A Hierarchical Programmable Controller System for Batch Material Handling

WARD A. GARRABRANT

Abstract—**From 1977 to 1979 PPG Industries, Inc. reworked the batch material handling systems in both of its fiber glass manufacturing plants in North Carolina. In December, 1976, PPG decided to use programmable controllers to handle the control system logic. The original control systems were handled by a GE-PAC Model 4020 process computer. The resulting control system is a multilevel hierarchical system using the process computer, a master programmable controller, 17 discrete-function programmable controllers, and analog scale control logic. The batch handling system, the programmable controllers, and the control hierarchy are described. Some of the decisions made in system design, controller selection, and problems encountered are discussed.**

INTRODUCTION

FIBER GLASS batch is a mixture of powdered ores and chemicals which have the consistency of talcum powder, unlike most other glass batch, which may contain cullet or added water. The raw ingredients are carefully weighed, mixed, and transported to holding bins at each furnace. From the furnace bins, the batch is fed continuously into the furnaces.

During the period from 1977 to 1979, PPG Industries reworked the batch material handling systems at both of its fiber glass manufacturing plants in North Carolina. Because both of these plants were in operation, an uninterrupted supply of batch was required during the installation period since fiber glass furnaces, like other glass furnaces, run for several years without shutdown. To insure a continuous supply of mixed batch, the new system had to be installed in segments, and the controls for the new equipment had to be segmented so that the new equipment could be placed in operation as each part was installed. In addition, after installation was completed, the system was to have a fully automatic control system which would function without an operator in attendance.

To meet these objectives, a distributed, hierarchical control system was designed which could be activated incrementally as the components of the new system were installed. This distributed system now consists of more than 20 functionally distributed programmable controllers housed within the semiautomatic control panels. In addition, a supervisory programmable controller coordinates the activities of all of the distributed controllers and also performs direct control of the batch system. To complete the automatic system, a process computer performs monitoring, alarming, and logging functions.

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The author was with PPG Industries, Inc., Lexington, NC. He is now with Hercules, Inc., P. O. Box 271, Hopewell, VA 23860.

The overall system is composed of the following five subsystems and components:

1) scale subsystem with programmable controllers,
2) mixer subsystem with programmable controllers,
3) mixed batch transport subsystem with programmable controllers,
4) redundant supervisory programmable controller,
5) process computer monitor.

Each of the three subsystems can operate independently in a semiautomatic control mode from a central control room with graphic operator's panels. The supervisory programmable controller and the process computer interface through the graphic panels and can operate the entire system automatically, replacing two operators.

SUBSYSTEMS AND COMPONENTS

Scale Subsystem

The scale subsystem consists of an independent scale for each of the batch raw materials. Each scale has an analog weigh controller and a programmable sequence controller and can weigh a variety of different formulas.

The operation of all scales is controlled in semiautomatic and in automatic by a master programmable controller which acts as an interface between the scales, the panel controls, and the supervisory programmable controller. There is an additional programmable controller in the scale panel which sequences a local printer for the batch material weights.

Mixer Subsystem

After weighing, the batch is dumped into one of the mixers, which homogenizes the ingredients for a predetermined time into a mixed batch. Once thoroughly mixed, the batch is transported to one of several furnace holding bins on an as-needed basis.

Transport Subsystem

There are multiple mixers, several holding bins, and several furnaces. The system was designed so that mixed batch can be transported from any mixer to any of the holding bins and from any of the holding bins to any furnace, resulting in a multiplicity of possible routes a given batch could take. This imposes severe interlocking requirements on the automatic transport controller. This constraint is made critical by the fact that the different formulas cannot be mixed in the same furnace. Consequently, the formula weighed and mixed depends upon the furnace to which it ultimately will go.

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Supervisory Programmable Controller

In full automatic mode, the operation of all of the distributed semiautomatic functions is coordinated by a single programmable controller. The supervisory programmable controller has 328 inputs and outputs and uses 13 000 words of memory, including the executive. The batch control program uses 44 software timers but no counters or shift registers. Because of the complex nature of the interlocks in the transport system, the need for flexibility of formula assignments to the furnaces, and the need for a first-in, first-out priority scheme, the supervisory controller was chosen on a basis of having the most flexible programming language available at the time. The bulk of the programming is done in a Boolean-type control language with 750 words of special assembler language subroutines. The program makes extensive use of subroutine calls. Because of the importance of its role, the supervisory controller has a redundant standby backup processor and power supply. In the event of processor failure, the I/O cables can be switched and the backup processor put on line in a few minutes.

To facilitate installation of the system, the supervisory programmable controller was chosen with remote I/O terminations. The I/O termination assemblies were shipped to the subsystem vendors before the control panels were built and were wired into the panels as they were assembled. The procedure made installation of the programmable controller I/O a matter of a few plug-connected cables, significantly reducing installation time and minimizing chances of field wiring problems.

The programming facilities for this controller allow operation of the controller with dummy inputs and outputs, which permits an off-line test and modification of the control program while the control panels for the system are still being assembled at the factory. This is another time-saving feature of the programmable controller.

Process Computer Monitor

To complete the system, the scale and transport subsystems are monitored by a process computer. The process computer performs all monitor, alarm, and logging functions for the systems. The process computer is interfaced to the supervisory controller for logging control alarms. It monitors and logs the weights of each batch and the number of batches weighed and transported to each of the furnaces. The process computer is not dedicated to the batch system, so care was taken to isolate batch inputs and outputs to protect the remainder of the system security.

HIERARCHICAL CONTROL STRUCTURE

Fig. 1 shows the interconnection of the distributed system. At the lowest level of control are the individual scale, mixer, and transporter programmable controllers. These controllers perform relay-replacement functions. Once activated, a controller will control a small sequence of operation, stop, and report back completion of that sequence to the next level of control. Each programmable controller is dedicated to a very small segment of the process as a whole. A programmable controller is dedicated to each of the scales in the weigh system, each of the mixers in the mixing subsystem, and each of the transporters in the transport subsystem. Because each of the first-level distributed programmable controllers is dedicated to a small segment of the process, the failure of any single programmable controller will not prevent weigh and delivery of the batch to the furnaces.

At the second level of control in the scale system, there are two programmable controllers (PC's), a scale master PC which coordinates the individual scales and interfaces to the control panel and to the supervisory programmable controller, and a printer PC which drives the local printer to log the weights of all ingredients in each batch. The local print function is suppressed when the process computer is monitoring and logging the batches.

At the third level are the operator control panels which are used as a manual backup when the system cannot run in full automatic because of installation, modification, maintenance, or supervisory controller failure. Within these panels are all of the interface field wiring for the supervisory programmable controller.

At the top level of the system are the supervisory programmable controller, which performs full automatic sequence control for weigh, mix, and transport, and the process computer, which performs the logging functions. So that some data logging can be done without the supervisory programmable controller, a limited number of direct interfaces exists between the process computer and the control panels. The process computer performs no control functions but does have supervisory capability to place the scale system on hold when data are out of tolerance.

Distributed systems, in general, can be functionally distributed, geographically distributed, or both. In this system, the geographical distribution is of secondary importance; the functional distribution is the principal reason for having a distributed system.

SEQUENCE OF OPERATION

In the sequence of operation, functional control for the process is moved from controller to controller as necessary. At certain times in the process, two or more controllers are functioning simultaneously but independently. To insure that the system keeps the bins satisfied without overfilling them, all control functions hinge on the operation of level detectors in the various bins.

Activation of the level detectors starts the operation of the system. When all of the various bins have been satisfied, the system waits until a level detector indicates a need for batch in one of the bins. When one of the furnace bin level detectors indicates a drop in the batch level, a signal is sent to the supervisory programmable controller.

The supervisory PC runs a delay timer to prevent false requests. At the end of the delay time, the supervisory PC then selects the holding bin which contains the proper batch for the furnace which is running low. It sets up the transport system between the selected holding bin transporter and the low furnace bin and checks the lines to be sure that the setup is correct. It then issues a "start transport" command to the transport system PC for the selected transporter. If an alarm condition occurs such that the supervisory PC cannot set up the transport system properly, it sends a coded alarm to the process computer. The process computer generates and types out

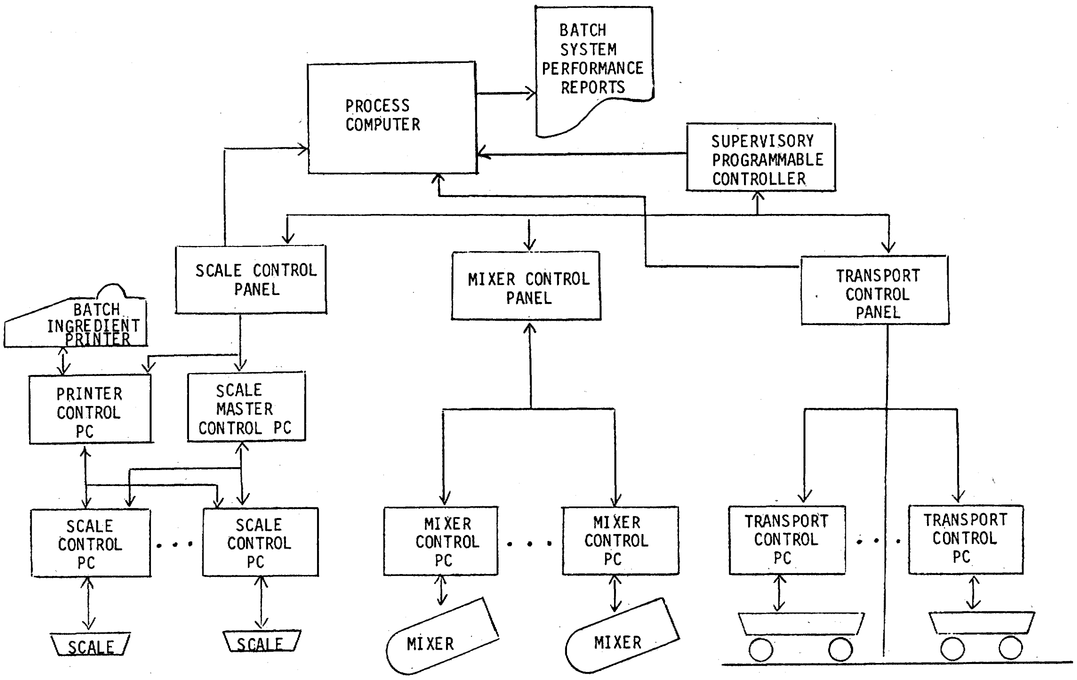

Fig. 1. Batch handling system hierarchical control structure.

the alarm message and alerts the standby batch technician that there is a problem with the system.

The transport PC removes the batch from the holding bin and conveys it to the furnace bin. It sends a contact to the process computer to acknowledge that a transport has been initiated to the desired furnace.

The process computer logs the event and monitors the transport time. In the event that a furnace does not receive batch after a desired interval, it will alarm. It is possible for several furnace bins to be receiving batch simultaneously.

The scale system is activated in a similar manner when one of the holding bin level detectors indicates a drop in batch level. The supervisory PC selects the formula to be weighed for the low bin and sets up the formula on the scale system.

The process computer checks the weight mechanism for the formula set points to insure that they are correct for the low bin. If they are correct, the process computer signals to the supervisory PC which activates the weigh by sending a command to the scale master PC.

The scale master PC sends the proper set point to each of the scale PC's and activates the "start weigh" for each scale PC. The scale PC will control the feeders for the individual scales, weigh the batch, cut off the feeders, and check the set point against the final weight in the scale. When a scale is satisfied properly, a "weigh complete" signal is sent back to the master PC.

When the scale master PC receives a "weigh complete" from all of the scales, it sends a "weigh complete" command to the process computer and to the supervisory PC. The process computer checks the weight on the scales against the set points and returns with a "weigh verified" signal.

The supervisory PC selects a mixer for the batch and sets up the transport system from the mixer to the holding bin. After the mixer and the mixing delivery system have been properly set up and checked, the supervisory PC sends a "discharge" command to the scale master PC.

The scale master PC forwards the command to each of the individual scale PC's. The individual scale PC's discharge their batch ingredients into the mixer, close the discharge gates, and automatically check themselves for empty. As each scale comes back on tare, it signals back to the master PC. When all of the scales have responded to the master PC, it sends an "on tare" signal to the supervisory PC and to the process computer. The process computer checks the scale signals for zero and alarms any off-tare condition. Simultaneously, the supervisory PC sends a signal to the mixer PC to tell it to begin.

The mixer PC mixes the batch ingredients for a predetermined length of time and delivers the batch to the holding bin according to the setup that was made by the supervisory PC. The weigh and mix cycles can occur at the same time transport cycles are occurring.

SIGNIFICANT PROBLEMS

The major difficulty in putting this system together was that of interfacing the programmable controllers to each other and to the process computer. All of the interfaces use digital I/O terminations. Unfortunately, the outputs are designed for low-impedance loads such as lamps, relays, solenoids, or motor starters. They usually are triac devices. The inputs are high-impedance sensors which are activated by the triac leakage current. In some cases it was necessary either to use buffer relays or to add shunt resistors to the input terminations to overcome this problem.

A second difficulty arose in trying to drive latching relays from triac's, as the triac's fire on zero crossover; but latching relays have isolation diodes which clamp the current to half-wave. This also was overcome using shunt resistors to provide the full-cycle ac current. These interface arrangements are shown in Fig. 2.

A certain amount of component failure was experienced at startup, but this mostly was limited to I/O blocks. By far

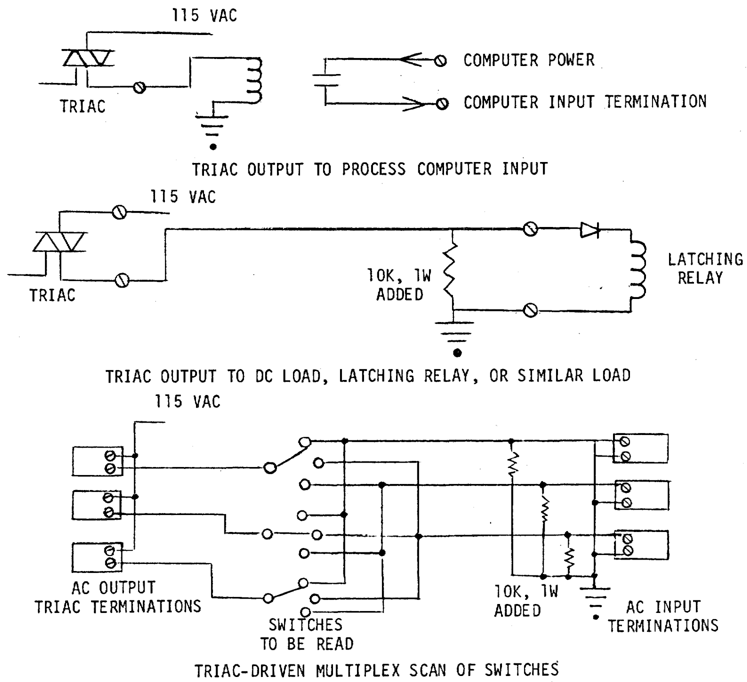

Fig. 2. Special I/O interface wiring.

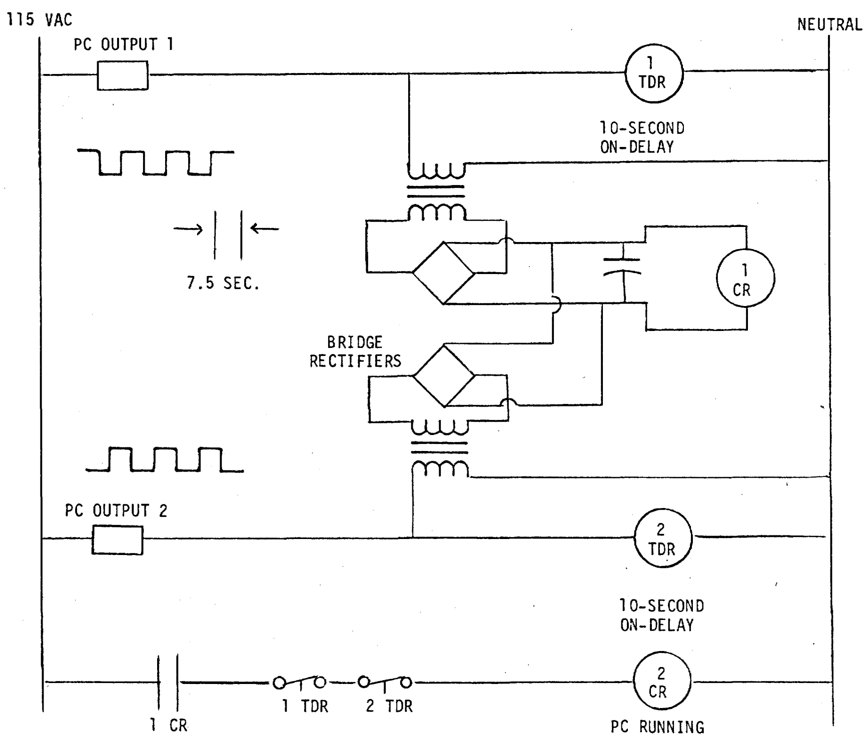

Fig. 3. Watchdog timer detector–circuit 1, two outputs.

most of the ongoing maintenance problems are in the process equipment motors, valves, limit switches, etc. There have been minimal programmable controller problems, which have been largely in the output triac devices and power supplies. Because of the redundant processor, no long-term outage has occurred from processor failure.

FAIL-SAFE INTERLOCK

A characteristic of microprocessor-based programmable controllers is that they can fail with the outputs latched on. As a fail-safe feature, the supervisory controller is programmed with a timed pulse output. The pulse is on for 7.5 s, then is off for 7.5 s. This continuous on-off signal is monitored by two external time-delay relays, so that if it does not switch within the required time duration, power for all of the control outputs is shut off and an alarm is sounded. Figs. 3 and 4 show two of the different "heartbeat" detector circuits used.

SYSTEM RESULTS

With the new batch systems, the scales and transporters have a significant improvement in throughput. Both systems

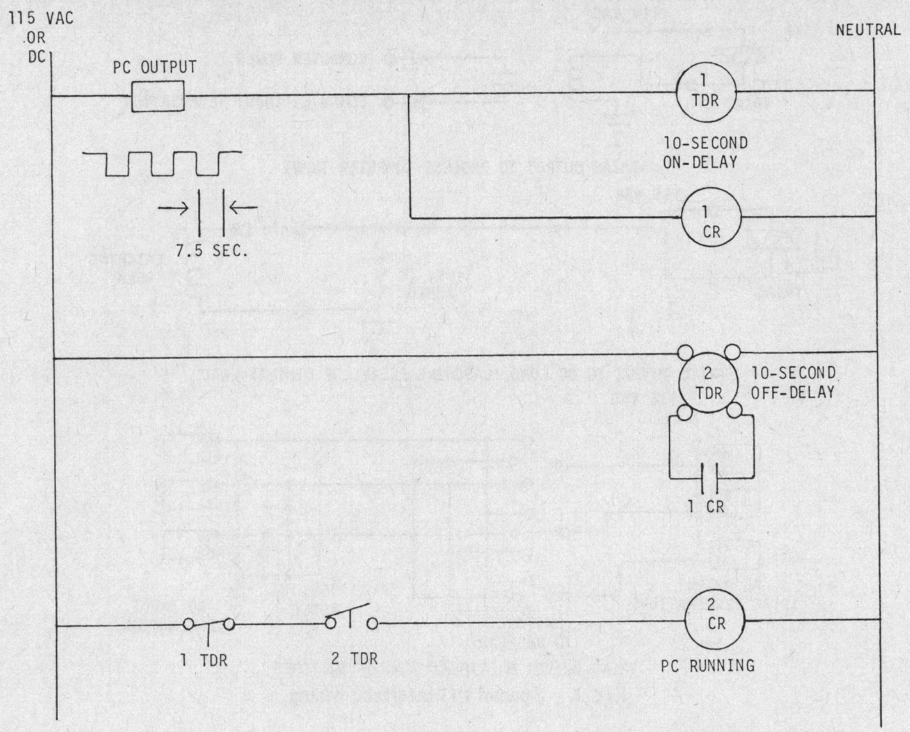

Fig. 4. Watchdog timer detector–circuit 2, one output.

were installed in existing plants with no loss of production due to batch run-out or improperly mixed formulations. The systems at both plants now are functioning in full automatic control, without operators in the batch contol rooms. In the event of a problem with the automatic system, a standby batch operator is alerted in another area of the plant.

The use of a distributed programmable controller system has been completely successful. It enabled controls to be completed before the process hardware installation was complete. The advantages of this type of system are

1) better control than obtainable with relays,
2) faster installation of control logic,
3) ease of system modifications as the segments are installed,
4) distribution of the programming effort. The distributed programmable controllers were programmed by the panel manufacturers while the supervisory controller and process computer were programmed in-house.

As a result of the successful experience obtained with these systems, a distributed and hierarchical structure is found suitable for all complex control systems.

Ward A. Garrabrant received the B.S. and M.S. degrees in electrical engineering from the University of Alabama.

From 1974 to 1981 he was a Process Computer Engineer for PPG Industries Fiberglass Division. He is currently a Process Computer Coordinator for Hercules, Inc., supervising and coordinating the design and startup of digital instrumentation and control systems at the Hopewell, VA, plant.

Mr. Garrabrant is a member of Tau Beta Pi and the Instrument Society of America.