Rich Merritt's paper on "Some PC Application Ideas" published in INSTRUMENTS & CONTROL SYSTEMS journal in January, 1982.

At Chrysler Corporation's assembly plant in Belvidere, Illinois, several Allen-Bradley PCs are controlling welding operations that involve robot welders. The robots make about 2000 welds on Horizon and Omni automobiles. These amount to 30% of the total number of welds needed for each car.

The first stage of assembly involves joining the car's floor pan to the left and right side aperture panels. Two PCs control the conveyors which bring the panels to the welding station. The side aperture panel conveyors are controlled by one PC while another controls the floor pan conveyors. The sides of four-door or two-door models have to be synchronized to meet the correct floor pan before

entering the welding robot, which fastens the parts together.

The eight welding arms of the robot are controlled by yet another PC. Final welds are made by 24 robot welders controlled by yet another PC.

Finally, when the car has been completely welded, it is moved to an overhead conveyor, controlled by a separate PC, and sent on for further assembly operations.

As can be seen, the PCs serve as master control for the robot welding operations, making sure that all of the events happen in the proper sequence. About 95% of the inputs are limit switches, but some optical sensors are also used. The majority of the outputs are solenoids. Two other PCs control tire mounting, inflating and balancing.

The applications discussed above are but a few of those within the realm of the PCs on the market today. As PCs become more and more sophisticated, the number and type of applications they can handle will increase vastly. Already some PCs rival microcomputers in intelligence and capability. Features such as communications interfaces, math packages, high-level languages, motion control algorithm and more make PCs very competitive in most aspects of the control market, assuring new areas of applications in the future.

IV. COMPARISON OF SOME MODELS ON THE MARKET

The programmable controller market, momentarily on hold at about \$500 million because of the international economic climate, is expected to regain a growth rate of about 20% in 1983. New models are being introduced almost every month and already there are over a hundred models available.

A few of the several models are discussed below to give an insight into the range of PCs on the market in terms of capacity, capability and use. The models are also summarized in a table (Table 3) for easier visual comparison at the end of the chapter.

MODICON MICRO 84

The Modicon Micro 84 is an easy to use solid-state system that is cost effective for the most basic relay control operations. It controls small machine operations reliably and economically and is ideal for jobs requiring from 6 to 60 relays. It performs all relay, timing, counting, arithmetic and sequencing functions and costs less to install than a panel of ten relays.

It uses the ordinary relay ladder diagram which obviates any special training of the factory personnel. Its Liquid Crystal Display allows the programmer to see the exact information programmed. Measuring only 11.5"H x 16.75"W x 5.875"D, it can handle upto 64 I/O points.

It is suited for applications such as small transfer lines, machine tools, small assembly machines, material handling, energy management systems, and virtually for every other small machine control job.

MODICON 584

Modicon 584 not only replaces relays, counters, and timers in control systems, it also performs computer like calculations as well as control and reporting functions on analog and numeric data. It is capable of performing sequential control, process (analog) control, data acquisition, numerical calculations, reporting and diagnostic monitoring.

The 584 provides indicators and displays to allow the plant electrician to troubleshoot any problem visually, without extra meters or oscilloscopes. Also, self diagnostic logic resides within the 584 controller to detect, identify and report equipment faults as they happen. It is designed to withstand high levels of electromagnetic and radio frequency interferences without special shielding.

The Modicon 584 has memory capacity, I/O capacity and speed in excess of the application needs of today. Its modular construction permits expansion with increasing needs.

SERIES SIX 60

The model 60 is a self-contained PC, combining CPU and I/O modules in one rack, and is suitable for small size applications. It can be used for applications requiring from 8 I/O points to a maximum of 256 inputs and 256 outputs. It has a memory capacity of upto 2K of CMOS (Semiconductor Random Access memory) together with a battery backup. It handles 16-bit words, has extended instructions beyond simple relay ladder diagram and can be connected to a data processor.

MELSEC KOE

Melsec model KOE is an ultraslim high performance PC ideal for small scale control with a memory of 2K . It is built around modules consisting of 16 I/O points combinable up to a maximum of 128 points. It is capable of addition and subtraction and can be used as a one-machine controller, a remote I/O unit in a larger system or as a local controller. Compact, slim, and with a depth of only 2.8", this model requires a greatly reduced panel depth. The external dimensions are approximately 12" x 18" x 2.8".

TI MODEL 530

The model 530 is a user friendly PC allowing the user to harness the full power of the PC. As a result it handles complex tasks such as position control applications and

machine diagnostics with the same ease as sequential logic, timing and counting. It offers both 110 and 220 Vac input voltage, has a user memory capacity of up to 7K and handles 16 bit words. The total overall dimensions are approximately 19.525" x 12.125" x 6.6".

PLE-30R

With 18 inputs, 12 outputs and a maximum of 300 steps of programming capacity, the PLE-30R is a compact PC that can be mounted on various machines. Keyed in data are directly indicated on the display which serves for easy confirmation of operation. In addition, I/O status is also indicated with LEDs during operation. Its a light weight, shallow profile, small size PC measuring 9.44" x 13" x 4".

AUTOMATE 35

The Automate 35 has two memories, two processors and understands two languages making it easy to program. Other than the usual relay ladder diagram, it also uses the language of Control Statements - a high-level, easy-to-use language specifically designed for industrial control. It helps an engineer to program complex control algorithms himself.

Its dual processors include a logic processor and a microprocessor. This allows logic functions to be quickly and efficiently processed, while other time consuming data

manipulations are handled by the microprocessor.

It has both a CMOS (Semi-Conductor Random Access Memory) R/W (Read/Write) memory with a battery backup, and EPROM (Eraseable Programmable Read Only Memory). This allows the debugging of a program in R/W and then loading into the EPROM for use.

Its I/O ports can be expanded from 64 to a total of 2048. The memory size ranges from 4K to 24K.

EPTAK 200

The EPTAK 200 is a small PC that provides a cost-effective alternative to relay systems using from as few as 5 to as many as 128 relays. It has capacity to perform arithmetic functions and has a total of 128 I/O points. The programmer has its own power cord and battery protected memory and thus functions totally independent of the processor. After completing the program in any location of choice, the program can be transferred by plugging the programmer into the processor directly.

It can also be connected to a printer to get hard-copy printouts of programs.

PLC-3

The PLC-3 is one of the largest PCs available on the market today. It is designed to undertake the more

demanding and complex industrial applications. Housed inside the 19" x 20" processor are six modules which direct all programmable controller operations. The main processor module directs internal functions and elements of the program like logic, data transfer and memory management.

It has a memory of 96K and offers both core and RAM (random access memory). Its 8192 total I/Os are divided into 4096 inputs and 4096 outputs. Peripheral devices like computers, printers, magnetic tape recorders and modems can become part of the PLC-3 system.

The PLC-3 also has the capability to compare data at two distant locations and add, subtract, multiply or divide their contents and control an output based on the result.

CLASS 8881

The CLASS 8881 PC offers medium to large system capability. It provides both ladder and Boolean logic programming and has 4 to 32k R/W magnetic core memory. It can replace systems utilizing upto 1023 relays and has an I/O capacity of 2048. Some of the applications where this PC is employed include automotive manufacturing, food processing, energy management and coal handling.

TABLE 3 : COMPARISON OF SOME MODELS ON THE MARKET

MANUFACTURER	MODEL	NO. OF BITS	SCAN RATE (msec)	TOTAL I/O	HIGH LEVEL LANGUAGE	NO. OF INSTRUCTIONS
GOULD INC.	MODICON MICRO 84	4	10	64	NO	9
GOULD INC.	MODICON 584	16	1.5	8192	NO	32
GENERAL ELECTRIC CO.	SERIES SIX 60	16	1	512	YES	76
MITSUBISHI ELECTRIC	MELSEC KOE	8	30	480	NO	26
TEXAS INSTRUMENTS INC.	TI 530	16	8	1024	YES	37
IDEC IZUMI	PLE-3OR	8	30	30	NO	10
RELIANCE ELECTRIC CO.	AUTOMATE 35	8	4	2048	YES	83
EAGLE SIGNAL	EPTAK 200	8	20	128	NO	30
ALLEN-BRADLEY CO.	PLC-3	16	2	8192	YES	74
SQUARE D ELECTRIC CO.	CLASS 8881	16	5	2048	YES	58

V. PC AND THE MICROCOMPUTER

In view of the increasing complexity of industrial control applications requiring complex mathematics, data communications, and report generation, standard programmable controllers may no longer be sufficient. With time, more and more companies are turning to the microcomputer as a cost effective alternative for their control needs.

With its increased power and flexibility, the microcomputer can bring versatility to industrial control concepts. Although it seems ideally suited to the growing demands of factory processes, there are some limitations to implementing these microprocessor systems.

LIMITATIONS OF THE MICROCOMPUTER

The problem originates in the fact that the microcomputer was not designed specifically for the factory environment and therefore production control engineers are finding the "fit" with their processes less than perfect. The microcomputer was basically built for data processing (DP). In its present form, it has not adapted to certain aspects of industrial control any better than most PCs are adapting to the DP functions now required in today's factory.

The limitations of the microcomputer in industrial control fall into two major categories: programming languages and speed of operations. These problems are

interlinked and both must be resolved for an effective solution.

As mentioned earlier, the major reason for the rapid acceptance of PCs over the past decade lies in the fact that they spoke the language of the control engineer - relay ladder logic. This allowed the control engineer, who had the full responsibility for supporting production applications, to program, monitor and debug his or her own equipment. It obviated the need for data processing experts and minimized extended downtimes.

On the other hand, microcomputers do not speak the graphic language (relay ladder logic diagrams) of industrial control. Typically, they are available with the higher level languages of data processing that are more appropriate for the purpose: BASIC, Fortran, Pascal and others. While many engineers are familiar with one or more of these languages, limitations become obvious when these languages are required to meet industrial application requirements.

First, the languages lacked any form of graphic display. In contrast, relay ladder logic of PCs enabled engineers to pictorially see the circuits of industrial processes on CRTs, in real time. The circuits contain the logic of the industrial processes. System users could also modify the program, on-line. General purpose languages, such as BASIC can not easily provide such graphic display.

But far more critical than graphic display is the impact the languages have on scan times in control applications. Neither BASIC nor Fortran was designed to solve the Boolean logic equations of industrial processes, with hundreds of variables interlinked in arrays of open and closed conditions.

In these higher level languages, each variable must travel laboriously through the entire maze of statements, "If A equal to zero and B not equal to zero or C equal to zero..." and so on. The result is a rapid deterioration of scan times, reaching in some cases to nearly a full second. In compressor control or even conveyor control, this can prove disastrous.

Moreover, as mentioned earlier, until recently microcomputers were not designed to withstand the harsh environment of the factory with its heat, humidity, dirt, dust and noise.

The PC, on the other hand, with all its advantages discussed in Chapter 2, is finding it increasingly difficult to cope with the increasing industrial control logic demands being placed on it.

ALTERNATIVE SOLUTIONS

There are several alternatives in dealing with the poor scan times of microcomputers. One alternative is to adopt

the design of PCs. PCs dealt with it through the development of specialized processing hardware designed to handle the Boolean algebra of relay ladder logic. However, as the newer PCs sought to emulate the microcomputer, they too have decayed in their scan speeds, because PCs have to deal with the added functions in real time. Each new added function, from data processing to communication, has to be processed during the scan of the processor. The effect is as though more I/Os were included. The more extended functions that are added, the greater is the resulting scan time.

Another alternative for the microcomputers is to write programs in assembly language, thereby avoiding the delays of the higher level languages. While this will improve scan time performance, it will also introduce new problems.

If assembly language is used, control is taken out of the hand of the engineer, who will usually rely on the data processing staff to program in assembly language. Also, it vastly decreases the flexibility of the micro based system. Assembly language software tends to be very specific and if changes are required in the process, the task can become very complicated.

The third alternative to improve scan times in microcomputers is to use new, superfast microprocessors which could continue to be programmed in BASIC. This too could solve the scan time limitations, but the engineers would still be left without a real time graphic display.

Moreover, superfast micros, though desirable, are very expensive and such a solution could increase the cost greatly.

So it would appear that the microcomputer, as it stands, is only a partial solution to industrial control applications, just as the PC. Both are vital tools, but neither is a perfect fit for the needs of today's factory. What is required is a hybrid of the two, taking the power and flexibility of the microcomputer and combining it with the design advantages of the PC.

Such a system would have a programming device which accepts relay ladder logic and translates it into the machine code of the computer for rapid scan time operation. In addition, the device should also accept a higher level language, such as BASIC, for the extended functions. Relay ladder logic is not designed to easily handle report generation or high level mathematics. The ideal programming device would accept both languages.

The industrial controller itself should be a combination of microcomputer functionality and the Boolean solving hardware of the PC.

With the power of the microprocessor, multi-tasking also becomes possible. This is vital if scan times are to be maintained while including all the data processing functions needed. By identifying the functions as critical and non-

critical, the micros could deal with critical functions such as relay inputs immediately, while deferring non-critical functions such as data processing, communications and report generation until after the critical functions are completed. In this way, scan times of 30 to 50 milliseconds would be possible while the system handled extended math, report generation, communications and other complex non-critical functions.

Fortunately, such hybrid systems are available today. Manufacturers have captured the power of the microcomputer, merged it with the hardware of the PC and housed it all in a chassis specifically designed for the harsh industrial environment. With this innovation, control systems will receive all the benefits of the microcomputer without sacrificing the functionality of the PC (35).

The PLC-3 and the Modicon 584 models discussed in the last chapter are examples of such hybrid systems.

VI. CURRENT AND FUTURE TRENDS

Competition in the programmable controller market continues to heat up. With some hundred different models already available from over thirty five manufacturers, development efforts appear to be stronger than ever. The year 1982 saw the introduction of a number of new PCs and there were four more entries in January of 1983.

SMALL PCs

It has been a problem to economically use a computer-based controller or a PC to solve a control application where only a few electromechanical relays are needed. When a control system is relatively simple, requiring just a handful of components, electromechanical relays have been the answer. Now, that is changing.

The newest generation of PCs packs much of the same power as the older, larger units into much smaller, low cost packages. Many recent offerings can be classified as "micro-PCs" - compact units with a relatively small number of I/O points. These are obviously aimed at the low end applications; that is applications requiring only a few inputs and outputs and hence having a less extensive programming and interfacing requirements.

This trend to smaller size works hand in hand with a trend to increased exploitation of distributed network

principles. Rather than a single large PC controlling a group of machines, an entire assembly line, or a complete process, a number of smaller units are used to control individual machines, or portions of larger systems. Coordination and, if necessary, central supervisory monitoring and control, is maintained by connecting the individual controllers together with some form of communications network.

There are two other major reasons for the great interest in this small size range. One reason is to compensate for losses in other product lines, the functions of which have been taken over by PCs. Component timers and counters are the principle casualties here, with timers leading the way. Consequently manufacturers of timers, rather than design a better stand alone timer than the competitors' PCs with in built timers, have decided to manufacture their own small PCs.

The other reason is the substantial percentage these small PCs represent of the total programmable controller market. Popular estimates place 80% of potential PC applications in this low end category. Also it is estimated that in 1982, PCs of 128 or fewer I/O took about half the programmable controller market in number of units sold and about one quarter of the market with respect to total dollar sales. In the next four years these percentages are expected to increase to about 65 percent for unit volume and

well over 30 percent for dollar volume.

AN EXAMPLE OF A SMALL PC

Allen-Bradley, one of the three giants sharing 80 percent of the small PC market along with Modicon and Texas Instruments, terms its newest PC the basic element for automation control. The self-contained PLC-Microtrol integrates processor, power supply, I/O, and memory in a single unit. Each unit provides 20 input and 12 output points and 500 words of 16-bit memory. Up to eight units can be interconnected for direct peer-to-peer communications, and groups of these small PCs can be linked to the Allen-Bradley Data Highway network as part of a factory wide control system.

The PLC-Microtrol is primarily aimed at relay replacement in small machines, particularly in machines which can and should be linked together for better production control. Its instruction set includes timers, counters, relays, and sequence control.

To meet various needs, the PC is offered with a choice of operating voltages: 120 V ac for domestic factories, 220 V ac for general industrial use internationally, and 24 V dc for offshore, off-road, and other portable or potentially hazardous applications.

A portable hand-held programmer functions as the human

interface, providing for ladder diagram programming, and for program storage in cassette tapes. The programmer can also be mounted with the PC to function as a permanent data monitoring or data entry device.

Up to eight of the Microtrol units can be connected together and data can be transmitted from one unit to the other. Maximum message transmit time is under 100 millisecond. By message here is meant a fundamental unit of code transferred between two PCs. For example, a message may be a two byte code or a four byte code. Addition of a separate communication interface unit allows connection to the Allen-Bradley Data Highway, Allen-Bradley's PC communication network.

At the other end of the spectrum, the very large PCs typified by the Allen-Bradley PLC-3 are continuing to look more and more like general purpose control computers than the device that was originally thought of as a PC. Large memory and I/O capability, communications, floating point arithmetic, and other computer like features obviously put this unit at the other end of the PC spectrum. Massive control tasks are possible, particularly if multiple units are interconnected via a data highway.

PCs AND THE FUTURE

Technological progress and future industrial applications are the two aspects that should be considered in forecasting a future for PCs. To some extent the latter will control the first.

Programmable controllers of the future will retain the characteristics of retentive memory, relay ladder diagram format, separate I/O section, modular maintenance, simple human interface and logic solved in scans. These features may be modified but will continue to be identifiable in PC's for the next few years. The conservative nature of the industry tends to slow acceptance of new devices, but acceptance speeds up when the device is proven, as with the PC.

PCs will continue to spread in capability and cost, from the very small and very inexpensive on the low end to the very large with computer like power on the high end.

The interest in the low end units is not surprising, as roughly 80% of the industrial logic control applications can be handled by PCs of 50 I/Os and smaller, and of these applications only 15 to 20% have so far been mechanized by PCs. From the dollar point of view, these small systems comprise only about 38% of the total logic control market, but with the relatively low penetration to date by PCs, this small systems area is very enticing.

PCs will acquire more sophisticated capabilities, and will effectively compete against minicomputers in the industrial environment. Stock inventories, maintenance diagnostics, report generation and maintenance scheduling will become more commonplace functions for PCs.

Future applications for PCs, like most of today's applications, will be based on productivity gain and cost effectiveness. PCs will contribute to the development of new products and, very likely, new industries with methods that require precision, reliability, flexibility and quick response.

In discrete parts manufacturing, added capacity and capability of PCs will foster increased use of transducers and signal transmitters as preventive maintenance subsystems. Monitoring the temperature, pressure, vibration, voltage, etc., of machine components will help in predicting pending failure and permit repair and/or replacement during scheduled shutdowns, thereby minimizing breakdowns and downtime.

Material processing and handling industries will increase their use of PCs primarily for their precise metering and programming flexibility. Material cost savings and producing a variety of products using the same equipment in varied sequences result in major economic benefits. New processes having critical formulae and timing will require PCs for control.

There has been a growing trend to use a PC in conjunction with a computer numerical control (CNC) unit to act as an interface between the control and machine functions such as indexing table positioning and coolant flow control. Also, marriages of PCs and tool-point control systems can be expected where the advantages of PCs can be applied to control the auxiliary machine functions.

In a nutshell, the following trends in PCs can be expected.

- * More sophisticated computer like functions as options.
- * Tremendous growth in communications network.
- * Integrating PCs together with computer-aided design and computer-aided manufacturing.
- * Lower hardware maintenance costs compared to replacing relays.
- * Faster scans and more and larger memory options.
- * Improved reliability with three to five years mean time between failures on CPUs and power supplies.
- * Growth of the low end PCs as a basic building block in the control function of the factory of the future.

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PROGRAMMABLE CONTROLLERS

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ABSTRACT

Programmable Controllers (or PCs as they are called) are a relatively recent invention. They are general purpose microprocessor controls that accept inputs, evaluate them and generate appropriate outputs to control machines or processes.

The importance of PCs as control devices in the industry has been recognized for sometime and will continue to grow in the future. To a large extent, they have replaced their predecessors - the electromechanical relays.

Many articles have been and will continue to be written about PCs. Some emphasize on the the boost they have given to quality control and productivity and others on application ideas, models on the market, PC versus the microcomputer, and the future of PCs, among others.

This report has attempted to put together many of the various aspects of PCs into one composite whole. It covers areas such as history and development, capabilities, applications and current and future trends, among others.