AN AUTOMATIC CONTROL SYSTEM FOR A
MANUFACTURING PROCESS IN AN EXPLOSIVE
ENVIRONMENT

D. O. Page and C. F. Draut

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Miamisburg, Ohio
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MONSANTO RESEARCH CORPORATION
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D. O. Page and C. F. Draut

Monsanto Research Corporation
Mound Laboratory*
Miamisburg, Ohio 45342

ABSTRACT

The authors describe a state-of-the-art automatic control system as it is used to control a manufacturing process in an explosive environment. Compact, explosion proof sensing devices and a custom designed interface to a controller input are discussed.

INTRODUCTION

An automatic control system was designed and installed in Mound Laboratory's pellet production area; it incorporated Digital Equipment Corporation's PDP-14 Industrial, Solid State, Programmable Controller. This type of control allowed the use of sophisticated control circuits with a minimum of installation time and material. The automatic control system produced a minimum production cycle time, limited only by optimum pellet pressing speed and optimum part movement speed.

The process equipment to be controlled was located in an explosive area and, therefore, required all electrical equipment to be "explosion proofed" (EP). EP equipment is normally expensive and quite often is too large to be accommodated in the controlled process. Some EP techniques were employed in this system which avoided many of the undesirable features of conventional explosion proofing. The PDP-14 was installed remotely in a non-hazardous area.

The PDP-14 Programmable Controller is similar to a computer in that it executes instructions sequentially and has a programmed memory. It has an operating speed of from 15 to 20 msecs. per 1K of memory. Its memory is of the hard-wired, "read-only" type, which cannot be altered electrically. This is a very desirable feature for reliable control in an electrically noisy, industrial atmosphere. The PDP-14 Controller is designed for modular expansion and thus will accommodate both large and small installations. The installation of the PDP-14 based control system consisted of wiring all inputs directly into an "input box" and all outputs directly into an "output box." Sophisticated automatic control was accomplished through programming.

Although the comparatively small size of this installation in terms of controller inputs and outputs may not have justified PDP-14 control, the planned future addition of similar systems, under control of this same PDP-14, more than justifies its use. From another viewpoint, the required sophisticated control, which is attainable with a PDP-14 at no additional cost, may have justified its use with only the original installation under its control.

DESCRIPTION OF CONTROLLED EQUIPMENT

The process equipment to be controlled consisted basically of a mechanical press to compact pellets from a high explosive powder and an air gage for measuring the pellet thickness. Both of these units were located in an explosive environment. The process was controlled by Digital Equipment Corporation's PDP-14 Programmable Solid State Controller which was located remotely in a non-hazardous area. The

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basic construction of the press included a method for accurately filling the die cavity with a predetermined amount of loose powder from which a pellet was formed.

An air operated, mechanical parts handling system was retrofit to the press (Fig. 1). It consisted of double-acting air cylinders and vacuum pick-up heads as well as a vacuum system for cleaning the die cavity. The mechanism positions a preformed insert into the die cavity, and removes the finished pellet. An air-operated clutch, which operates in a fail-safe manner, was installed on the press to provide a means for positively controlling the press cycle.

A second parts handling system was retrofit to the air gage which measures pellet thickness (Fig. 2). It consisted of double-acting air cylinders and fiber optic sensors for determining pellet presence. The system accomplished gating of the pellets through the gage, movement of the gaging transducer against a pellet, and operation of an accept-reject gate.

Fig. 1. Press Parts Handling Mechanism.
Fig. 2. Gage Parts Handling Mechanism.
OUTLINE OF PROCESS SEQUENCES

Press

A pictorial view of the air-operated, mechanical parts handling system that was retrofit to the press is shown in Fig. 3. The process sequence of the press is as follows:

Step 1. AC-1 extends, placing vacuum head #2 over the cavity.
   AC-3 extends, sliding a preformed insert from the magazine to the pick-up position.
Step 2. AC-2 lowers vacuum head #2 on finished pellet.
   AC-4 lowers vacuum head #1 on prepositioned preformed insert.
Step 3. VAC-2 activates, clamping pellet.
   VAC-1 activates, engaging preformed insert.
Step 4. AC-2 retracts, lifting pellet from cavity.
   AC-4 retracts, lifting preformed insert from pick-up position.
Step 5. AC-1 retracts, placing pellet over ejection chute.
   AC-3 extends, cleaning the cavity with a sweeper vacuum and placing the preformed insert over the cavity.
Step 6. AC-2 lowers pellet into ejection chute.
Step 7. AC-4 lowers preformed insert into cavity.
   VAC-2 deactivates, releasing pellet in ejection chute.
Step 8. VAC-1 deactivates, releasing preformed insert.
   AC-2 retracts
Step 9. AC-4 retracts
Step 10. AC-5 retracts
Step 11. Air clutch is activated starting press cycle. (Press cycle includes filling the cavity with powder and pressing the pellet.)
Step 12. Repeat 1, starting the next pellet producing cycle.

Fig. 3. Metal Insert Loading And Pellet Removal Mechanism
A pictorial view of the parts handling system that was retrofit to the air gage is shown in Fig. 4. The process sequence in following a pellet through this system is as follows:

Step 1. Pellet arrives at first gage station after sliding down ejection chute.

Step 2. Sensor 1 detects the pellets presence and AC-6 retracts, allowing pellet to slide into pre-gage station.

Step 3. Sensor 2 detects the pellets presence and AC-6 extends, segregating this pellet from any others in line.

Step 4. AC-7 retracts, allowing pellet to slide into gaging station.

Step 5. Sensor 3 detects the pellet's presence and AC-7 extends.

Step 6. AC-8 extends, lowering air transducer into contact with pellet, thus gaging its thickness.

Step 7. AC-8 retracts after preset gaging time.

Step 8. AC-9 retracts, allowing pellet to slide out of gaging station.

Step 9. Depending upon results of gaging, AC-10 will either extend or retract, gating pellet into accept or reject channels.

Step 10. When pellet slides past sensor 5 (accept sensor) or sensor 4 (reject sensor), AC-9 extends.

Step 11. This completes the sequence for one pellet through the gage parts handling system. It should be noted that all stations can handle pellets simultaneously, permitting minimum delay in processing.

Fig. 4. Pellet Gage Mechanism.
COMPACT, EP LIMIT SWITCHES

The environment in which the controlled process was located was defined as Class II, Group G, Division 1, a National Electric Code rating. This rating presented many problems concerning electrical equipment in hazardous areas.

Since the "closed-loop" control technique requires verification that a command has been carried out as well as issuing the command, it was necessary to monitor the position of all air cylinders. The comparatively small size of the parts handling systems prohibited the use of conventional explosion-proof limit switches; and micro-switches, although probably small enough, did not satisfy the EP requirement. An air cylinder manufacturer offered air cylinders, depicted in Fig. 5, with built-in "reed" type limit switches which were operated by the magnetic pistons of the cylinders and were infinitely adjustable over the entire stroke of the air cylinder. The switches were hermetically sealed in glass tubes which in turn were encased in aluminum housings. Two of these switches, installed on an air cylinder, effectively provided the sensing required for closed-loop control and did so with a minimum of clutter on the tooling.

A LIMIT SWITCH TO CONTROLLER INTERFACE

Although the "reed" type limit switches were hermetically sealed and further protected with an aluminum housing, they still did not meet the Class II, Group G requirements for electrical equipment in hazardous areas. To accomplish this, an exceptionally low control power level of approximately 16 milliwatts was selected for use in all "reed" type limit switch circuits. This low power level, 16 milliwatts, was well below the accepted limit of intrinsically safe operation.

To complete this "intrinsically safe" limit switch circuit, an interface, as shown in Fig. 6, was designed to couple the limit switches with the input to the PDP-14 Controller. The interface converted the limit switch signal from approximately 4 V d.c. to 110 V a.c., as required by the PDP-14 Controller, while positively preventing any unsafe voltages from appearing in the explosive area. This isolation was accomplished by use of an approved circuit called a "Redding Barrier". The "Redding Barrier" uses series resistors to limit current and Zener diodes to control the voltage level; also, it is fused to protect the Zener diodes. Further isolation was gained by the use of "photo diode" coupling between the safe and unsafe voltage areas and the physical separation of these two areas on the printed board of the interface.

An inherent problem in the use of low power levels in sensing circuits is the susceptibility of that circuit to false triggering due to electrical noise. To combat this, a technique called "digital filtering" was employed to assure that no false signals would be transmitted to the PDP-14 input.
basically, digital filtering requires that a signal pulse be of at least 20 milliseconds duration before it will be accepted as a true signal. Common electrical noise sources, such as 60 cycle a.c. pulses due to collapsing inductive fields and random noise, all normally have pulse durations less than 20 milliseconds and, thus, are rejected.

A cable, consisting of individually shielded pairs of wire, was used to connect the limit switches to the input of the interface. The shields were then grounded to one common point. This technique gave further assurance of no false signal inputs to the PDP-14 Controller.

The fact that the "reed" type limit switches were hermetically sealed and operated at extremely low power levels prevented oxidation and corrosion of the limit switch contacts and eliminated all the problems associated therewith.

USE OF SOLENOID VALVES AND VACUUM SWITCHES

The air supply to the air cylinders was controlled by three-way, double solenoid, detented valves, as shown in Fig. 7. These valves required only a momentary signal to operate. A PDP-14 programming technique produced electrical signals of minimum duration to all solenoid valves.

The valve that controlled the air clutch on the press was a three-way, single solenoid, nondetented valve. This was selected so that an electrical power failure or a malfunctioning solenoid valve would always cause the press to halt.

Housed in the same cabinet with the valves were two vacuum switches (Fig. 7); these monitored the vacuum on the pick-up heads. If a vacuum head failed to pick up a preformed insert or a pellet, no
Fig. 7. Solenoid Valve Cabinet.

The Nema 12 cabinet, which housed the vacuum switches and solenoid valves, was located in the explosive area and would be detected by the vacuum switches, and the proper signal would not be sent to the PDP-14 Controller input. The process would then stop and the operator would correct the malfunction.

THE AIR PURGE METHOD FOR EP

The vacuum switches and solenoid valves.
thus, required some modification to bring it up to National Electric Code standards for Class II, Group G, hazardous areas. The "air purging" method was selected as most appropriate for the conditions that existed. Air purging is a method in which a higher than ambient pressure inside a cabinet prevents any hazardous material or atmosphere from entering the cabinet because of this pressure differential. A mechanical safety blow-off was installed in the wall of the cabinet for use in the event of excessive pressure.

A pressure switch (Fig. 7), installed inside the cabinet would cut off all electrical power to the cabinet if the positive pressure level dropped below a preset value. A Magnehelic pressure gage was used to monitor the actual cabinet pressure.

EXTERNAL SAFETY CIRCUITS

It was possible through the simultaneous occurrence of two or more electronic and/or mechanical malfunctions, the parts handling mechanisms could be damaged by the press punch. The "preformed insert positioning" and "pellet removal" mechanisms were both, at different times, under the press punch and, therefore, were subject to damage in the event of failures. An additional magnetically operated "reed" type switch was installed on the appropriate air cylinders which indicated when these mechanisms were under the press punch. By means of a circuit completely separate from the PDP-14 Controller, these switches would inactivate the solenoid valve which controls the press cycle whenever either mechanism is under the press punch. A similarly designed circuit was incorporated to prevent the "preformed insert positioning" or "pellet removal" mechanisms from being activated whenever the press cycle was in progress. With the installation of these safety circuits, any chance of collision between the parts handling mechanisms and the press punch was eliminated.

THE PDP-14 CONTROLLER

The PDP-14 Controller operates similarly to a computer in that it executes a program of instructions sequentially. It has a hard-wired, read-only memory in which the program is stored, and which cannot be altered electrically. This is a very desirable feature in an electrically noisy, industrial environment. A control program is a collection of control equations which are solved in a period of milliseconds. Every output device such as a solenoid valve, a motor, a pilot lamp, etc. has its own individual equation which states under what conditions that output device will be energized. These equations are written in Boolean symbology and are composed of any input and/or output. The versatility of this type of control is tremendous and a high degree of sophistication can be obtained at no additional cost.

The PDP-14 has complete software for both control programming and diagnostic trouble shooting. There is a software program which will convert the Boolean equations, which were written in symbolic form, into terms of inputs and outputs. Another program will convert that form into actual twelve bit, binary instructions which are used to make the ROM (read-only-memory). Other software programs are used for locating trouble in the central processor, the input and output boxes, and the ROM. Another program can be used to simulate the actual controlled process, when debugging a new control program, so that many start-up problems can be avoided. All software requires the use of a mini-computer.

SUMMARY

An automatic control system incorporating a PDP-14 Programmable Controller was designed and installed in an explosive pellet production area. The PDP-14 was installed remotely in a non-hazardous area. The Programmable Controller utilized here is one of several state-of-the-art controllers that operates similarly to a computer in that it executes a program of instructions in a sequential manner. The many advantages gained from using this type of automatic control more than offset the problems arising from the use of electrical equipment in hazardous areas. To minimize these problems, some new techniques were used for adapting electrical equipment to a hazardous environment.