Distributed control system controls demineralized water plant

Leopoldo Bello

ABSTRACT: In the recent upgrade of the Aracruz Celulose pulp mill, a distributed control system (DCS) was successfully used to provide control and interlocking for the demineralized water plant. The plant, a conventional ion exchange facility with two identical lines, treats 90 m^3/h (396 gal/min) per line. This article briefly describes the process and the control of the different vessels and lines, outlines the control implementation using function sequence tables (FST) in a hierarchical arrangement, and reports the results of control solution tests.

KEYWORDS: Brazil, control systems, deionization, distributed control, expansion, process control, pulp mills, water treatment.

Aracruz Celulose S.A., a world leader in producing short fiber pulp from eucalyptus, recently concluded a mill upgrade that will double its pulp production from 500,000 metric tons/year to 1 million metric tons/year.[1] The mill, located in the state of Espirito Santo in southeast Brazil, went through an expansion project that included new power and recovery boilers, additional turbine generators, a continuous digester, a bleach plant, and two additional drying machines. Total investment reached US$ 1.3 billion. Full production rate will be achieved by late 1993.

An important part of the project was the introduction of a distributed control system (DCS) to perform all monitoring and control and to provide the base for a future mill information management system.

Larger than usual for this industry, this DCS handles about 10,000 points. Its architecture includes four local area data highways tied together via a communications network. At the heart of the control functions are 42 advanced multiloop controllers, and for operator interfaces there are 14 operations consoles (32 stations) distributed over various control rooms.

Among the areas controlled by the DCS is a demineralized water plant in the new boiler-water treatment system.

[1]Young, J., Pulp & Paper (8): 46(1991).

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Process description

Two complete lines, each rated 90 m^3/h, form the new demineralized water plant (**Fig. 1**). Each line is composed of the following vessel types: activated carbon filter, cation exchanger, weak anion exchanger, strong anion exchanger, and mixed bed exchanger.

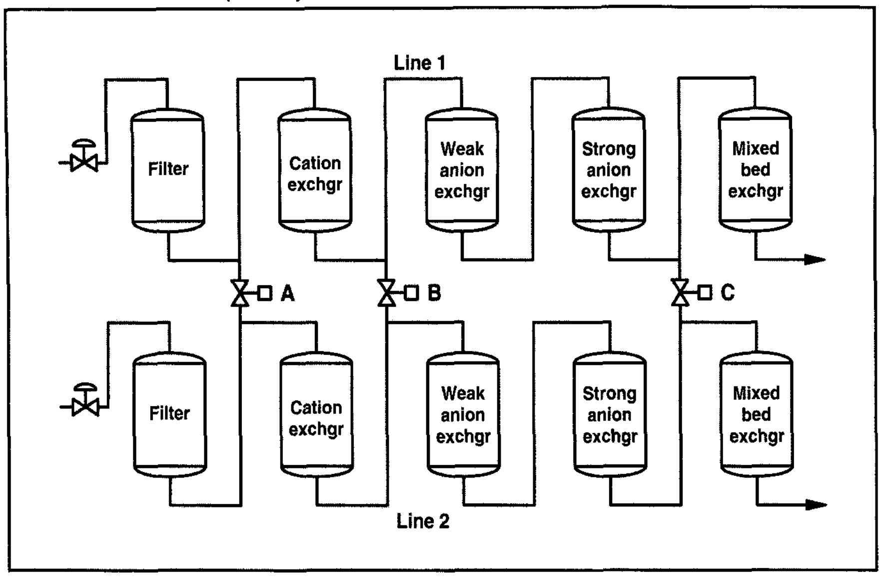
In addition, there is a common system for proportioning regeneration chemicals, as well as piping and on–off valves, analyzer instruments, and ancillary equipment.

The lines are designed to run separately most of the time. Only under unusual conditions would they be interconnected using three connecting valves (A, B, and C in Fig. 1).

Incoming water first flows through the filter to get rid of residual chlorine and organic material. It then goes through the cation exchanger (ions of calcium, magnesium, sodium, potassium, etc., exchanged by hydrogen ions), and the weak and strong anion exchangers (ions of sulfite, chloride, bicarbonate, and silica exchanged by hydroxide ions). At the end of the line, the water passes through the mixed bed exchanger, where it is "polished." A resin trap prevents resin carryover; any carryover that occurs is detected by differential pressure across the trap. A pH meter and three conductivity meters monitor water quality as it flows downstream.

The cation exchanger resin is regenerated by applying a hydrochloric acid (HCl) solution in the counterflow direction. Anion exchanger resin is regenerated by applying a caustic soda (NaOH) solution in the flow direction. Mixed bed exchanger resins are re-

1. Demineralized water plant layout



generated using a combination of these two methods.

A group of on–off diaphragm valves associated with each vessel operates in a sequence determined by the process designer. A vessel may involve most but not necessarily all of the following valves: main inlet valve, main outlet valve, backwash inlet valve, backwash outlet valve, vent valve, regeneration drain valve, outlet drain valve, sealing air valve, mixing air valve, analyzer valve, HCl solution valve, and NaOH solution valve.

At any particular time, any of the vessels may be in any one of the following operational states:

- OPERATION: Water passes through the pressure vessel, producing demineralized water within certain quality parameters.
- REGENERATION: When the vessel saturates and thus cannot hold water quality, it is taken out of service and regenerated. Regeneration is the process of recovering the ion-exchange ability of the resin.
- IDLE: This state—a "rest" position for the vessel—is important as a transition between operation and regeneration and vice versa.
- A special case of IDLE is the MAINTENANCE state, which adds some safety features to protect the equipment and personnel during a maintenance job. Only a special operator permission will disable those safety features.

When a line is in operation, all its vessels should be in the operation state. When a line or a portion of it is in regeneration, some vessels will be in regeneration, operation, or even idle state.

When the lines run independently—that is, with all connecting valves closed—the plant is in the TRAIN mode. If at least one of the connecting valves is open, however, the plant should be in the MIXED mode, which implies that only one "compound line" is running. This compound line is a mixture of vessels from both lines, with one operator-selected vessel of each type. The non-selected vessels remain in either IDLE or MAINTENANCE state. This MIXED mode provides operational flexibility when two or more vessels cannot operate.

Vessel control

When an ion exchanger is in operation, it will continuously effect the desired ion exchange until any one of the following preestablished limits is reached:

- Treated water volume (service cycle)
- pH indication
- Conductivity indication
- Silica leakage.

In any of these events, the ion exchange capability of a resin is lost. To recover it, a regeneration process should be applied. The process usually includes the following steps:

Backwash

Backwashing decompacts the resin bed. Backwashing is not necessary every time regeneration includes HCl application since this happens in the counterflow direction. Typically, a backwash happens after 10–15 regenerations without backwash.

An important finishing sub-step is a "settling" period, which allows some time for the resin bed to calm down.

Drain

Also called level lowering, draining is executed after backwash or after slow rinse to discard the water above the resin bed.

Regeneration

This is the actual application of the regenerating material, in concentrations of about 3–6%. Dosing (metering) pumps feed the regenerating material from storage tanks, and demineralized water is used to dilute it to required concentration. The dilution happens at a mixing tee. Other aspects of this dosing system are described later.

When HCl is being applied in the counterflow direction, the resin bed is prevented from expanding by sealing it with pressurized air.

Slow rinse

A slow rinse completes the previous step, displacing regenerating material by applying dilution water only, with the dosing pump turned off.

Rapid rinse

Soluble salts are removed by running water through the vessel as in real operation, but dumping it to the drain.

The initial part of this step is known as "refill," because the vent valve initially remains open to let air bubbles leave the vessel.

Test

At the end of the rapid rinse, an analyzer valve opens to help determine water quality (pH or conductivity).

The order and number of these steps vary slightly from vessel to vessel. For instance, the mixed bed exchanger has an additional step called "air mix" (backblowing air). This step helps destratify the resins bed, which becomes stratified during backwash.

Line control

A line is placed in service from the idle condition. However, during the time the vessels were at rest their ion balance may have changed, making the water they hold unacceptable. Therefore the first step in placing the line in service is to remove the water in the vessels by executing the following sequence:

- Prewash: Dumping vessel water to drain
- Test: Checking water quality
- Operation: Once the test is accepted, the vessel goes to actual water production.

These steps are conducted in all vessels, in the following order:

1. Filter and cation exchanger together
2. Weak anion exchanger
3. Strong anion exchanger
4. Mixed bed exchanger.

When one or more ion exchangers become saturated or a particular service cycle is attained, the complete line or part of it should be regenerated using one of the following methods:

- LINE regeneration: Regeneration of all vessels in the line, including filter backwash and with the option of backwashing the cation exchanger.
- KIT regeneration: Similar to line regeneration, but excluding the mixed bed exchanger.
- GROUP regeneration: Regeneration of the cation and anion exchangers only.
- INDIVIDUAL regeneration: Regeneration of any one of the ion exchangers alone.

The most general case is the line regeneration, which follows this sequence:

1. The mixed bed exchanger starts its regeneration, effecting backwashing while the rest of the vessels are in operation to supply water.
2. When backwashing of the mixed bed exchanger is completed, then the strong anion exchanger starts its regeneration while upstream vessels continue in operation.
3. When backwashing of the strong anion exchanger is completed, the weak anion exchanger starts its regeneration while upstream vessels continue in operation.
4. When backwashing of the weak anion exchanger is completed, the cation exchanger starts its regeneration. Backwashing occurs (or not, depending on operator selection) with the filter in operation.
5. When backwashing of the cation exchanger is completed or if it does not occur, the filter starts its backwashing.
6. When backwashing of the filter is completed, it goes to idle state. In the meantime, the rest of the vessels simultaneously execute the steps of their own regenerations until they finish the step previous to rapid rinse. At that point, they will wait for all the upstream vessels to successfully finish regeneration so they can supply good quality water. The sequence will then continue with rapid rinsing of the cation exchanger while the filter goes back to operation.
7. When the cation exchanger finishes regeneration, the weak anion exchanger starts its rapid rinse, with upstream vessels in operation.
8. When the weak anion exchanger finishes rapid rinse, the strong anion exchanger starts its rapid rinse, with upstream vessels in operation.
9. When the anion exchangers finish their regeneration, the mixed bed exchanger starts its rapid rinse, with upstream vessels in operation.
10. When the mixed bed exchanger finishes its regeneration, the line regeneration is done and all vessels go to idle.

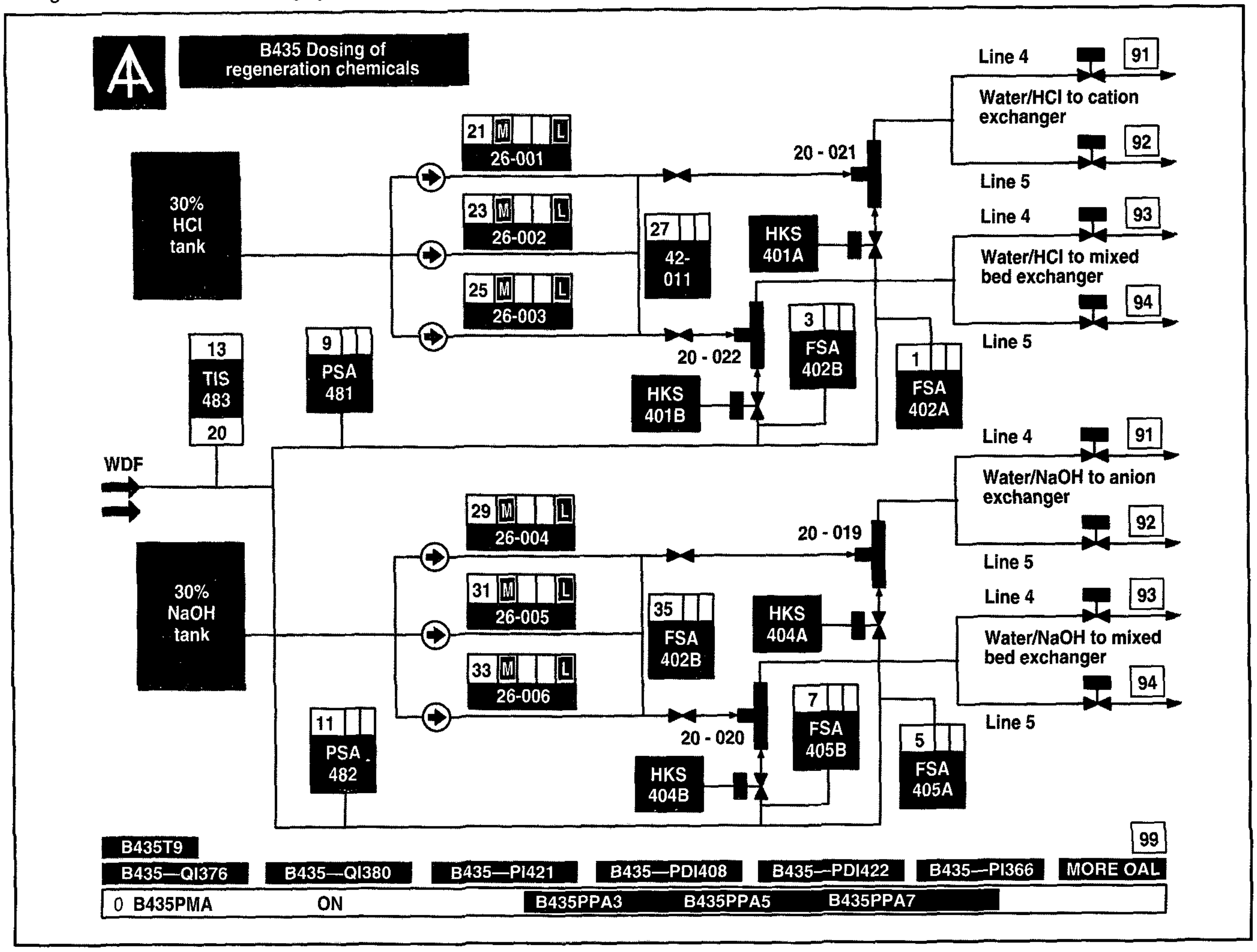
The KIT regeneration may be considered a special case of the line regeneration, skipping all steps related to the mixed bed exchanger. Similarly the GROUP regeneration is also a special case of the line regeneration, excluding all steps related to the mixed bed exchanger and filter backwash.

In INDIVIDUAL regeneration, all the steps will execute for the selected ion exchanger, with all upstream vessels available when needed for water supply.

One important issue in running the line is the operation of the flow controller at the line inlet. If the controller is in manual or automatic mode, the operator will have to provide the controller output or setpoint, respectively. However, if the controller is in supervisory mode, the setpoint will be provided by the line controlling logic and determined based on the operational condition. The design flow controller setpoints are:

- Operation—90 m^3/h
- Filter backwash—90 m^3/h
- Cation exchanger backwash—66 m^3/h
- Weak anion exchanger backwash—34 m^3/h
- Strong anion exchanger backwash—20 m^3/h
- Mixed bed exchanger, backwash—23 m^3/h
- Rapid rinse—90 m^3/h.

2. Regeneration chemicals dosing system



For flow modulation purposes, the setpoint is automatically ramped up or down at rates adjustable by the operator.

Common systems

Three common systems were also covered by the DCS: regeneration—chemical dosing, the timing interface, and service cycle totalizers.

Dosing of regeneration chemicals

Two similar subsystems control HCl dosing and NaOH dosing (**Fig. 2**). Each includes the same components: storage tank, three dosing pumps (two main, one standby), two dilution tees, two dilution water valves, water rotameters, and sampling pots.

When the regenerating material needs to be applied, the control system first opens the dilution water valve. Then, when the water flow is sufficient and steady, a flow switch starts the dosing pump motor. During the slow rinse step, the dosing pump motor stops but the dilution water valve stays open.

Timing interface

The timing interface (**Fig. 3**) lets the operator easily enter and adjust duration times for each regeneration step of any vessel. After the line to regenerate is idled, the operator calls this display, selects a particular step and vessel (shown with a highlighted box) to be modified, and enters time values in minutes. Regeneration may start whenever ready.

Additional features of this interface allow the zeroing of time values to skip selected regeneration steps, as well as entering a full set of reference time values recommended by the process designer.

Service cycle totalizers

A service cycle is defined as the water volume treated in a vessel between two consecutive regenerations (or backwashings in the case of the filter).

One service cycle totalizer was implemented for each vessel displaying the water volume that already went through it. Based on this information, the operator could plan and prepare for next regeneration. Over a long period of time, the service cycle values will eventually indicate resin decline.

The totalizers are also furnished

3. Time entering interface

Line 4 regeneration/step duration (minutes)

	Vessel \ Step	Back-wash	Drain	Acid application	Caustic application	Slow rinse	Air mix	Rapid rinse	Test
	Dechlorination filter	A 5							
4	Cation exchanger	B 5 ■	C 5	D 5		E 5.0		F 5.0	G 5.0
	Weak anion exchanger	H 5	I 5		J 5	K 5.0		L 5.0	
7	Strong anion exchanger	H 5		I + J =>	10	K 5.0		M 5.0	N 5.0
	Mixed bed exchanger	O 5 ■	P 5.0	Q 5	R 5	S 5.0	T 5.0	U 5.0	V 5

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Line 5 regeneration/step duration (minutes)

	Vessel \ Step	Back-wash	Drain	Acid application	Caustic application	Slow rinse	Air mix	Rapid rinse	Test
	Dechlorination filter	A 5							
2	Cation exchanger	B 5 ■	C 5	D 5		E 5.0		F 5.0	G 5.0
	Weak anion exchanger	H 5	I 5		J 5	K 5.0		L 5.0	
3	Strong anion exchanger	H 5		I + J =>	10	K 5.0		M 5.0	N 5.0
	Mixed bed exchanger	O 5 ■	P 5.0	Q 5	R 5	S 5.0	T 5.0	U 5.0	V 5

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with an alarm at a pre-established volume setpoint, and also an automatic reset when a new cycle starts after every regeneration.

Control design

The foundation of the control implementation is a powerful tool called Function Sequence Tables (FST). An FST is a set of instructions (functions) placed in a specific arrangement to provide program-like capability at the multifunction controller level. An FST may resemble an assembly program, with functions that perform arithmetic calculations, logic operations, branching, bit manipulation, timing, database access, conversion, etc.

For this application, the control problem was first defined and then divided into logically separate tasks. The obvious choice was a division by vessel. Therefore, an FST was assigned to carry out all the sequencing, calculations, and interlocks for each vessel, with the exception of the anion exchangers, which are treated as a single unit. To keep a moderate vessel FST size, another set of FSTs was defined to handle valve commands for each vessel as well. In the hierarchical FST layout (**Fig.** 4), the vessel FSTs are at the lower or base level.

Another separate task that needed a specific FST was the coordination and supervision of all the vessels in one line. The line FST falls at the intermediate level in the FST hierarchy because those functions require that all vessel FSTs of one line be subordinate to it. Should the plant run in the mixed mode, that is, using a mixture of vessels from both lines, a mixed line FST with functions and hierarchy position analogous to those of the line FSTs will become active.

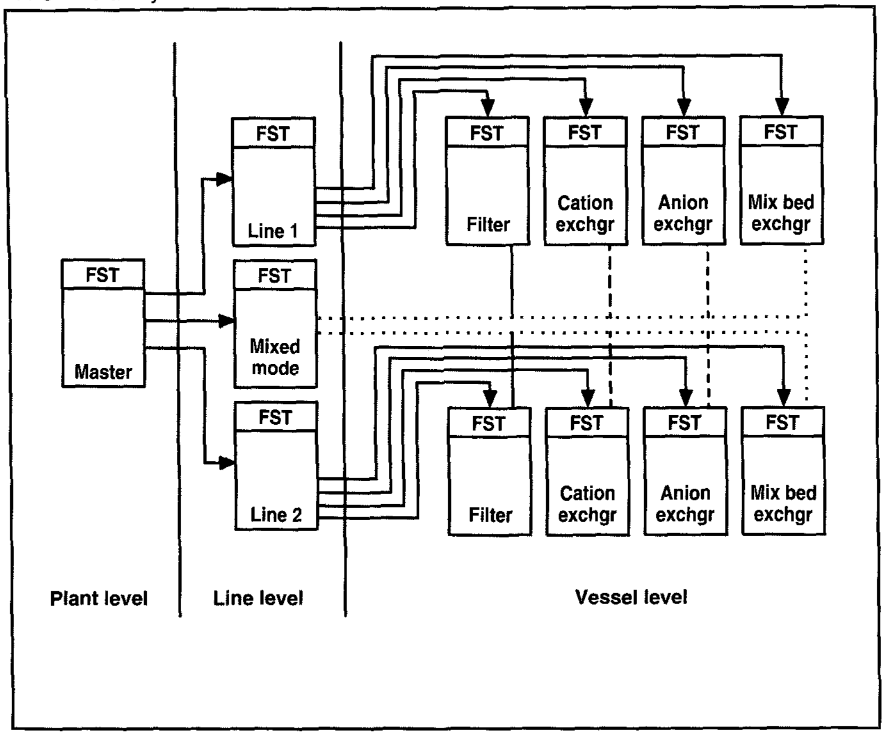
At the top of the FST hierarchy is a master FST, which enables the line and mixed-line FSTs to run (toggling from one to the other), in addition to performing some other supervisory duties.

The FSTs were each outlined using the flowcharting technique explained below.

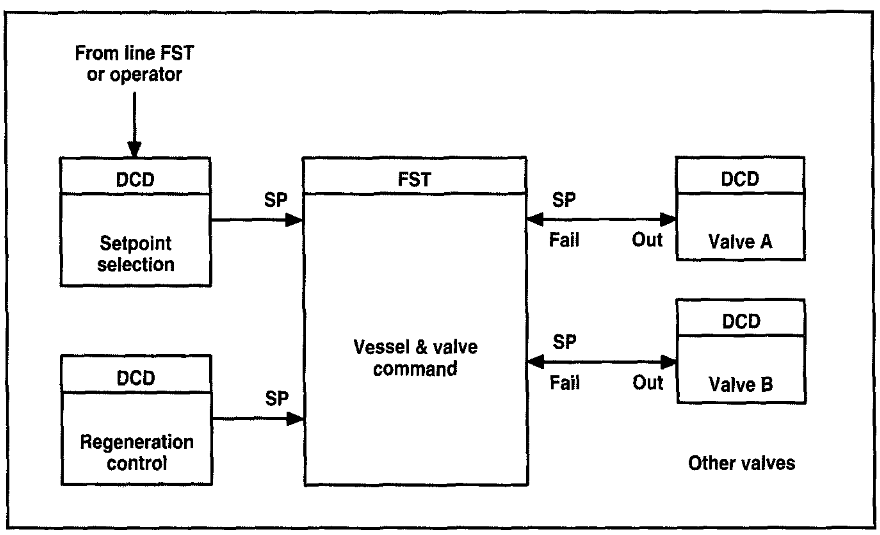
Vessel flowchart and FST

Figure 5 illustrates the relationship among the control elements associated with a vessel FST. The FST takes advantage of Discrete Control Device (DCD) points, which allow control of

4. FST hierarchy



5. Vessel control elements



on–off valves and electric motors, as well as simulation of selector switches.

The vessel FST reads operator- or computer-entered commands (DCD setpoints) of two types:

- Operational status (idle, operation, regeneration, maintenance)
- Regeneration control (start, continue, repeat, stop).

The vessel FST also writes setpoints to valve or motor DCDs (open/close or start/stop). The valve command FST executes setpoints as required by the different DCDs, and keeps track of their fail condition.

Every FST scan (at 1-s intervals) begins by detecting if the operational status should change, and if so, determining what the new status should be. Then the FST checks whether that change is valid (e.g., from idle either to operation or to regeneration). If no change is required, the FST keeps executing as before.

Figure 6 shows a very simplified version of a vessel flowchart. There are two basic branches: a vertical branch to identify the vessel operational status, and a horizontal branch where an enabled flag allows execution of a vertical sub-branch. These sub-branches, which are usually numerous, include most of the actual interlocking, timing, sequencing, etc. Execution commonly transfers from branch to branch by properly setting and resetting flags within them.

A flowchart following these principles was adapted to fit each vessel's specific needs, and then the FST code was written and processed such that it could run on the multifunction controller.

Line flowchart and FST

In a similar way, the technique just described was used to develop a flowchart for the line FST. On the vertical branch of the flowchart, the line setpoint is defined; whereas on the horizontal branch, a number of flags will conduct all vessel FSTs to their different concurrent activities.

The mixed-line flowchart and FST are similar, with the addition of an algorithm for selecting the vessels for the mixed line.

Custom displays

A number of custom displays were configured to provide an efficient and organized operator interface with the process. These displays range from general overviews to line displays and individual vessel displays. **Figures 7 and 8** show examples of these displays.

In addition to process equipment symbols and indicator/controller faceplates, the displays also have control boxes or "windows" to produce dynamic indications or to allow operator commands. For instance, an individual vessel display may show a window with a decreasing indication of the time left (in minutes) to complete a regeneration step.

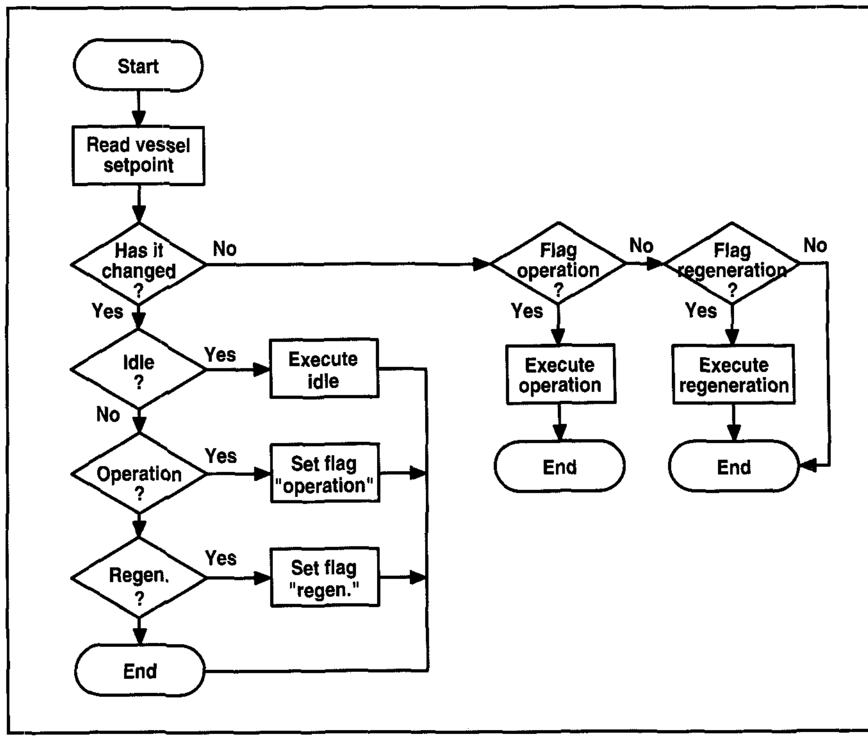
Debugging and testing

The DCS configuration for the dimineralized water plant, and particularly its FSTs, were verified in two phases: factory testing and on-site testing.

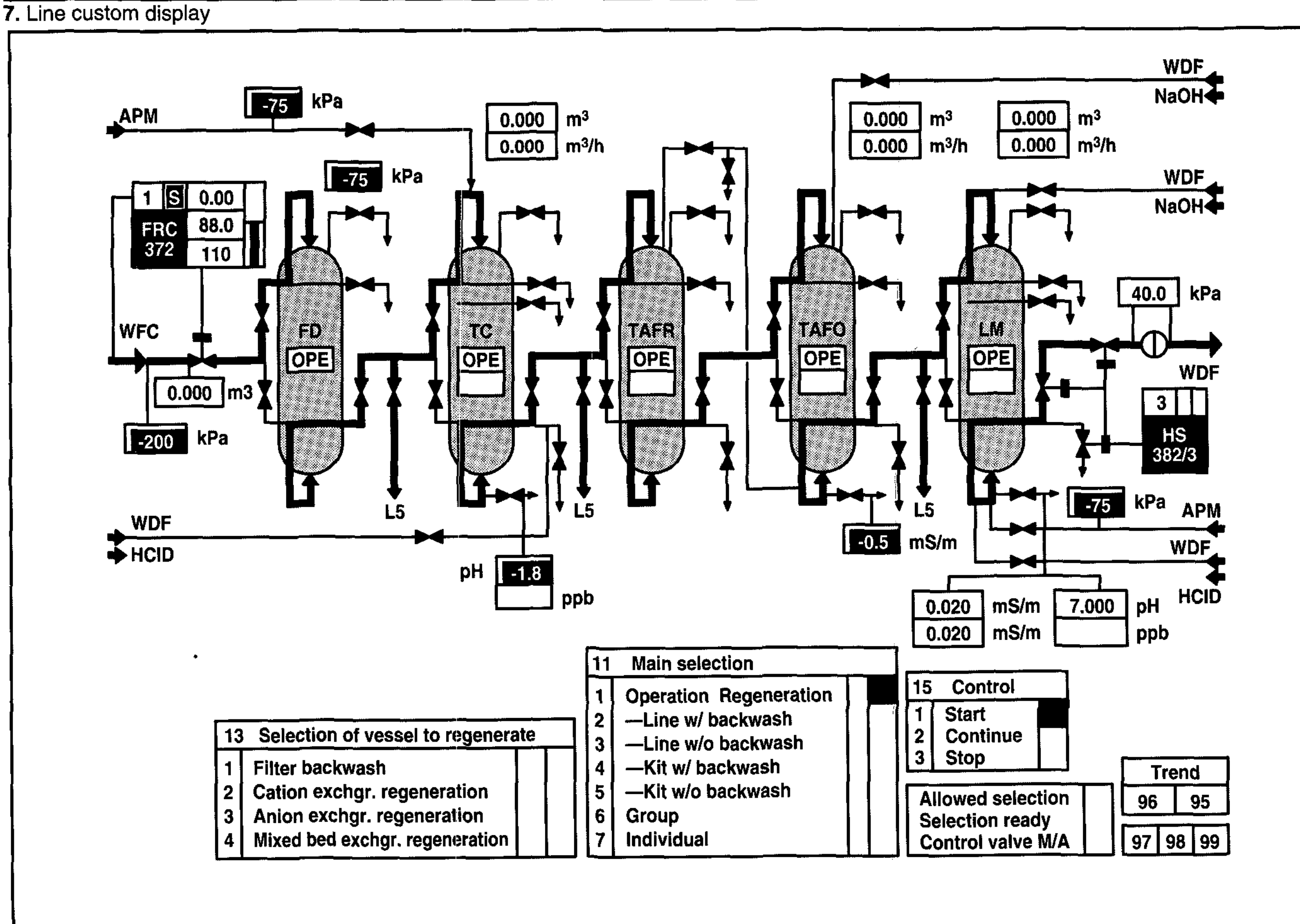
Preliminary testing was performed at the factory, using the actual control hardware after being staged. A hardwired simulator was used for every vessel, and main sequence and interlocks were tested. This testing under laboratory-like conditions offered a major advantage over testing in a mill startup environment.

In on-site testing, the DCS configuration initially underwent a no-load

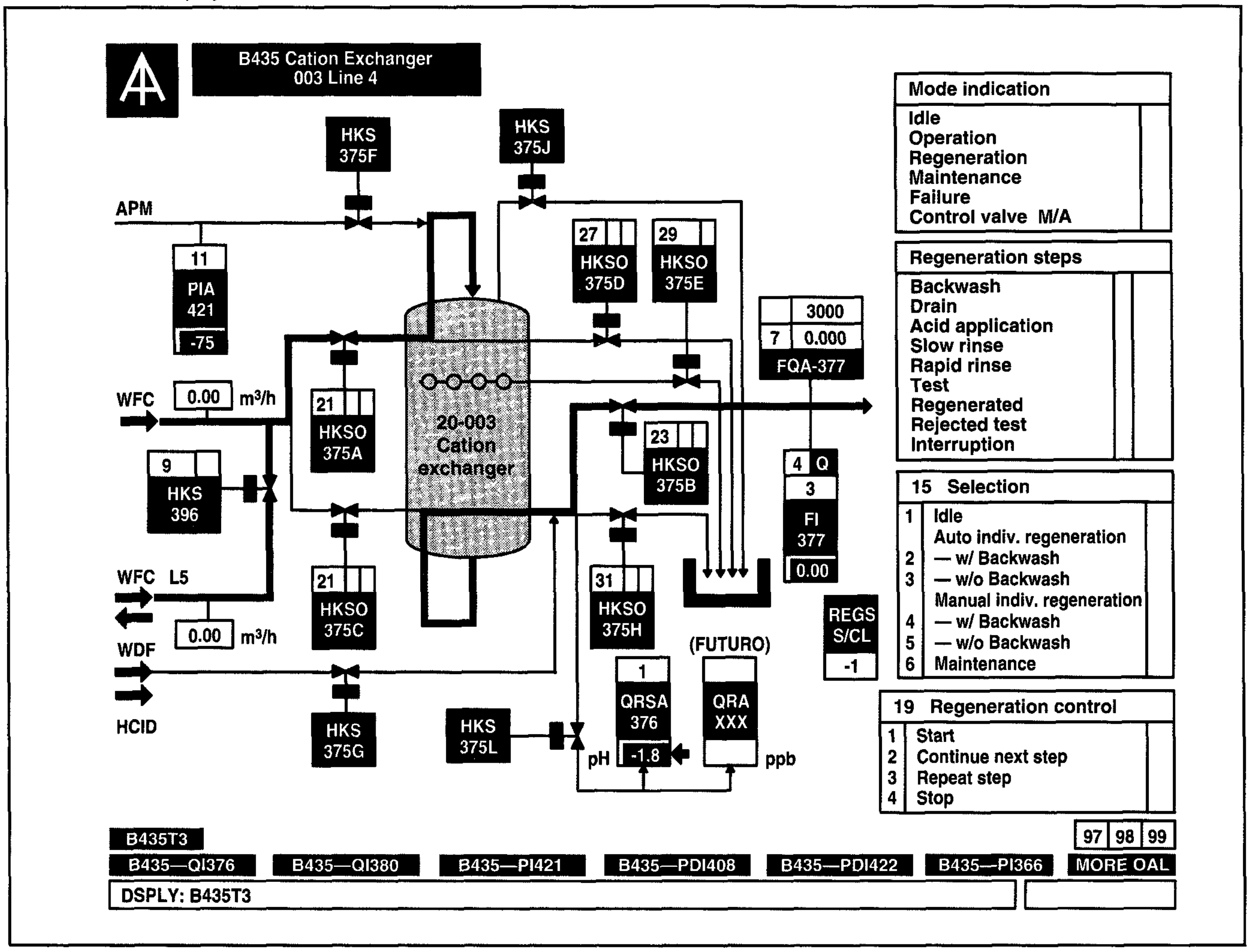
6. Vessel FST flowchart



7. Line custom display



8. Vessel custom display



test (vessels without resins), leading to the solution of some valve actuation and timing problems. Once minor FST bugs were cleared, all vessels were loaded with resins and run under actual operating conditions. Several minor adjustments were made to the analyzer by-pass, flow controller supervisory mode, regeneration auxiliary steps (settling, refill), regeneration reference time adjustments, etc., to improve and enhance system performance.

An important debugging tool at this phase was the system's TRACE utility, which allows stepping through an FST and determining intermediate results after execution of each instruction.

Training and documentation

Transferring the DCS technology to the end user would not be complete without proper training and documentation. A training effort was devoted to two groups of people: the operations crews and the maintenance crew.

The operations crews had a good process background but none in the DCS area. A system school and a lot of hands-on training provided the skills to switch from a "knob-turning" to a "keypad-stroking" style of operation. Confidence and effectiveness have increased as operators get better acquainted with the DCS.

The maintenance crew had also a good deal of learning to do, not only of the hardware, but mainly of the software. Formal schools and lots of hands-on experience improved the learning curve.

The most important documentation for this DCS configuration was the flowcharts. They were used initially as a program design method and a training aid, but will also assist in maintaining and redesigning FSTs.

Conclusions

Traditionally, demineralized water plants have relied on mechanical and/or electric timers and relays for control. More recently, programmable logic controllers have been used as well. The introduction of DCS control for this application offers a new way to solve the pure sequential control problems of such plants. A DCS can provide:

- Improved flexibility in changing operation and tuning parameters
- The ability to provide a hierarchical structure among FSTs, which is necessary to supervise and coordinate subordinated FSTs
- Direct integration of plant information with the rest of the mill via the data highway
- Maintenance and operation procedures similar to those used in other mill areas
- Easy implementation of supervisory control techniques (such as for the flow controller, which allows a smooth operation free of pressure surges).

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