APPLICATION OF PROGRAMMABLE CONTROLLERS FOR AUTOMATED BRIDGE CONTROL

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Abstract

Today's state of the art technology offers reliable, cost-effective, adaptable solid state logic systems known as programmable controllers.

This paper reviews the design concept of programmable controllers, more commonly known in industry as PCs. Along with this, we will review the adaptability and application of programmable controllers to bridge control.

Introduction

Bridge control from a logic standpoint has involved relays, timers, counters, drum sequencers, limit switches and other electro-mechanical control devices. Along with these have been the traditional operator interface devices such as push-buttons, pilot lights, bells, horns, etc..

Today the same control actions and reactions are necessary in order to properly operate a bridge. However, technology has offered a new concept in equipment which can interface with the same input and output devices, including those utilized by the operator, but provide many enhanced features and benefits compared to the traditional hard-wired relay system.

These enhancements allow the logic system to be more intelligent, flexible, modular, reliable and cost effective Modern industry worldwide has seen the advantages of the programmable controller system making it one of the fastest growing segments of the electrical market.

The programmable controller can bring these improvements to bridge control, thus offering an improved method of bridge operation.

This paper is arranged in sections which will cover the following topics:

What is a PC? PC System, PC Principles of Operation, Major Sections of the PC, PC Program Structure, Scanning Process, PC Features and Benefits and Relationship of PCs to Bridge Control.

What is a PC?

A programmable controller is a solid state control system or more definitively, a stored-program control system. Since there are other forms of solid state logic systems, we must point out that the stored-program feature separates PCs from other systems.

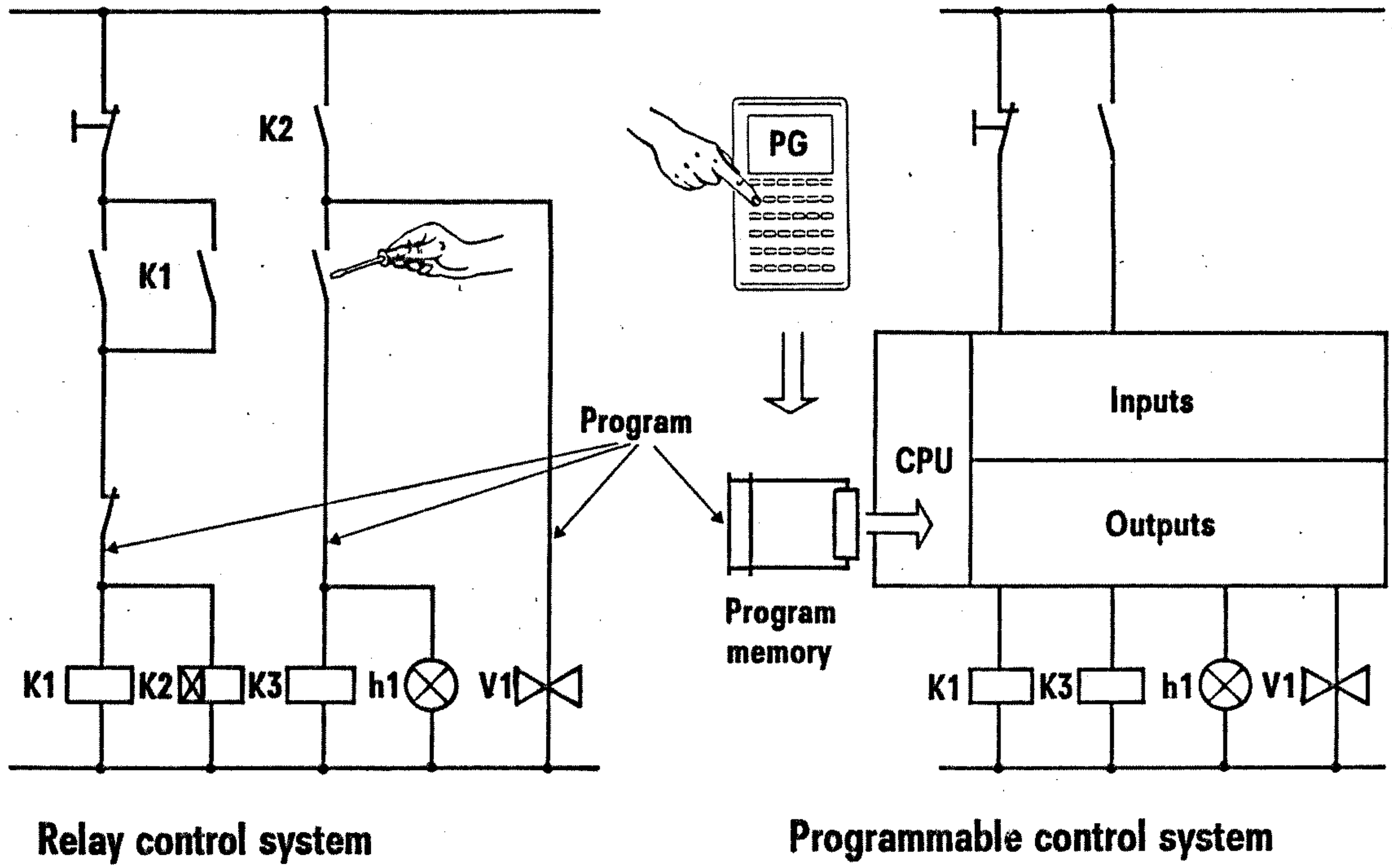
Unlike a hard-wired control system, whose functions are determined by the arrangement of switching devices (NO/NC contacts) on relays, for example, and the wiring between them; the function of a PC is determined by the stored program in memory. (Fig. 1) and (Fig. 1A)

With a hard-wired (relay) control system, changes to the system's function must be made by adding, removing or altering the wiring or components of the system or panel. Timers must be physically altered in order to vary the delay periods.

The programmable controller allows these changes to be made by altering the program inside the controller. This process involves connecting a programming unit to the PC and making changes via a keyboard and display screen or CRT screen. In most instances, the time and effort to make changes is greatly reduced.

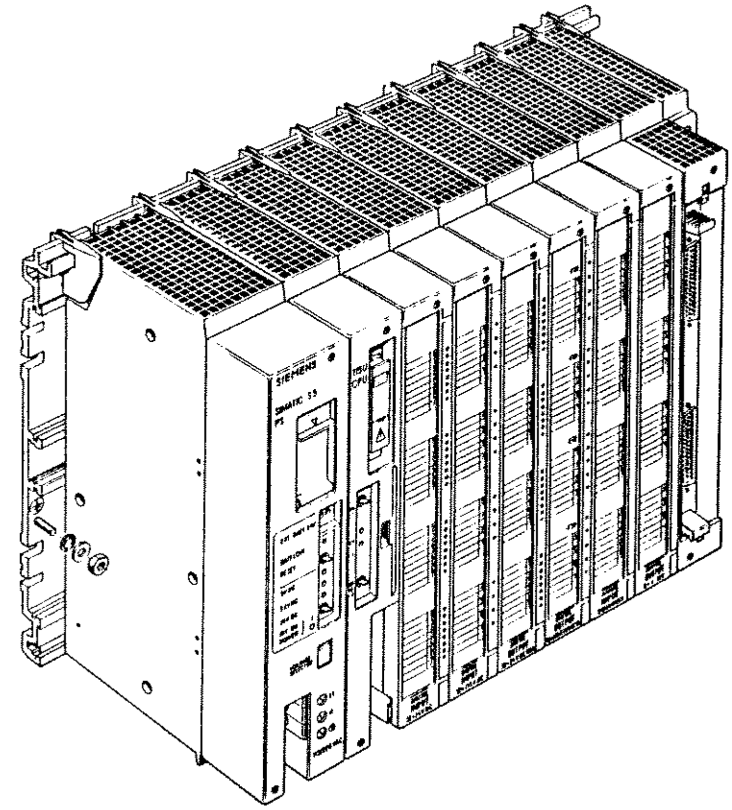
Also, the time and effort involved in establishing a program within the controller can be significantly less than that involved in a hard-wired system.

Although the PC is a type of micro-computer, it is designed and manufactured to live in an industrial environment. It also has the capability to interface with basic industrial control devices such as push-buttons, limit switches, and starters, etc.. The design criteria also allows this interacting to take place at standard control voltage and current levels (120VAC, 220VAC).



Comparison between relay and programmable control systems

Fig. 1



SIMATIC S5-115U
Programmable controller

Fig. 1A

PC System

A programmable controller system consists of five basic components. As follows:

1. Central Processor Unit Module - The CPU Module is comprised of the processor and memory module. The CPU module coordinates the activities of the PC system. The input information is gathered, compared with the program memory and outputs are activated accordingly.

The CPU is constantly scanning the program to make comparisons between the real world inputs and the program stored in memory. When certain comparisons match the CPU activates outputs according to the action plan residing in memory. In this manner, the closing of push-buttons, limit switches, etc., will initiate the energizing of motor starters, contactors, alarms, etc..

The CPU also has other features such as built-in timers and counters that can be accessed and utilized via the programming unit. With these features, the PC can also replace timers and counters normally found in a panel, as well as relays.

Along with these features, the CPU may have other inherent capabilities such as math functions: add, subtract, multiply and divide; comparison operations, shift functions and more. These enable PCs to perform highly sophisticated control functions and be utilized in a variety of applications.

The memory module contains the program for basic operation of the PC system that is accessed by the CPU. Memory in most of today's PCs is in the form of RAMC (Random-Access Memory), EPROM (Electrically Programmable Read Only Memory) or EEPROM (Electrically Erasable Programmable Read Only Memory).

RAM memory can be programmed with a basic programming unit, usually either a CRT/keyboard device or a small hand-held unit with a display screen and keys. These units are physically similar to a calculator. The stored program is easily alterable making it very easy to to work with during start-up. However, a main deficit is the volatility of RAM memory. Should power be removed the data stored in memory is lost. In order to compensate for this a secondary power supply, typically a battery, is recommended to maintain power to the memory.

Other forms of memory are available which are non-volatile, such as EPROM and EEPROM. The E2PROM is usually preferred, due to its ability to be electrically altered thus allowing the programming unit to be used to write and change programs stored in the module.

While the EEPROM is an excellent means of non-volatile program storage the RAM memory is the primary tracking and operating memory where the status of inputs and outputs is maintained on a continually updated basis.

2. Power Supply - This module supplies power, typically 5V, to the memory and logic circuits of the PC. The supply is connected to an external power source, such as 115VAC. The module then converts this voltage to the levels necessary to operate the PC system.

The power supply usually offers protective features to the PC system such as short-circuit protection, transient protection and RFI suppression.

3. Rack - The CPU power supply and I/O modules reside on a backplane known as a rack or chassis. This serves as an electrical connecting mechanism (bus bar) between the CPU, power supply and I/O modules.

4. I/O Modules - The input and output modules act as the interface between the PC and the real world. The input modules are connected to such devices as pushbuttons, limit switches, selector switches, pressure and temperature switches. The module accepts incoming signals from these devices then converts and conditions the signal levels to a low level, which is utilized by the CPU.

The output modules receive signals from the processor which cause a reaction with the load devices, such as contactors, solenoids, starters, pilot lights, annunciator panels, etc.. These devices are energized or de-energized depending on the signals transmitted from the processor to the output card.

Input and output modules vary in voltage and current ratings. Typically they are 115VAC, 220VAC or 24VDC, with input currents in the mA range and output currents from .5A to 2A.

Analog and intelligent I/O modules offer more flexible and enhanced real world interfacing capabilities. With the use of analog input modules the PC can be used to accept signals from analog devices such as pressure current transducers, current transformers, and other sensing devices.

The analog output module can send analog signals to control load devices such as variable speed drives and meters. Various analog signal ranges are available such as ± 10V, ± 20mA and +4 to 20mA.

Other specialized modules are available today, including positioning modules, counter modules, temperature control modules and digital position decoders.

5. Programming Unit - The programming unit is a device used to insert a program into the CPU. This device can be in the form of a CRT screen with a keyboard or a small hand-held device with a display and keypad. The program is written onto the screen or display and inserted into the CPU by depressing keys in a prescribed manner.

Once the program is inserted a roadmap or picture of the control scheme is available for the processor to follow.

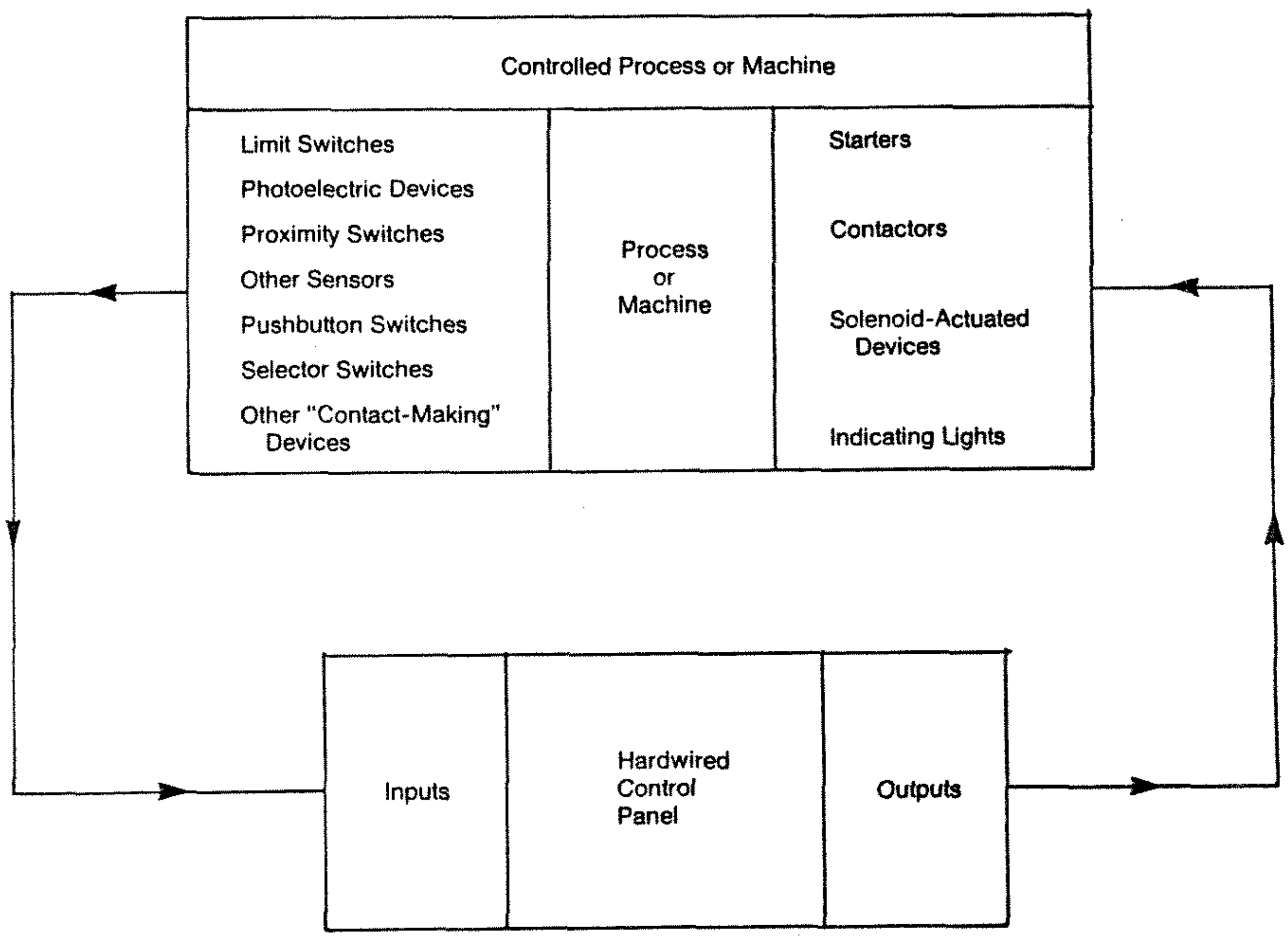
The most prevalent programming language in the United States is ladder or relay type language. The program resembles a ladder diagram, with the symbols appearing on the screen depicting the control scheme. In this manner, a traditional relay control diagram can be easily translated to a PC program through this programming language.

Since PCs traditionally were designed to operate on the factory floor, they had to be operable by plant electricians. The ladder language concept allowed a familiar bridge between hard-wired panels and PCs. The electrician had a product he could work with and understand.

Other programming languages are available on certain PC models and are becoming more popular. Due to their flexibility and adaptability to certain application functions, languages such as statement list, which is a form of boolean language, control system flowchart and graphic sequencing are improving programming techniques and efficiency.

PC Principles of Operation

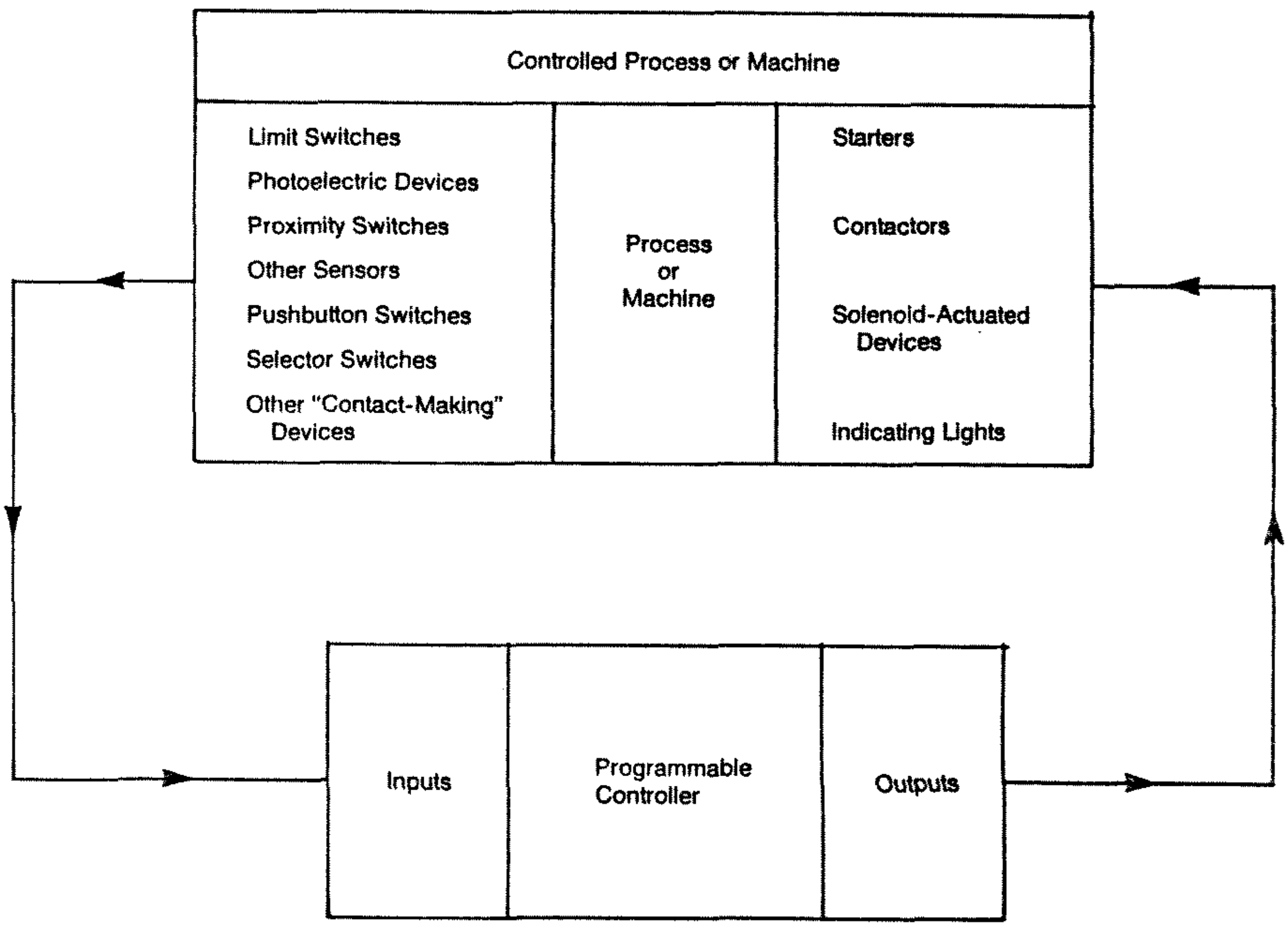
1. Hardwired Machine Control - The control task is established by the arrangement of NC (normally closed) and NO (normally open) relay contacts and their connection to other devices in order to form a logic scheme. Output commands are sent to the starters, contactors, solenoids and lights for actual machine operation. (Fig. 2)



A block diagram of traditional hardwired control equipment.

Fig. 2

2. Programmable Control - The PC interfaces with the same external devices and performs the same logic functions as the hardwired panel. However, it is more easily altered, compact and reliable than a relay system. (Fig. 3)



A block diagram of programmable controller (PC).

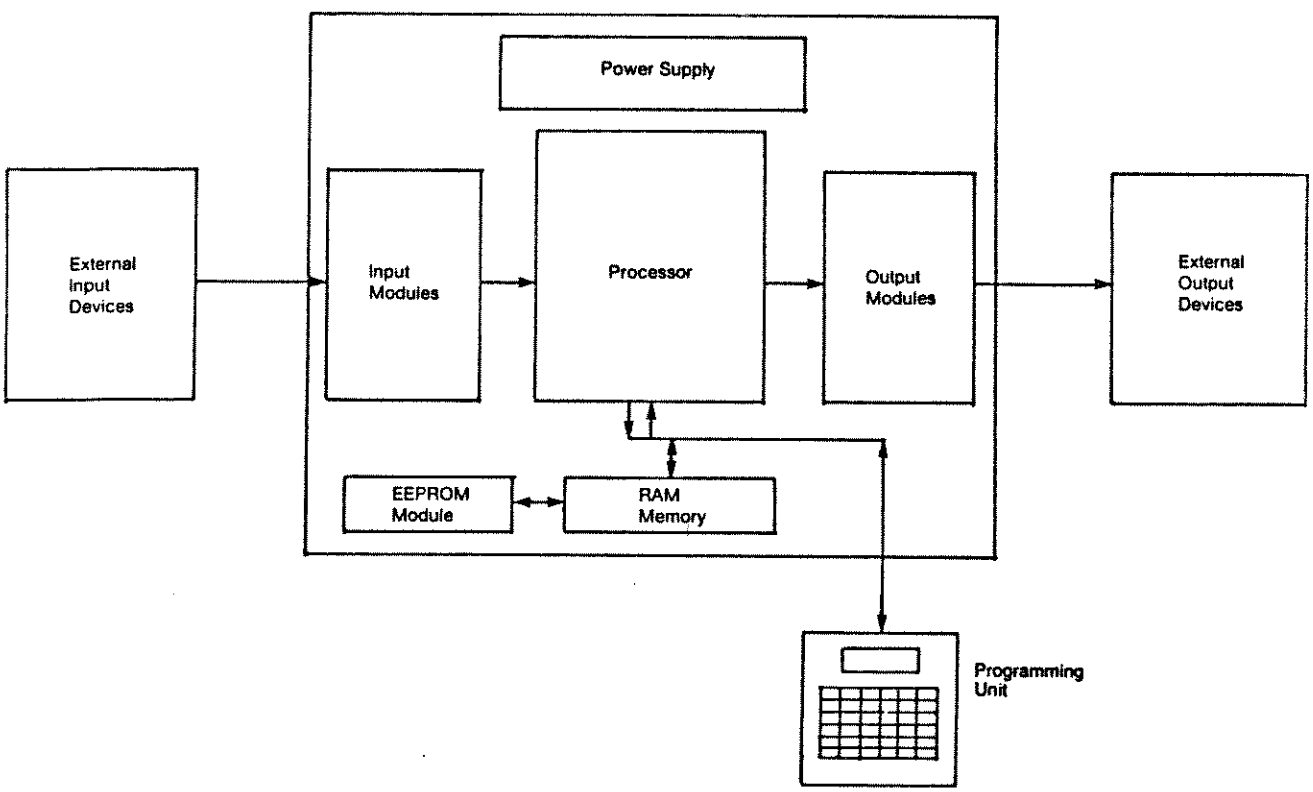
Fig. 3

3. Major Sections of the PC.

a. Block Diagram of PC. The input devices operate at the control voltage level (115VAC and 220VAC or 24VDC) and interface with the input modules at these signal levels. The input modules send a 5VDC signal depicting the status (on/off) of the input to the processor.

The processor must perform various functions such as examining input status, examining the program and sending command signals to the output modules.

The output modules use the 5VDC signals to control output switch devices, such as tracs or transistors capable of interfacing with control voltages (120VAC, 220VAC or 24VDC) and load currents of .5A to 2Amps. (Fig. 4)

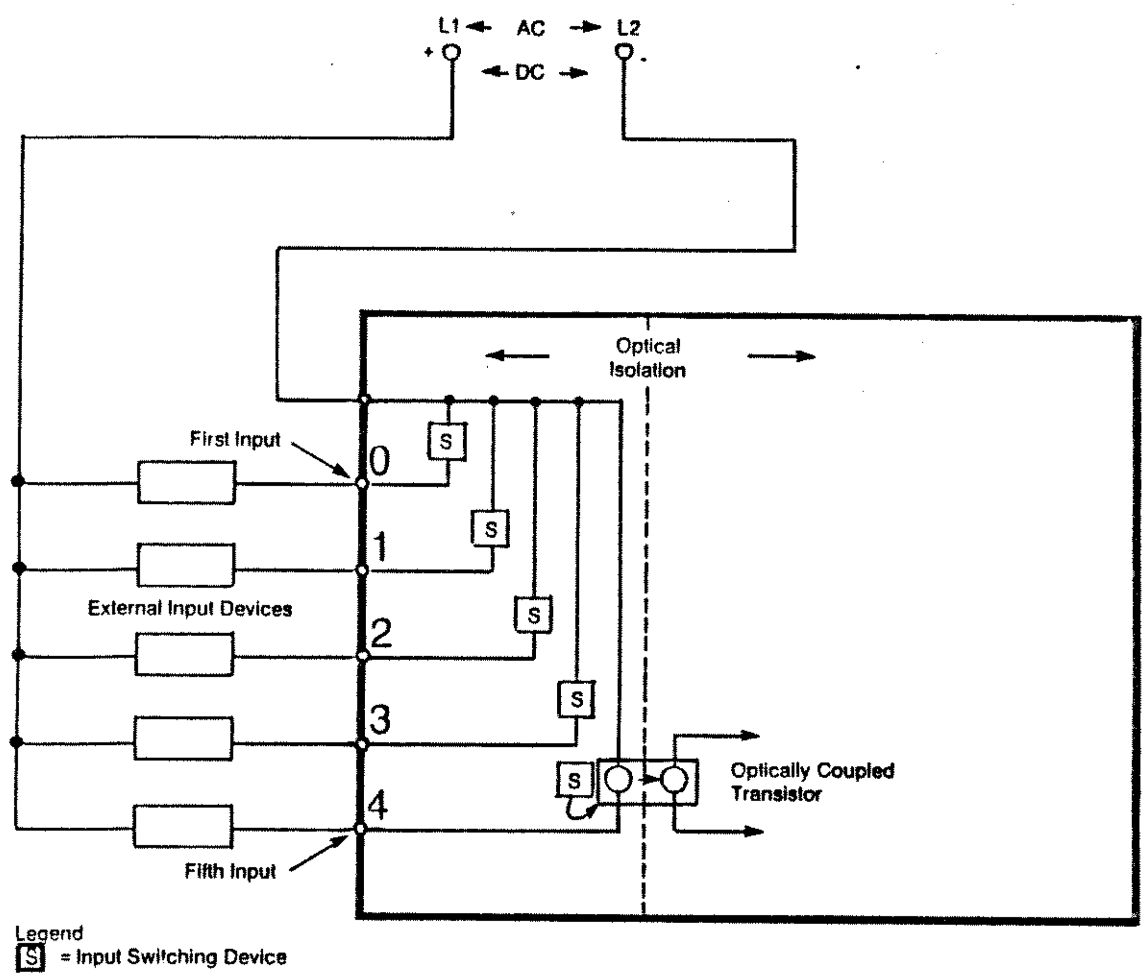


A block diagram of the S5-105R PC.

Fig. 4

b. Input Circuitry. When input device #5 closes, current flows from terminal L1 through input point #4, through a diode in S to L2. Due to the current flow through the diode, a small light signal is generated which controls the switching of the transistor in the device. The transistor is operating at 5VDC while the diode is at the control voltage level.

As shown in the diagram, the diode and transistor are isolated from each other. Therefore, the difference in voltage levels doesn't affect the operation of the input module. (Fig. 5)

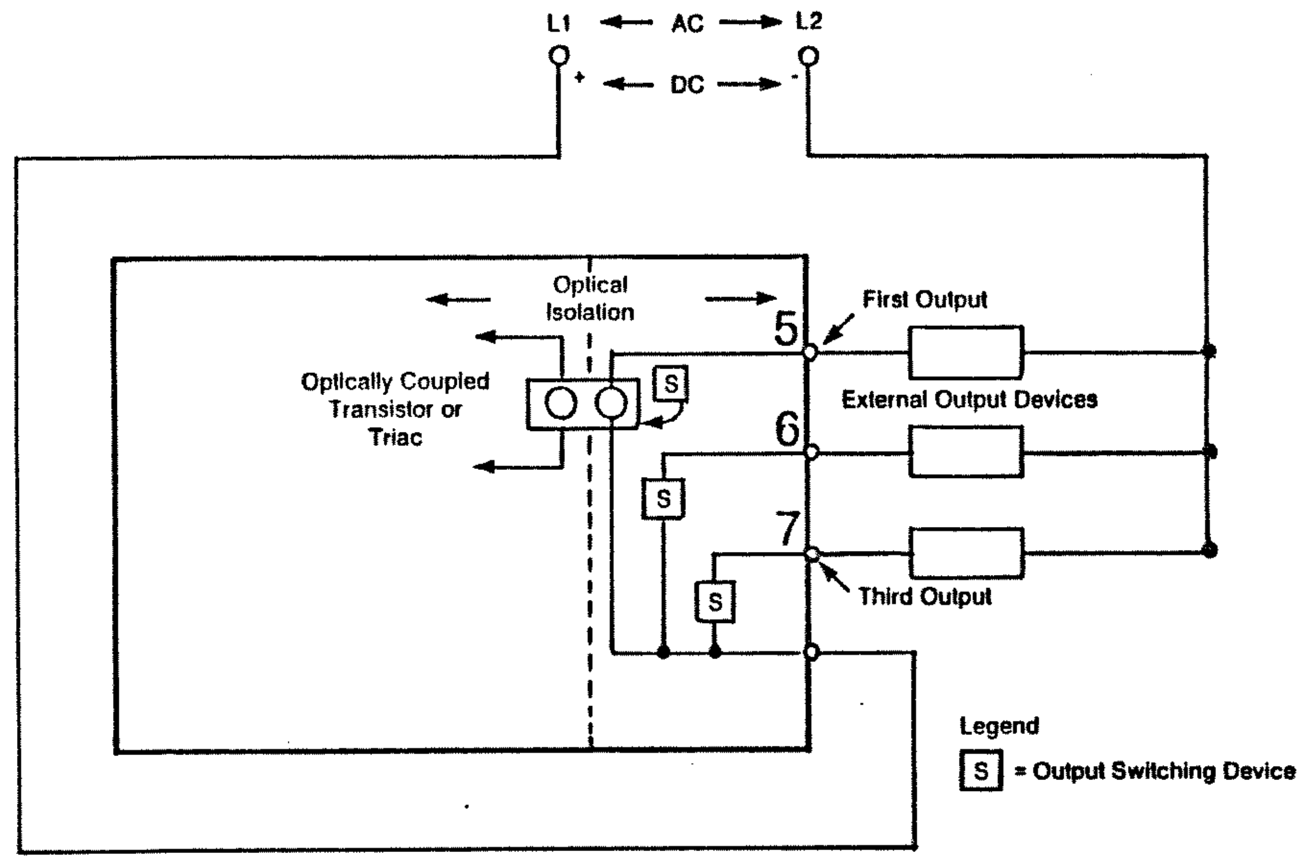


An elementary diagram of the input section of an 8-point I/O module.

Fig. 5

c. Output Module Circuitry

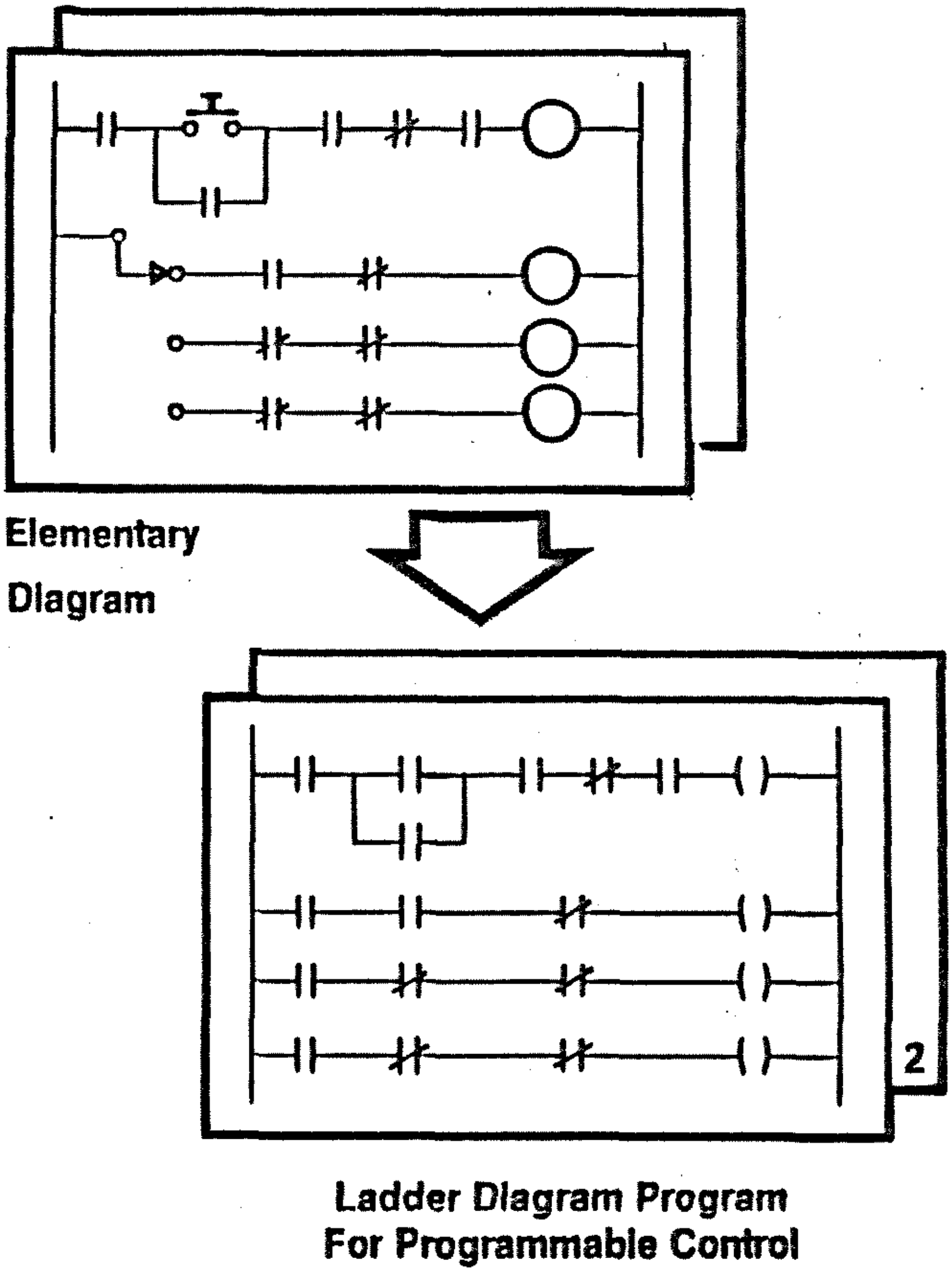
To energize output #5 a small current will flow through the diode of the switching device, at 5VDC. The light produced switches on the output switching device. This allows current to flow to the output load device, such as a motor starter, at the control voltage level (120VAC, 220VAC, or 24VDC). (Fig. 6)



An elementary diagram of the output section of an 8-point I/O module.

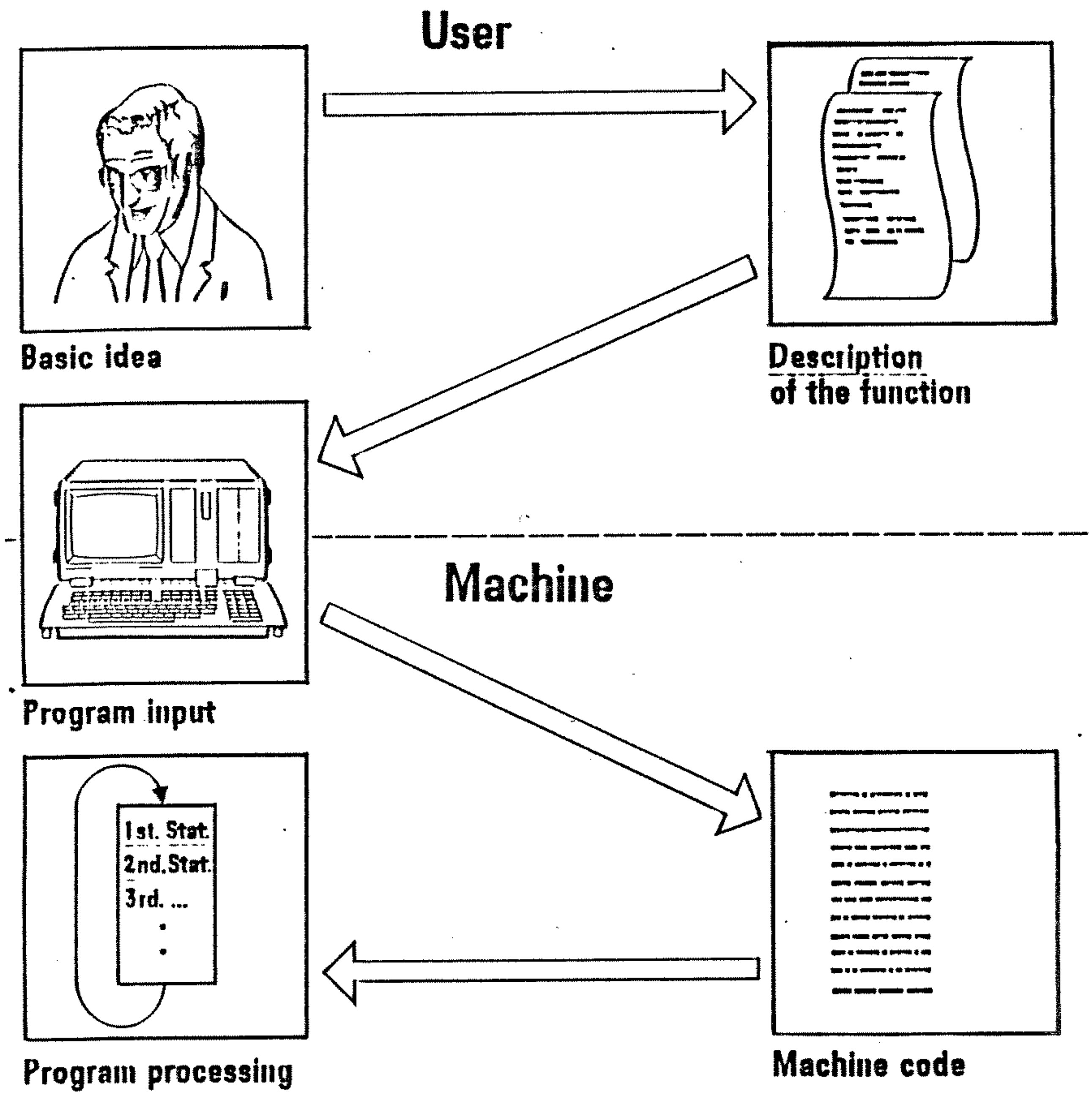
Fig. 6

4. PC Program Structure - The elementary control schematic is translated by the programmer into a ladder diagram. As the diagrams depict, the basic elementary control diagram and the corresponding ladder diagram program are very similar. (Fig. 7) and (Fig. 8)



A simple elementary control-system diagram (top) and the corresponding PC ladder diagram (bottom).

Fig. 7



How are PC Programs Generated?

Fig. 8

PC Program Structure - continued

Other methods of process control schematic representation and PC program structure are also available. This gives the flexibility necessary for the best representation of various control operations in a programming language that the PC system will accept and understand. (Fig. 9)

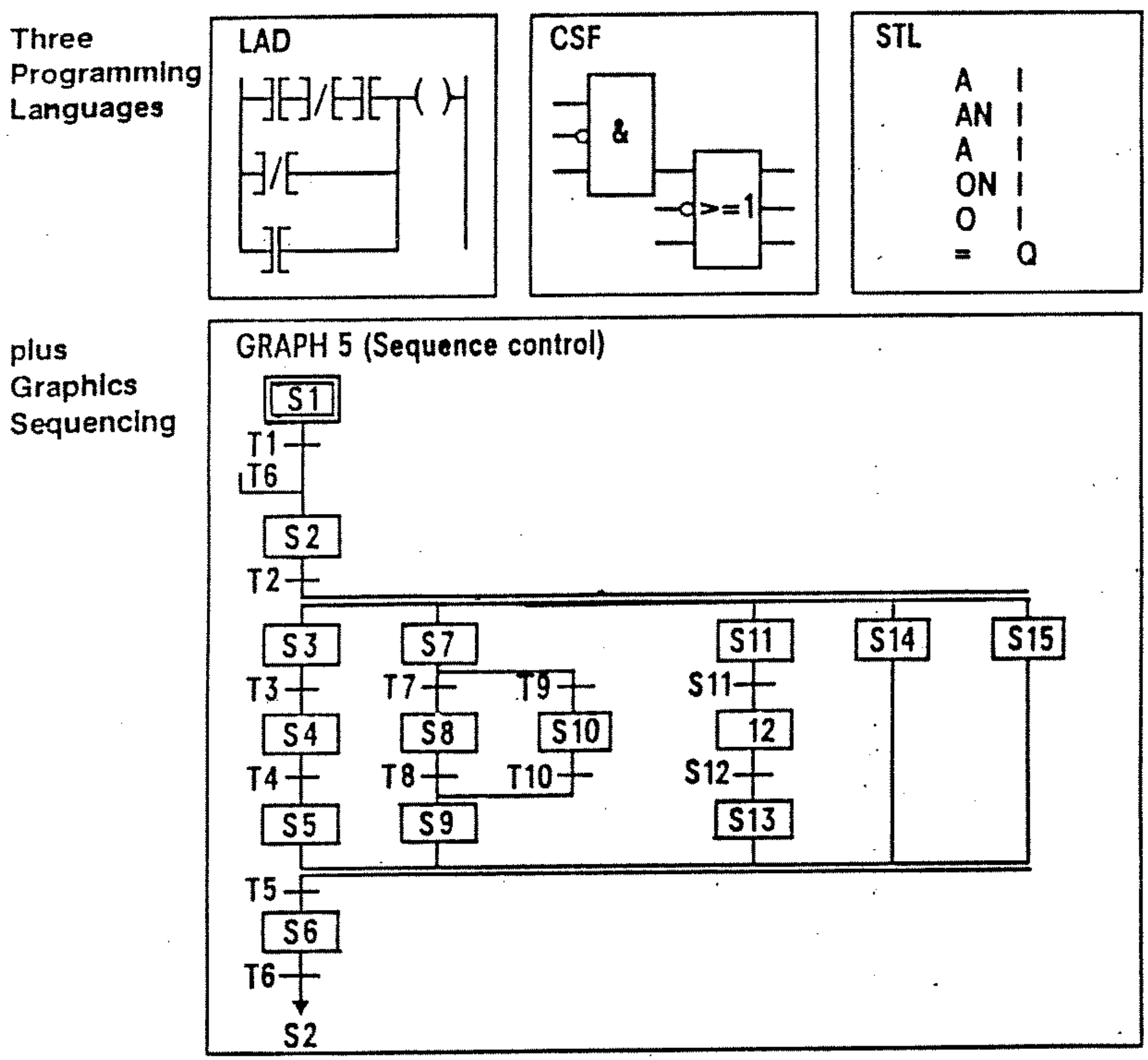
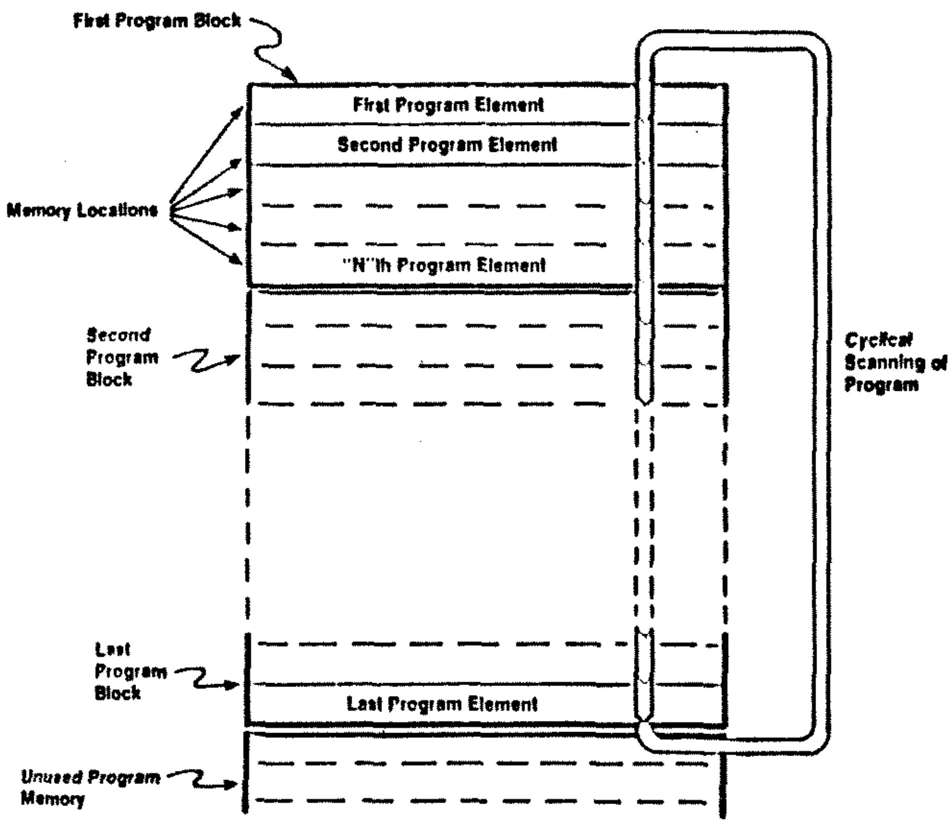


Fig. 9

5. Program Scanning Process - The scanning process is one unique feature of a PC compared to a computer. A computer will generally respond to a program by processing input data, executing a reaction, such as a computation, or report, then cease operation until another command is given. The PC continually scans the program to process the control scheme now residing in the program.

In the diagram below, the program is divided into program blocks containing program elements. Multiple program blocks consisting of various groups of logic such as rungs of ladder logic, formulate the program. These groups of logic consist of program elements, which are the internal and external control devices and contacts. (Fig. 10)



How the PC scans its program.

Fig. 10

The scanning process is now expanded to include inputs and outputs. The steps involved in the entire process include the following:

1. Status check of inputs is made.

2. Input status is transferred to image table in memory.

3. The image table is referenced throughout the scan.

4. The scanning cycle proceeds through the program, examining each program block along with the status of timers, counters and internal relays.

5. The status of outputs and internal relays as prescribed by the program is changed or remains the same.

6. The status of outputs is placed in the output status image table.

7. The status of external outputs remains unchanged during the scan.

8. When the last program element is examined, the output status image table is completed.

9. The output image is then transferred to actual outputs. The outputs are energized or de-energized based on the conditions present in the output image table.

10. The program processing is reviewed. If an error has occurred or the "watchdog timer", which is monitoring the scan time, exceeds the prescribed time limit; the PC shuts down and all outputs are de-energized.

11. Once the cycle has been verified as operating correctly it is then repeated.

12. Scan times are typically in the multiple millisecond range. The amount of memory used, which is relative to the program length, will proportionately affect the overall scan time. (Fig. 11 and Fig. 12,13)

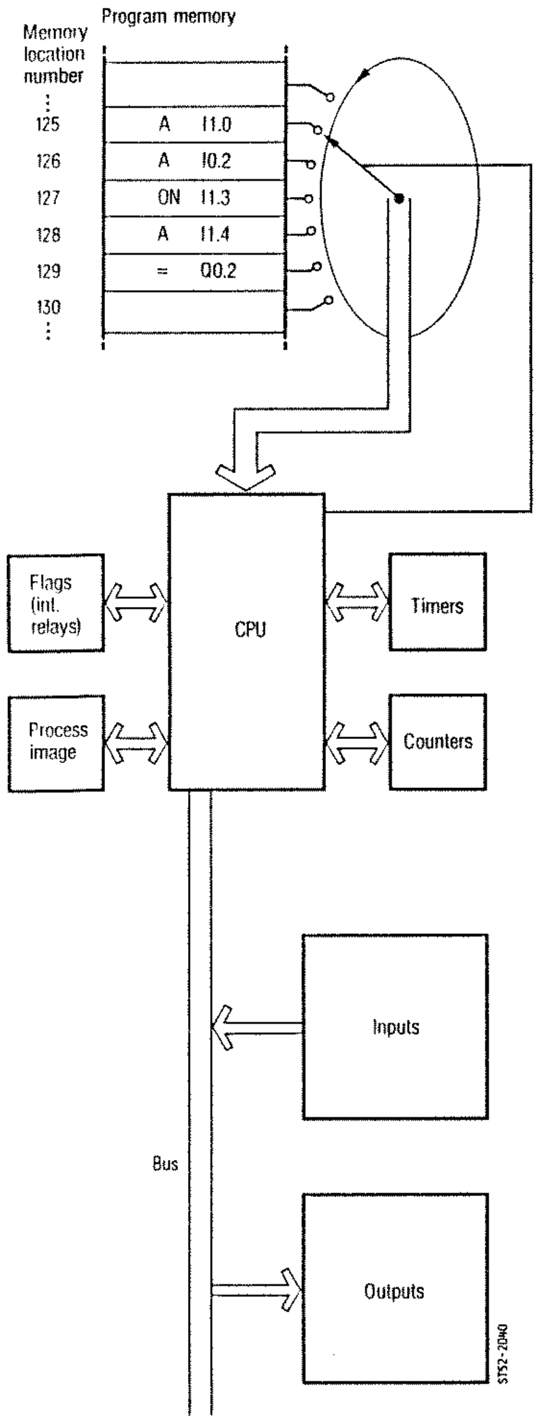
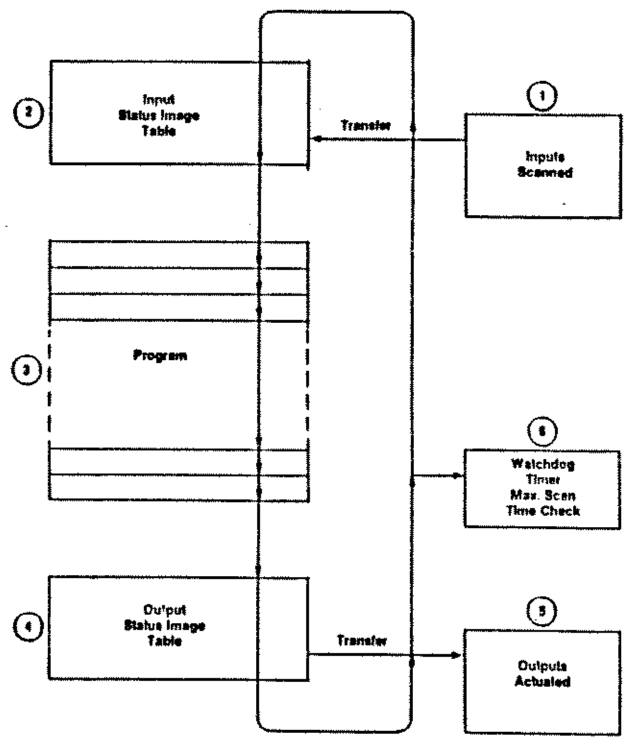
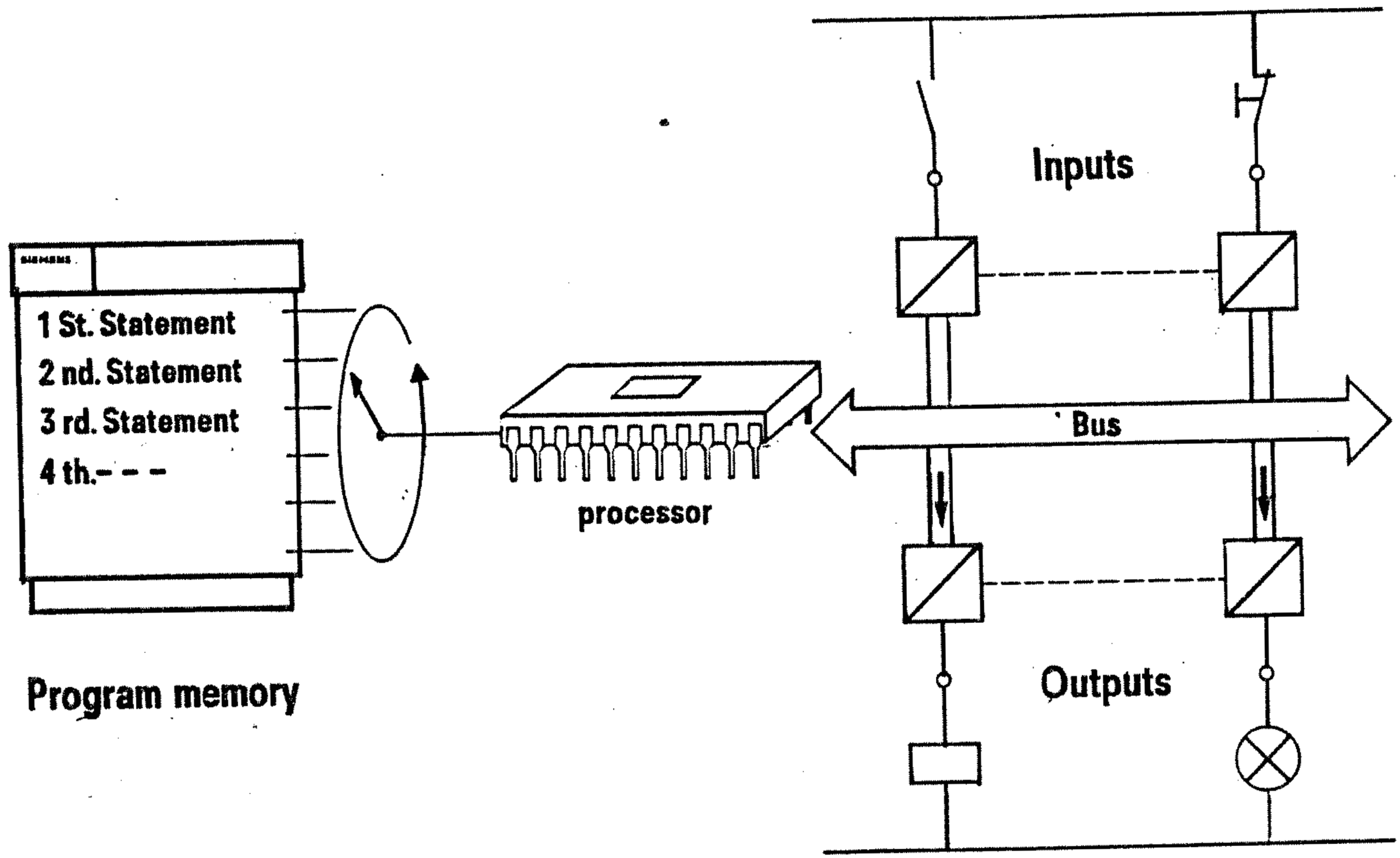


Fig. 11



How the PC scans its I/Os.

Fig. 12



How a Programmable Controller Works

Fig. 13

Features and Benefits of Programmable Controllers

State of the Art Technology - Since a PC like other solid state devices, has no moving mechanical parts to wear out, the life expectancy of a PC is very long. After the initial burn-in period, if the components are still functioning properly, chances are very good that the components will deliver high performance, when incorporated into a PC system.

The history, research and development, and wide spread usage of PCs by industry has led to a product of high reliability and greatly enhanced features.

Quality Control - Today's manufacturing techniques place high emphasis on product quality. Very sophisticated quality control mechanisms are prevalent in today's solid state component manufacturing.

The typical burn-in period for PC modules is 48-72 hours at extreme environmental conditions, such as high temperatures (55^{o}C and above).

These kinds of controls help to assure a product's reliability in the field. Within certain recommended constraints, the PC is designed and therefore tested for operation in "real world" industrial environments.

Modularity - The PC is designed as a modular device which enables the design engineer and installer to take "off the shelf" hardware and apply it to various control requirements. This feature along with the programming aspect enables modules to be grouped into various systems, for various applications.

Along with this, the modularity of the PC allows for ease of trouble-shooting and repair. When a problem is isolated to a particular module, such as an I/O card or Power Supply, the system repair can be accomplished by the excange of the faulty module for a new module.

Due to the mounting and wiring connections involved with a relay panel, the exchange of a faulty relay or timer can take much longer.

Most input and output (I/O) modules offer a wiring connector device to which the external devices are wired. In order to change a module, this connector is removed from the faulty card and connected to the new card. This eliminates having to re-connect each external device to the module and the possibility of incorrect wiring, upon connecting to a new module.

Industrial Rating - The PC, unlike the basic personal computer, has been designed from conception to operate in an industrial environment. Ratings of 0-55°C, 5-95% humidity (non-condensing), noise immunity and transient suppression characteristics built into power supplies and output modules capable of energizing NEMA size 3 and 4 motor starters have become general characteristics of PCs.

Affordability - PC systems today range from very small (16 I/O or less) to very large (30-40,000 I/O or more). As with most solid state or electronic devices, the cost has dropped over the years, based on cost/input or output figures. This has made PC systems cost-effective replacements for small as well as large control systems. For the cost of installing six or eight relays in a panel, a PC can be installed, instead.

The cost per I/O and the standard PC features, such as program flexibility, timers, and counters, make the PC an economical approach to control. Although, it must be remembered that programming time is a consideration and a cost factor in the total system; this can usually be justified in the wiring time saved combined with the flexibility and additional benefits offered with programming.

With many large systems, much of the PC hardware cost can be recuperated in savings associated with reduced panel space and wiring.

Utilizing the remote I/O capability of PCs, which enables the I/O modules to be close to the external devices or mounting the I/O inside a motor control center, for example, has proven to offer savings, particularly in wiring costs, in many instances.

Since PCs are compact compared to electro-mechanical type industrial control devices, space savings can be a very important benefit of a PC system.

PC System Diagnostic Characteristics - Most PC systems have inherent diagnostic features, which assist the maintenance personnel in trouble-shooting and diagnosing problems, as well as, confirming system operation. These features usually are in the form of LED (light emitting diode) indicators associated with each input and output point, on the I/O modules. Along with these, other indicators may be available, such as low battery and internal DC power indication on the power supply and Run/Stop indication on the CPU.

Upon initially energizing most PC systems, an integrity check is made within the system.

This system check may involve a determination of operational functions, such as the processor, power supply and communication channel (bus path) to the I/O modules.

During normal operation, a PC will monitor certain functions, in order to indicate fault conditions. If a fault occurs, various trouble-shooting techniques are available within PC systems to assist maintenance personnel in finding and correcting the problem.

System diagnostics beyond the LED indicators is also inherent in PC systems. Usually in conjunction with the programming unit, the PC can be investigated to assist the maintenance personnel in determining the exact fault. This will include pinpointing certain errors, within the program processing, as well.

Specialized I/O Modules - The expanded capability of certain PC models to include special modules designed to perform certain functions, such as temperature control, valve control, closed-loop control, communication and analog signal input and output; creates many possible uses for PCs. This feature allows many aspects of a particular application to be monitored and/or controlled by a PC. In this manner, the PC can be utilized to control all areas of certain machines or processes.

Process or Machine System Diagnostics - Along with the PCs internal fault diagnostics, as shown by LED indication; the PC system can be utilized to indicate other criteria such as power flow, and to assist in wire tracing to verify proper external device wiring. The status display of inputs, outputs, internal relays, timers, counters and other system parameters, can be displayed, along with messages to indicate operator errors, and other process messages.

This information can be utilized by maintenance personnel in trouble-shooting and repairing the system.

System Monitoring and Data Acquisition - The PC system can be used to monitor and collect process data, as well as perform the control functions. Data can be acquired relative to such areas as; number of motor starts and stops, total process run time, type and time of faults, number of cars crossing a bridge each 24 hour period, number of bridge raising and lowerings each 24 hour period, time of day that signals were operated and gates lowered, current drawn by bridge drive motors and much more.

Report Generation - The PC system cannot only acquire and accumulate process data but also display or record the data for a permanent record or reference. Peripheral equipment, such as printers, chart recorders, and graphic display screens, can record or display the information gathered by the PC. In this manner, engineering and maintenance personnel can have the information that is needed to make equipment repairs, schedule preventive maintenance, and maintain process run time figures,relative to time of day operation, and total operating time.

The math functions associated with PCs enable process analysis to be made, such as trending and statistical analysis. An average daily traffic figure for each 24 hour period could be calculated and printed. The ratio of bridge openings to the number of vehicles crossing the bridge each day could be calculated and printed, as an example.

In general, the PC,with the assistance of a calendar real time clock, which is a feature of certain models, the external sensor devices and data recording equipment can be used to monitor, gather and generate information and reports on a wide variety of areas,pertaining to the process system. This information can be reported as the event occurs, at the end of a period of time, only when a fault condition occurs, or on a continual basis.

Communication - In conjunction with collecting and recording information on a local basis, certain modules enable the PC to communicate over a long distance via telephone lines or radio link. The PC can be programmed to transmit the acquired information over telephone lines to a remote station. Depending on the modem module and type of PC, various kinds and amounts of information can be transmitted and received by the PC system.

These modem interfaces can allow information to be acquired about the system hundreds of miles away. They also offer the potential for input of data and making program changes to the PC from a long distance.

Conclusion

The features and benefits, including the basic design and manufacture, of programmable controllers make this product a very useful device for bridge control. Characteristics,such as: industrial design, modularity, enhanced process functions, diagnostic features, monitoring and report generation capabilities, ability to interface with external standard bridge input and output devices, cost; also, the ability to display messages for operator information or acknowledgement or fault analysis, system flexibility through programming, non-volatile memory, and more enable the programmable controller to be effectively applied to bridge operations.

The size, modularity and ease of wiring make PCs a particularly useful product for bridge rehabilitation projects where space and re-wiring costs can be at a premium.

Other aspects relative to bridge control and design, both from the engineering and operational aspect, are the various programming languages and control scheme representations that are available. An example of this is the graphic representation of sequence control.

The step to step operation of a bridge can be easily and directly represented in this manner. Certain external I/O devices relative to a bridge are traffic lights, gates, bells, horns, span drive motors and lock motors, operator console devices and display or annuciator devices, such as pilot lights or an alphanumeric display. The bridge operation involves the operational sequencing of these devices, based upon prescribed conditions being true, before the next step is taken.

The graphic sequencing approach to programming will allow the step by step sequence of operation to be represented, as a control scheme in an easy to understand format. In this manner, the thought process for programming can match the way a user normally thinks about the process.

Special conditions can be established, as a prerequisite for each step. These are the same conditions that are normally met prior to such actions as raising or lowering the bridge or traffic gates.

Each step or sequence block and each transition is defined by program elements in an appropriate programming language, such as a control system flowchart.

An example of this would be the conditions requiring the traffic gates to be lowered, the traffic signals operating properly and the brakes released or in a true condition prior to the bridge being raised. (Fig. 14)

The traffic lights illuminated yellow could be a step block, while the energizing of external devices controlling the lights could represent the transition prior to that step block. The entire bridge operation process can be represented in this manner.

Along with the sequence representation, the process can be monitored for status indication of each step or transition and can be used to analyze a fault and indicate its location within the sequence. Time limits can also be entered in each step which can cause an error message, if the time allowed for a step is exceeded.

Sequence conditions can be organized in series or parallel arrangements to allow for and - or conditional statements, such as two limit switches having to close in order to initiate an event or having switch A or switch B initiate the event. (Fig. 15 and Fig. 16)

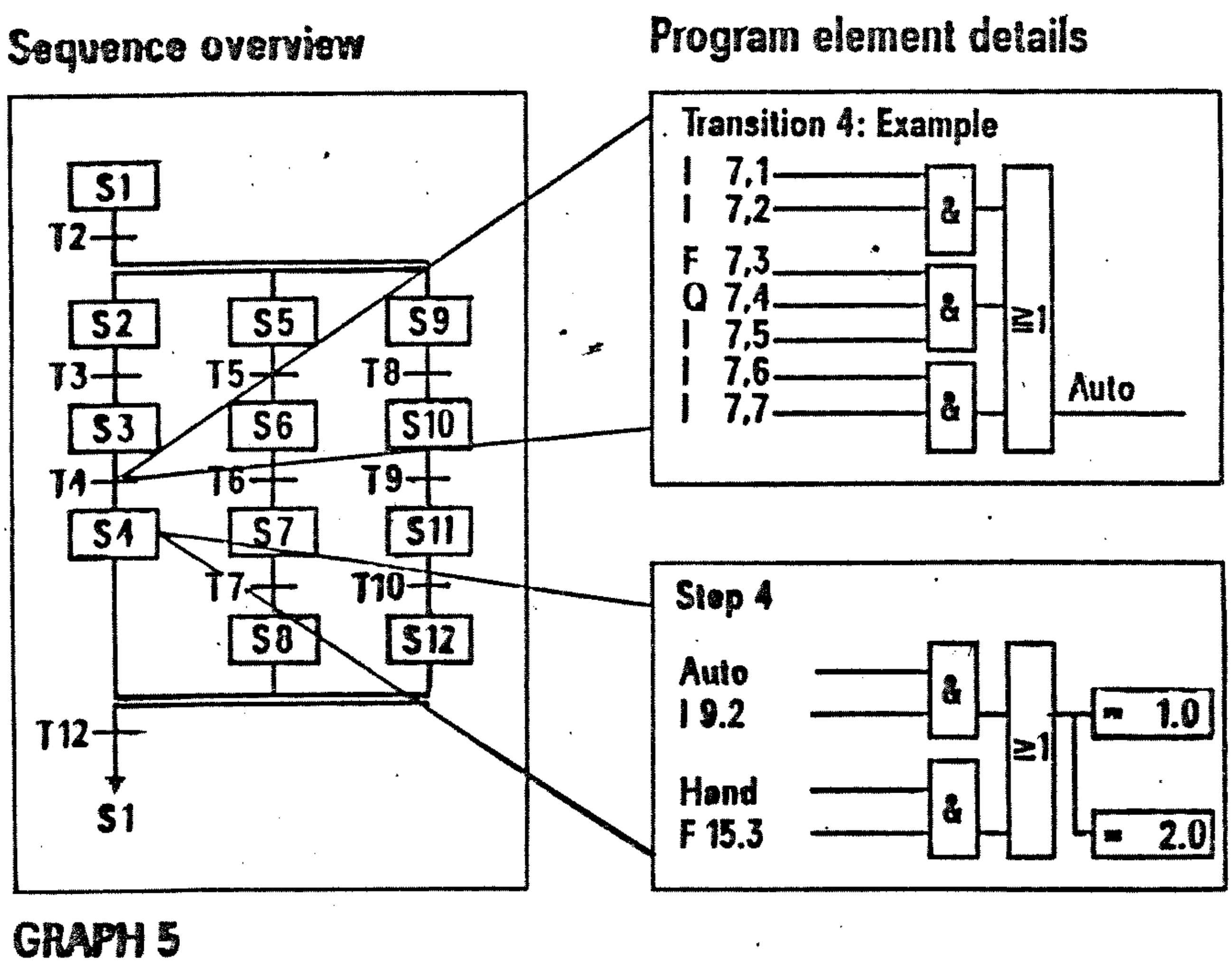
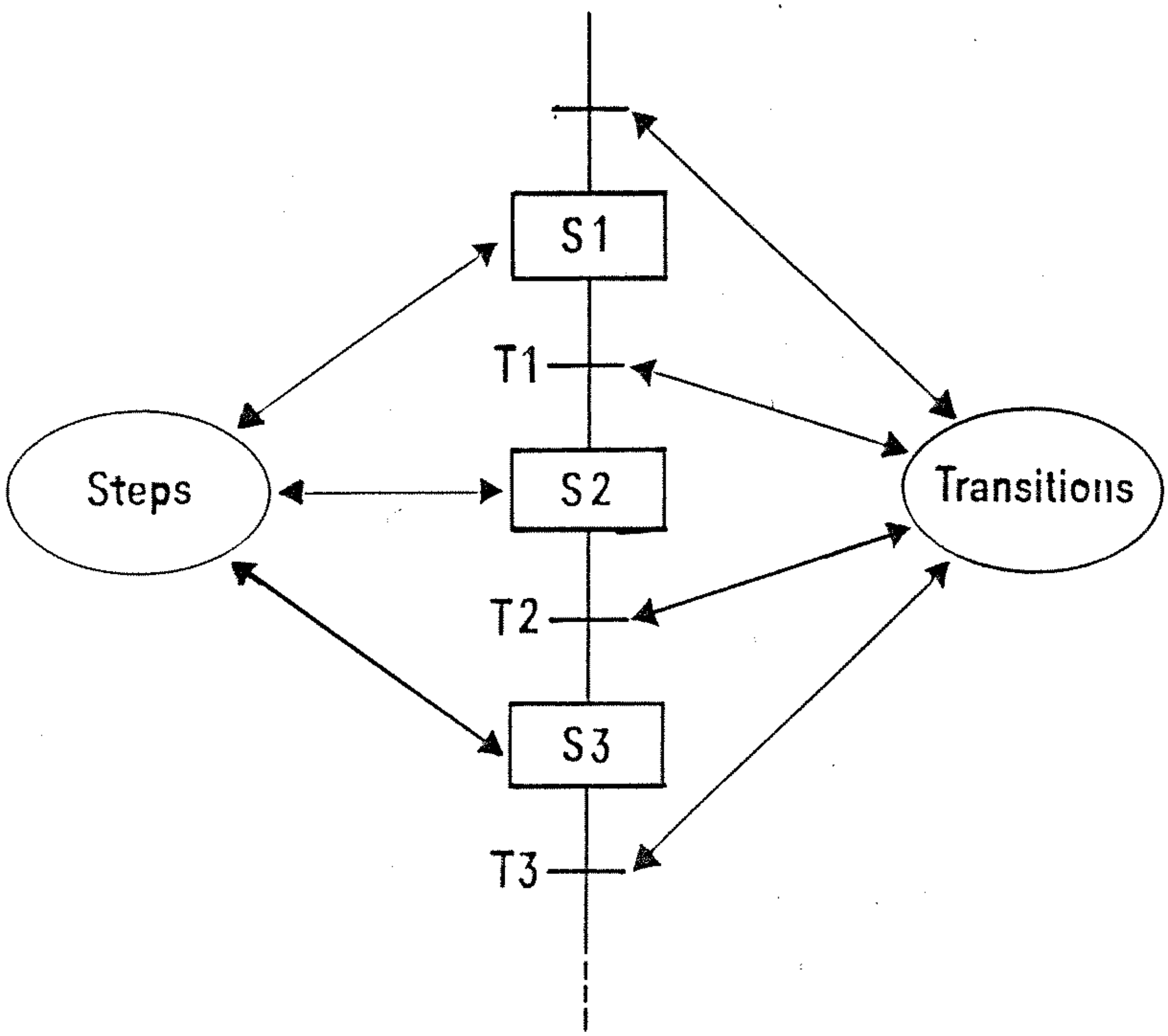
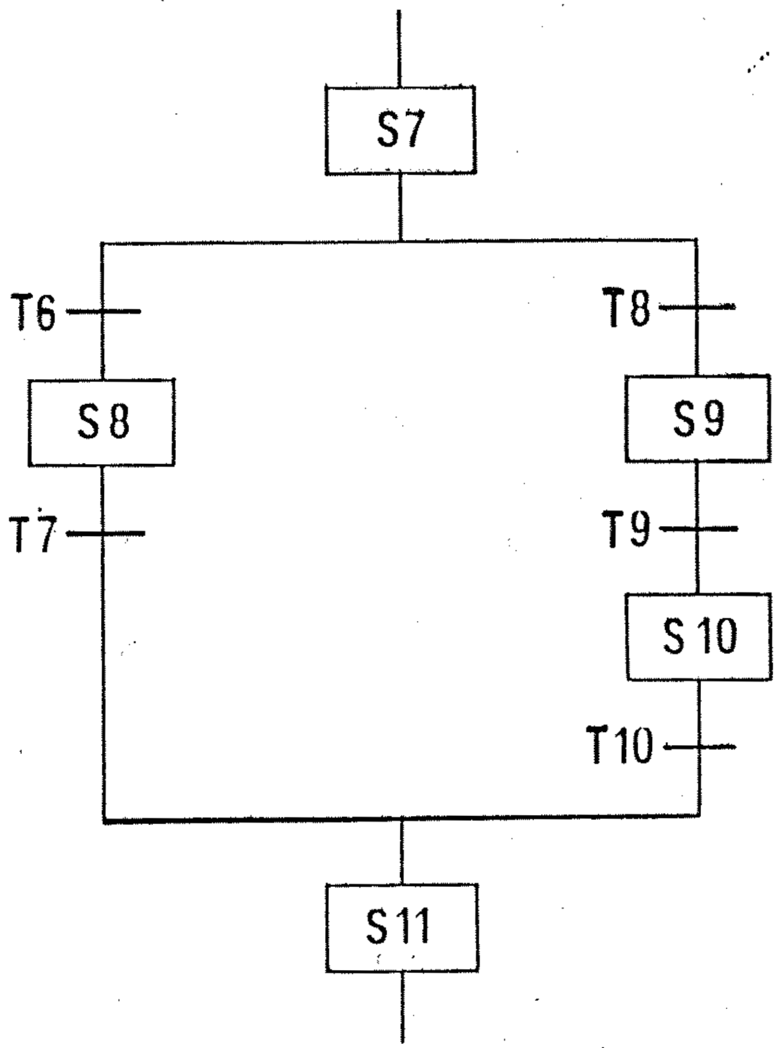

Sequence overview
Program element details
S1
T2
S2
S5
S9
T3
T5
T8
S3
S6
S10
T4
T6
T9
S4
S7
S11
T7
T10
S8
S12
T12
S1
Transition 4: Example
I 7,1
I 7,2
F 7,3
Q 7,4
I 7,5
I 7,6
I 7,7
&
≥1
Auto
Step 4
Auto
I 9.2
Hand
F 15.3
= 1.0
= 2.0
GRAPH 5

Fig. 14



Graph 5
Linear sequence of steps and transitions

Fig. 15



Switch Sequence —
S11 is conditional on completion of either path.

Graph 5
Alternative branch

Fig. 16

Documentation can also be added to the sequence representation. Each block and transition can be defined as to what the block represents and the action that should be taking place. This can be in the form of a few words or a few sentences. This information can appear on a CRT screen and/or a hardcopy printout. (Fig 17)

Although each part of the entire bridge control process must be evaluated relative to automated control, the characteristics of programmable controllers offers many features and benefits for bridge control. The extent to which PCs are utilized for bridge control must be determined, by those responsible for design, construction and maintenance of the bridge. However, programmable controllers certainly have attributes that, when properly applied, can benefit the operation and monitoring of bascule bridges.

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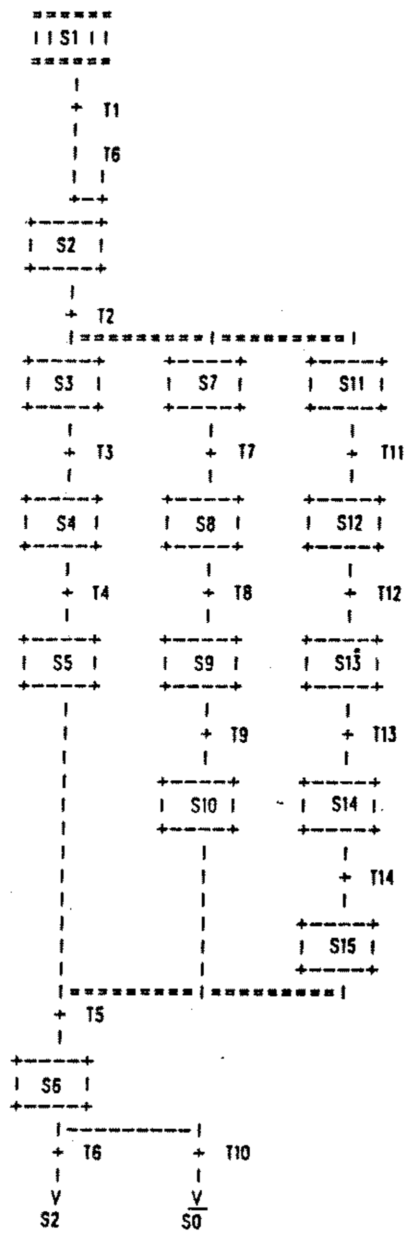

S1: LOAD BLANK

T1: ENABLE AUTOMATIC OPERATION

S2: 1/3 ROTATION

T2: END OF ROTATION

S3: REMOVE PART
S7: FAST LOWER
S11: FAST LOWER
T3: PART REMOVED
T7: MACHINING POSITION REACHED
T11: MACHINING POSITION REACHED
S4: LOAD PART
S8: DRILL
S12: TAP
T4: PART MOUNTED
T8: LOWER POSITION REACHED
T12: LOWER POSITION REACHED
S5: CONCLUDE
S9: FAST TRAVEL
S13: ROTATION IN OPP. DIRECTION

T9: TRAVEL FINISHED
T13: DRILL OUT OF THREAD

S10: DRILLING SEQUENCE OVER
S14: FAST TRAVEL

T14: TRAVEL FINISHED

S15: ENABLE TAPPING
T5: LOGICAL =1

S6: BLANK STEP

T6: AUTOMATIC OPERATION
T10: "END OF CONTROL SEQUENCE"

Graphics representation of a sequential control

Fig. 17

SIEMENS