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APPLICATION OF PROGRAMMABLE LOGIC CONTROLLERS TO SPACE SIMULATION

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PART I

MODERNIZATION OF SPACE ENVIRONMENT SIMULATOR AT THE GODDARD SPACE FLIGHT CENTER

As a contractor at GSFC, NSI Technology Services Corporation is involved in operating the Center's Test and Integration facilities, and in planning and implementing modernization projects.

The Space Environment Simulator located at the Goddard Space Flight Center in Greenbelt, Md., is a large chamber designed for system level thermal vacuum testing of spacecraft. It was built in the early 1960's and at that time represented a the state-of-the-art vacuum pumping and control system. It was supported by the following subsystems:

Vacuum pumping system - consisting of 17 large LN_2 trapped, oil diffusion pumps.
Thermal system: LN_2, GN_2 and Helium skids
Solar simulator - capable of projecting one solar constant filtered to a close spectral match of the Sun.
Data acquisition system.
CCTV system.
Voice and data communication.

The vacuum system upgrade included: replacement of seventeen diffusion pumps with eight cryogenic pumps and one turbomolecular pump, replacing a relay based control system, replacing vacuum instrumentation, and upgrading the data acquisition system.

This paper discusses incorporating a state-of-the-art process control and instrumentation system into this complex system for thermal vacuum testing.

The challenge was to connect several independent control systems provided by various vendors to a supervisory computer. This combination will sequentially control and monitor the process, collect the data and transmit it to color a graphic system for subsequent manipulation.

Even though most manufacturers claim to have some sort of computer interface, there is no standard computer interface. Among several types of interfaces were: Binary Coded Decimal (BCD) both at TTL level and low true 30V open collector; analog (5 volts pressure signal, linear on a logarithmic scale, and 0-10 volts linear signal); and RS-232C, RS-422. Equipment was scattered over a large area, and the floor space for the control console was limited.

To accommodate all these essential considerations and to reduce development time, it was decided to select off-the-shelf hardware and software packages. After review and demonstration of several methods, we selected a system compatible with the requirements.

A control device called a Programmable Logic Controller (PLC) was chosen to perform numerous control functions, and to serve as a gateway between multiple control and measurement subprocesses.

Initially developed to replace the use of the electro-mechanical relay, PLCs have gone far past that requirement. Modern PLCs are powerful industrial computers with a broad assortment of highly sophisticated input and output devices and advanced instruction sets.

Among many advantages offered by the PLC are the following:

- PLC-based systems can be easily altered through a programming device to handle changes in the process control requirements without having to rewire relays.
- PLC-based systems are easy to maintain and repair because of plug-in assemblies, and are more reliable in an industrial environment - thus reducing downtime.
- PLCs are also smaller than relay control panels, saving expensive floor space.

Several functions executed by PLC's that cannot be performed by relays are: supplying data to computer-based monitoring and data acquisition systems. Personal computers, loaded with appropriate software and linked to PLCs on the data highway can provide a full graphical operating environment for operators, as well as a programming and applications development capabilities for engineers.

Placing the programmable controller's main processor in the control console and a using a remote input/output (I/O) interface to equipment minimized wire runs and simplified start-up and maintenance.

Proper grouping of remote I/O's allows minimization of single point failure impact on other systems. The grouping of the I/O's allows signal and power lines to be routed properly through the wiring ducts, so that crosstalk interference is substantially reduced.

PLC system architecture for this project was mapped in the following manner:

- Two Central Processing Units (CPU) arranged in redundant configuration to assure a high level of reliability;
- Fourteen remote I/O drops on a single coaxial communication link;

- Two 386-33MHz colorgraphic systems, communicating to both PLC's on the data highway.

Intelligent devices exchange data on the following independent levels:
1. Primary CPU to secondary CPU
2. Primary CPU to remote I/O drops
3. Primary CPU to colorgraphic systems
4. Intelligent field transducers to PLC input modules.

All the communication nodes on the system are distributed among the following physical sites:

Vacuum Console
Field Interface Cabinets
Facility Monitoring Console
Mimic Panel.

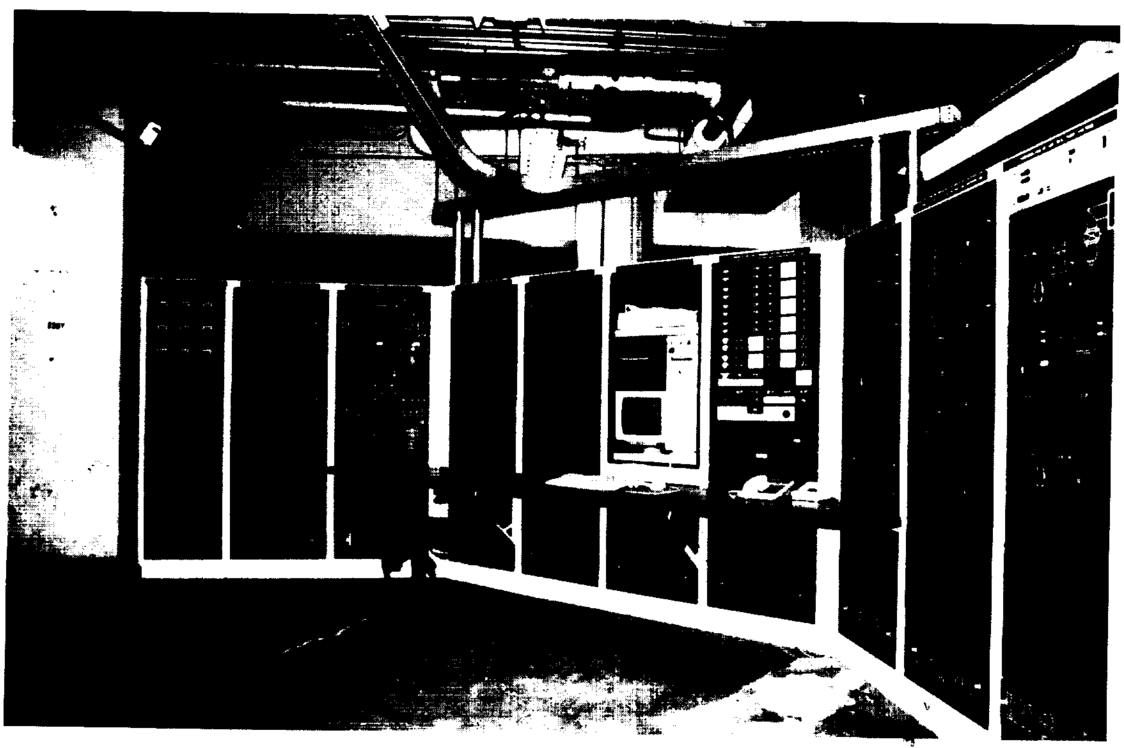

Figure 1: Vacuum Console

Communication Between Primary and Secondary CPU's

In the relay-based control system, a relay failure can take the whole system out of operation. By configuring the PLC system for hot backup communications, shutdowns caused by processor faults are virtually eliminated.

However, a PLC hot backup communication scheme will not guard against shutdowns caused by faults in equipment other than the programmable controller, s.a. power losses, instrumentation faults, etc.

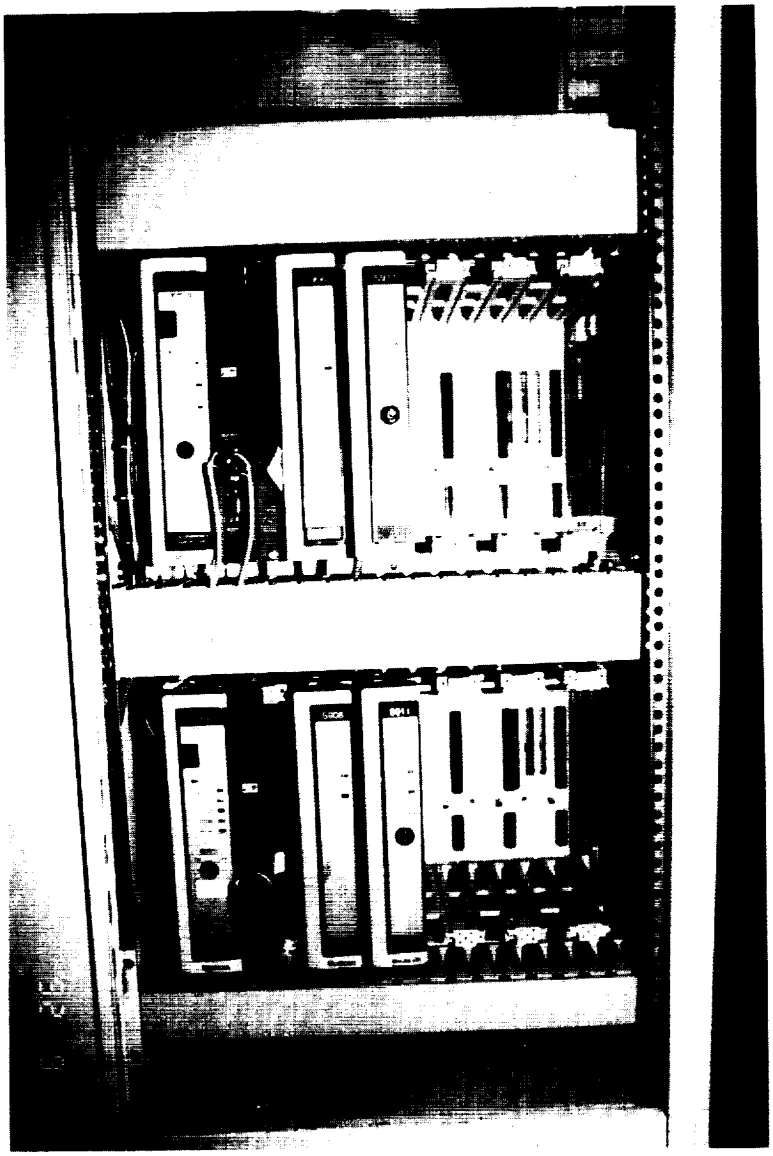

Figure 2: Two CPU's arranged in redundant configuration

The hot backup scheme works as follows: both the primary and backup processors monitor the same inputs; the backup processor takes control quickly (within 40msec) when the primary processor shuts down.

Peer to peer communication between the primary PLC and other equipment on the communication link is set up in the same manner as with a PLC without backup. Both processors have the same station number.

Every PLC switchover is detected and properly reported on the annunciator panel.

The program scans are not synchronized and the switchover, although fast (conservatively estimated, 50 msec) is not instantaneous. Therefore, it is possible that the processors could see different input conditions during a given program scan and the outputs may be assigned different states in the two processors. This can cause a sudden change in operation when switchover occurs.

Possible consequences of such an event are:

-An output controlling pump can switch to the OFF state.
-Any input pulse with a short duration (less than 40 ms) can be missed by the processor.

The probability of such pulses occurring is not great but it has to be considered.

The situation is handled as follows:
Should a pump pause briefly, it will not restart automatically; all vital inputs (such as Emergency Shutdown) are hardwired to interrupt power.

Primary CPU to remote I/O drops

Due to the fact that equipment is widely spread over a large area and pulling a lot of cables to one central location would not be practical, the PLC's inputs/outputs were distributed throughout the lab. A group of cabinets housing I/O modules was strategically placed to collect all the data associated with the process, as well as to control its machinery and equipment. Sequencing of the equipment and coordination of the independent control systems requires the system to communicate with the I/O's.

Figure 3: Field Interface Cabinets

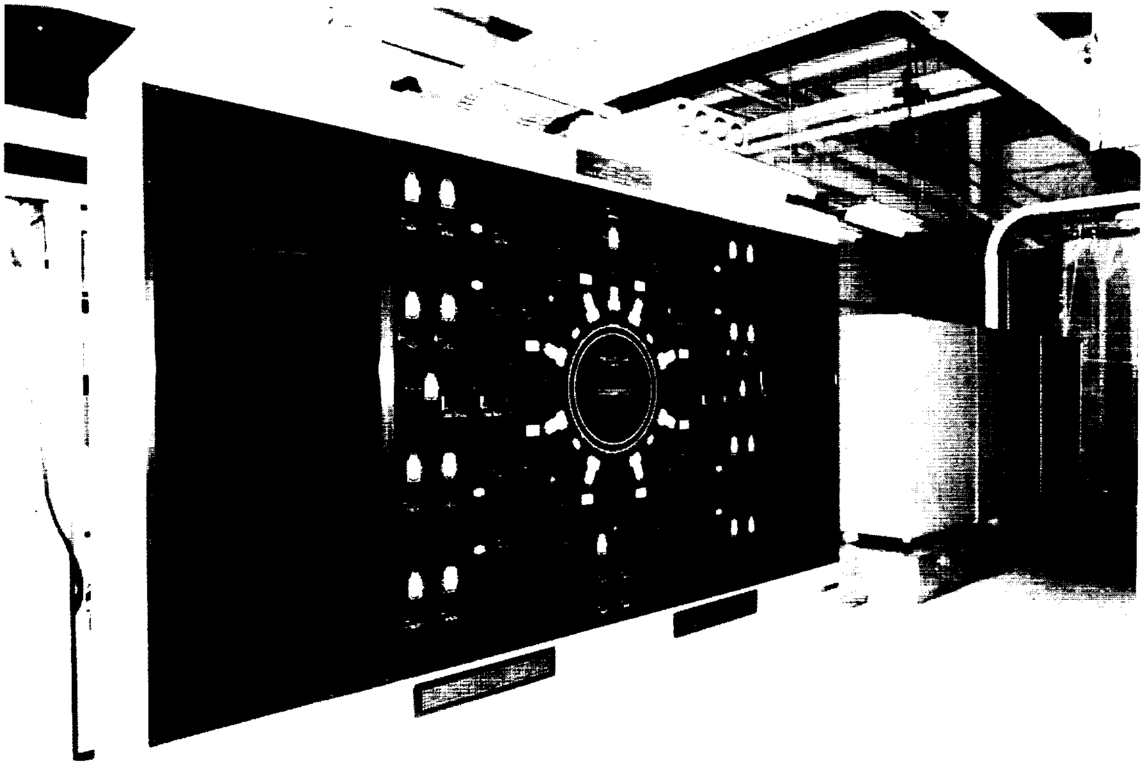

Figure 4: Mimic Board

The mimic board provides a graphical representation of the process as well as information on process status, s.a. pump status, valve position. Digital readouts provide the process variables (pressure & temperature) information.

Primary CPU to colorgraphic systems

One of the desired system features included an effective operator interface with high quality graphics and multiple screen capabilities. To provide this feature two identical colorgraphic systems were utilized for the operator interface. Both monitors display a facility mimic screen for any of several standard configurations selected by the operator. Each display provides a graphical representation of the valves, piping and equipment used for this particular subsystem. The status of the valves (Open/Closed), pumps (On/Off), process variables are dynamically updated. Screen selections in the system are made with a mouse. This simplifies operator learning and eliminates the possibility of pressing the wrong key on a keyboard.

System development was based on a total quality management approach in which the users - that is both operating and maintenance technicians viewed animated sequences and display screens at various stages of development. This approach promoted operator acceptance of the system, while enabling numerous changes to be implemented to improve the facility operations.

Figure 5: Colorgraphic System

Intelligent field transducers to PLC intelligent input modules

The PLC gathers information from vacuum instrumentation in the following manner:

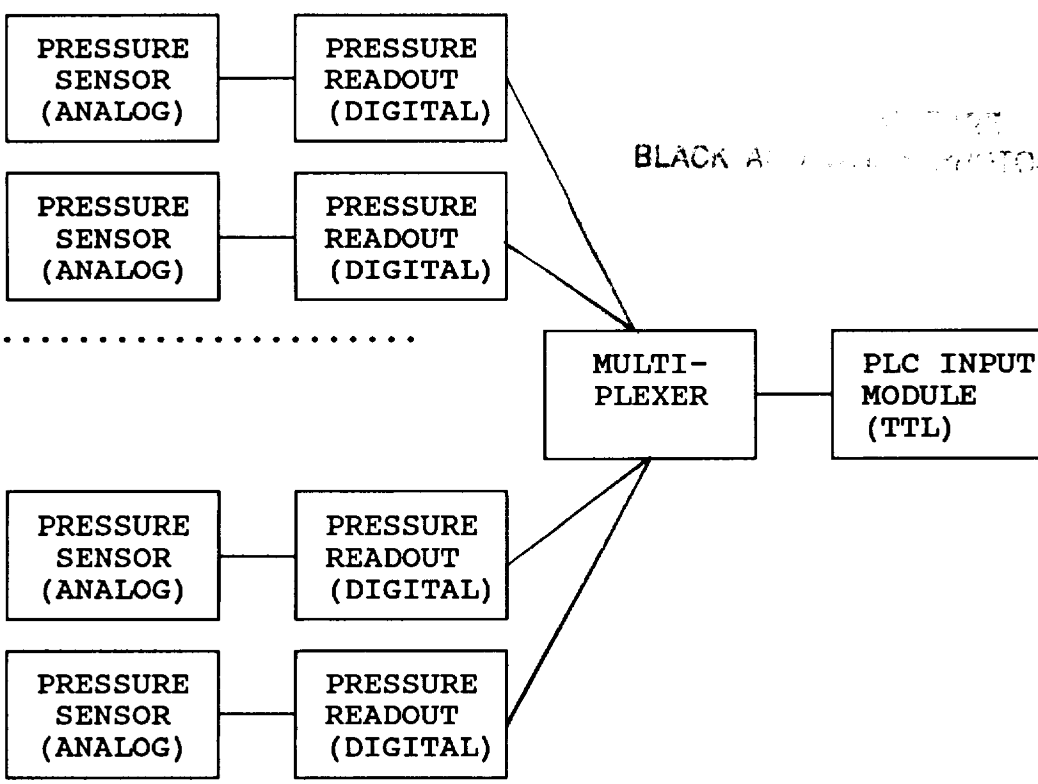

Figure 6: Gathering of Pressure Data

It then gets distributed to a number of key locations, where this information is important: operators, experimenters, engineers.

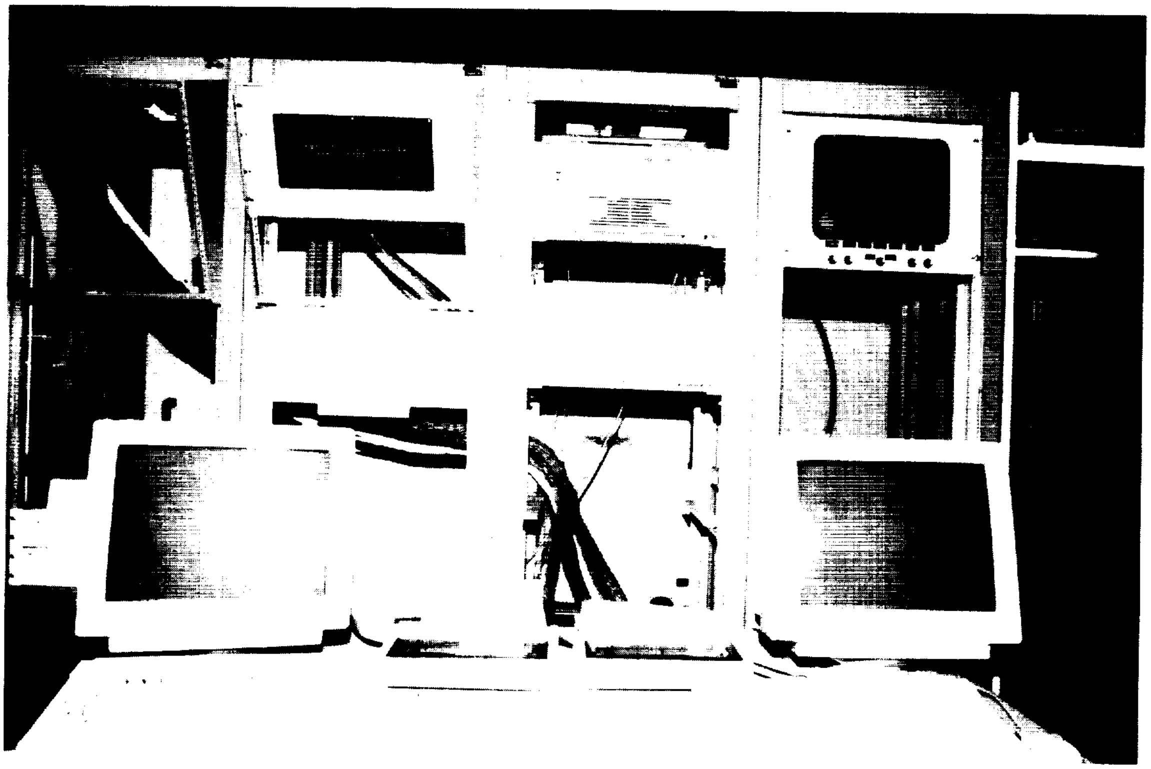

Figure 7: Chamber Pressure Display at the Experimenter's Station

PROCESS OF REDUCING CHAMBER PRESSURE

The system is initially evacuated using mechanical pumps, backed by blowers. When the pressure reaches a designated level, the cryogenic compressors are turned on, which evacuate the chamber to pressures 10^{-4} Torr or below. The turbomolecular pump is then used to pump on helium and other inert gases. When the pumps are turned on, sequential manipulation of the process valves is performed to stage the pumpdown process.

Results The upgraded chamber has performed successfully during a 45-day spacecraft test without a single failure. The greatest achievements of the project were:

- Reliability
- Color graphics interface
- Networking data highways
- Advanced I/O interface
- Capability of unlimited future expansion.

PART II

IF YOUR NEXT UPGRADE PROJECT INCLUDES UPGRADING A CONTROL SYSTEM

Consider the following:

If the requirements of the project are:

Improved control,
Better operator interface,
Higher reliability,
Less maintenance - then a PLC is your best solution.

If the types of controls required are: interlock logic and sequencing, continuous control (PID), custom optimization - then a PLC is your best solution.

If flexibility - the ability to modify control strategies, displays, etc., expandability - extension to other process units, addition of I/O or consoles, interconnectability - present or future communication with other systems or devices are important - then a PLC is your best solution.

Process interface and control functions must be clearly defined and documented. Additional drawings and specifications, addressing specific design areas of the PLC based system, must be issued and transmitted to the vendor and affected design disciplines. This stage of the project represents a period of information gathering, decision making and communication with the vendor and client.

- **Point count**. An accurate point count must be developed to determine the total number of analog and digital inputs/outputs serviced by the system. This information is taken from the latest mechanical Piping and Instrument Diagram. A percentage of spare I/O's based on number of points controlled and monitored by the system should be calculated and a total point count established.

- **Types of I/O's**: High level analog (-10 to +10 VDC), low level analog (mV, T/C), discrete I/O, power outputs for large inductive loads, interface to other devices (Data Acquisition System, printer).

- **System Architecture and Rack Layout**. Once the point count has been established, the type and quantity of input/output modules, switches, pushbuttons, pilot lights, enclosures and other supportive hardware can be identified. From this equipment list, the system racks can be identified and laid out.

- **Field Terminal Assignments**. After the rack layout has been finalized and termination panels located, field terminal numbers are assigned. These assignments should be structured in a logical and functional manner.

■ **Control Panel Interface.** The control panel interface with a large distributed I/O system must be designed carefully. To minimize installation costs, the digital equipment racks and control panels can be wired with receptacles, and multi-conductor cable assemblies used to make the final connection. Coordination between different vendors on matters of signal grounding, fusing, shielding and pin assignments can be very cumbersome. Errors discovered once the computer racks and control panel fabrication is underway can be very costly to correct.

■ **Grounding and Shielding.** A single ground reference should be provided for all logic, instrument and shield grounds. All vendor recommended grounding practices should be followed. Clear guidelines for grounding and shielding are not always available, especially for large customized systems. Grounding practices are further complicated when the digital system must interface to an analog control panel. In such cases an integrated approach to grounding must be followed for both the digital system and analog instrumentation. A single common ground reference must be established for both the analog and digital systems. All signal interfaces between the two systems must be analyzed to ensure that ground loops are not inadvertently introduced into shields and signal returns. Analog and digital input cards should be selected with adequate input filtering, isolation and common mode noise rejection characteristics.

■ **The Field Wiring Interface** should be accomplished in such a manner that the I/O cards and field equipment can be removed without disconnecting the field wiring.

■ **Signal power and interconnection requirements.** Power supplies are usually required to provide the necessary power for energizing transmitters and sensing contact inputs. Digital outputs may be dry contacts (passive), or may provide necessary power to drive certain loads (active). When configuring digital inputs and outputs it is advisable to avoid connecting two common points together and run two wires for each contact input and output. This method is more labor consuming but it provides a clean interface and avoids wiring problems when connecting to other control systems.

■ **Data Highway Communications.** Communication requirements must be established for remotely located color graphic man-machine interfaces. Our system communicates over a twisted pair, which functions as a data highway. The data highway links the remote units together in a daisy chain. Typically, total cable length varies from 5,000 to 10,000 feet. In general, these maximum lengths are for the total length of cable on the data highway, including branches and loops. The most popular communication protocols are: master/slave access (CSMA/CD carrier sense multiple access with collision detection), and masterless access (token passing). Both protocols utilize bus topology rather than star topology.

■ **Operator Console Design.** The operator's console consists of an interactive CRT station with operator keyboard. Additionally, pushbutton stations, pilot lights indicating status of equipment, and a hardwired annunciator are mounted on the operator console. A separate control console as installed next to the CRT station to house the hardwired instrumentation. In general, CRT console provides a much more efficient and cost effective operator interface with the process than dedicated instruments.

■ **Communication with Data Acquisition System.** Process information can be communicated on a timely basis utilizing either IEEE-488 or RS-232C communication links.

■ **Software Configuration.** The PLC system must be programmed with the process information, control algorithms, safety interlocks, and operator interface instructions necessary for proper operation. Without the configuration data, the control system is incapable of performing its intended functions. System performance and payoff is ultimately determined by the software that is implemented. Normally, point addresses and hardware assignments need to be defined early, as this information is required for racks and equipment layouts, wiring lists and field terminal assignments. Sufficient time must be allowed for loading and debugging the configuration data prior to acceptance testing.

■ **Color Graphic System Data Base Generation.** Most software packages come with standard, fill-in-the-blanks software for data acquisition, process control, alarming and operator displays. Data base generation requires identification of necessary process and control information for each point. Information for the data base is gathered from many sources, such as piping and instrument drawings, instrument loop drawings, and instrument user manuals. Process and instrument information must be organized for each point in the system. Decisions must be made as to what input processing, control algorithms, alarm types and other software functions are required for each point.
Data base forms must be filled out, reviewed and updated. The data base is then loaded and errors are diagnosed by the system and corrected. Normally, the data base is in a constant state of revision, which continues through acceptance testing, start-up and system operation.

■ **Displays.** Process indication and control are provided through a variety of displays. In general, the displays include a plant overview, group and detailed formats. In the process of data base generation the user assigns points to various groups to perform indication, alarm and control functions. Once points are assigned to a particular display, other information pertaining to that point can be assigned (such as controller modes, limits, scaling factors, etc.) After that plant flow diagrams, schematics, one-line diagrams and other customized displays can be built. Chambers, heaters, pumps, valves and other equipment are drawn with interconnecting process lines. Process data indication areas are defined for the display. Color, intensity, blink action and character size are assigned for each shape and process data readouts. Tabs can be set on the display, allowing convenient paging to another display. This feature can be used on an overview display to provide a zooming effect. More information can be presented on the screen by positioning the cursor in the area of interest and using the tab function, which addresses a detailed display of the selected area.

- **Reports.** Facility operations require the capability to format and print out process data, alarm, software configuration and system diagnostics. A printer interface provides hard copy of alphanumeric information displayed on the CRT. The computer is capable of storing historical data on selected points, and of generating reports on both a periodic and a demand basis. Historical data points must be identified in the data base, as well as sample periods, process averaging and data storage requirements.

- **Maintenance and Spare Parts.** These requirements should be addressed during the bid evaluation stage of the project instructing the vendors to list and price their recommended spare parts for start up and one year of operation.

- **System Start-up and Check-out.** Every component in the system should be exercised during the acceptance test. Each input and output should be tested to check wiring and point addressing. Analog inputs are simulated with a potentiometer and power supply. Analog outputs are checked with the milliammeter. Digital inputs and outputs can be simulated in several ways. Contact inputs can be shorted with test leads and alligator clips. An ohmmeter (or a voltmeter) can be used to test output operation.

Backup systems should be tested by failing the primary components and observing the system response. System diagnostics are tested by simulating failures, observing what alarms are initiated, and verifying the diagnostic information presented on the CRT. The data highway card for each highway should be removed to test the system's response to failures in the data highway electronics.

Once the system is on-line and the data base is operating properly, additional functions, such as operation logs, system reports, and custom programs can be added. Process can be further optimized and automated. As new applications and future expansions are implemented, the system's hardware and software configurations can be in a constant state of change throughout equipment useful life.

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