A Language for Integrated Process Control Application

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Abstract

The process control work following the Purdue Workshop initiatives generally focused on general purpose (e.g. FORTRAN) language standards, system/communication standards, and special applications languages to represent different aspects of process control. Notwithstanding this start, the industry continues to support a Tower of Babel of control data bases and languages, suggesting the need for an entirely different and more integrated understanding of the problem.

For some years, the author has argued the distinctive ease of use of certain traditional and novel language concepts. These include: Ladder Diagrams, Idioms, Activity Brackets, SuperVariables, and Theme Statements. Despite their separate treatment, the work has been aimed at the integrated use of these concepts, ideally allowing the application engineer to describe an entire application within a single documenting and diagramming framework. This paper presents the current state of author's work in that direction.

The development is based on an idealized continuous (not batch) Styrene Plant application, still complex (realistic) enough to require an integrated sequenced, logic, continuous control treatment. The paper presents the top level control program, integrating start-up, continuous running, and normal and emergency shutdown, with enough development of lower level control routines to show the workings of the language and the potential for such a language to define such an application clearly and in its entirety.

Introduction

Teaching and practice of process control would be greatly advanced if applications could be defined within a single computer information model and language framework. Such a model would integrate the full range of control and general computation. No accepted technology addresses the human-use design of the related tools.

The paper presents a language for integrated process control, extending the earlier control Idiom and related work.[1-10] In lieu of formal development, it illustrates integrated multi-unit automation on a hypothetical styrene plant[11-12], including startup and shutdown. The resulting language differs inherently from conventional computer languages in many ways:

- Expression of real-time sequential, parallel, and continuous computation, not just compute time sequencing.
- Structured, about the process and control organization.
- Leveled to reflect levels of human activity.
- Generating an integrated data base, for plant operation, monitoring, control, and historical recording of operating parameters and production states.
- Formatted, in semigraphic form, for readability.

The references address language components. But language issues are best summarized by example; this paper presents the structured, integrated, startup/shutdown/run of a multi-unit, process control example.

The example process mixes ethyl benzene and superheated steam at temperatures approaching 700˚C and passes them over a catalyst bed to produce Styrene (plus H_2 and CO_2). The steam serves three purposes: it heats the reaction, it buffers the styrene molecules to prevent their polymerization, and it prevents liquid water from poisoning the catalyst.

As shown in Figure 1, the plant includes five units: Furnace, Reactor, Heat Recovery, Separator, and Feed Tankage. A simpler, more reversible process might be started by starting each of its parts; but this process requires coordinated event sequencing of all stages of operation.

In more detail, Ethyl Benzene is pumped from the Feed Tankage, initially vaporized in the Heat Recovery exchangers, combined with the steam, further heated in exchangers, combined with superheated steam from the Furnace, reacted in the Reactors, cooled in the Heat Recovery exchangers, condensed in the air condenser, and separated into H_2, CO_2, H_20 and distillable product.

The Reactors should be purged of oxygen (explosion hazard with H_2). The Furnace should be heated slowly, minimizing wall thermal stress. The initial O_2/H_2O free purge and heating is carried out under a N_2 atmosphere.

Process Nomenclature

The table below lists the process variables from Figure 1, generally coding each in terms of the associated process unit, the particular stream, an inlet/outlet differentiator, and the variable type.

Global Styrene Plant Variables

FST: Furnace Steam Temperature
TRF Tank Recycle Flow
TFF: Tankage Feed Flow
TF=TRF+TFF: Tankage Flow
POL: Product Outlet Tank Level
WOL: Water Outlet Tank Level

Furnace Variables (See Global also)

FSHV: Furnace **Steam** Hand Valve
FSV: Furnace Steam Valve
FSF: Furnace Steam Flow
FSP: Furnace Steam Pressure

FNHV: Furnace **Nitrogen** Hand Valve
FNV: Furnace Nitrogen Valve
FNF: Furnace Nitrogen Flow

FFV: Furnace **Fuel** Valve
FFF: Furnace Fuel Flow
FFIg: Furnace Fuel Ignition
FFFl: Furnace Fuel Flame

FSVHV: Furnace **Steam Vent** Hand Valve

Reactor Variables

RSV: Reactor **Steam** Valve
RSF: Reactor Steam Flow
RSR=RSF/TF: Reactor Steam Ratio

RX1SV: Reactor **Exchanger** 1 Steam Valve
RX2SV: Reactor Exchanger2 Steam Valve
RX1PT: Reactor Exchanger 1 Product Temperature
RX2PT: Reactor Exchanger 2 Product Temperature

RPIT: Reactor **Product** Inlet Temperature
RPIP: Reactor Product Inlet Pressure
R1PIT: Reactor 1 Product Inlet Temperature
R1POT: Reactor 1 Product Outlet Temperature
R2POT: Reactor 2 Product Outlet Temperature
R3POT: Reactor 3 Product Outlet Temperature
RPOP: Reactor Product Outlet Temperature
RPOA: Reactor Product Outlet Analysis

Heat Recovery Variables

HSV: Heat Recovery **Steam** Valve
HSF: Heat Recovery Flow
HX1L: Heat Recovery Exchanger 1 Level
HX2L: Heat Recovery Exchanger 2 Level
HX2SV: Heat Recovery Exchanger 2 Steam Valve
HX2SP: Heat Recovery Exchanger 2 Steam Pressure
HX3L: Heat Recovery Exchanger 3 Level
HSR=HSF/TF: Heat Recovery Steam Ratio

HWV: Heat Recovery **Water** Valve

HSVHV: Heat Recovery Steam **Vent** Hand Valve
HSX2VV: Heat Recovery Exchanger 2 Steam Vent Valve

HPHF: Heat Recovery Product Hand Valve

Feed Tankage Variables (See Global also)

TFL: Tankage **Feed** Level
TFPp: Tankage Feed Pump
TFV: Tankage Feed Valve
TRL: Tankage **Recycle** Level
TRPp: Tankage Recycle Pump

TRV: Tankage Recycle Valve

Separator Variables

SPFn: Separator **Product** Cooling Fan
SPT: Separator Product Temperature

STV: Separator **Top** Valve
STP: Separator Top Pressure
STPp: Separator Top Pump

SMV: Separator **Mid** Valve
SMP: Separator Mid Pressure
SMPp: Separator Mid Pump

SMV: Separator **Bottom** Valve
STP: Separator Bottom Pressure
STPp: Separator Bottom Pump

Control System Structure

The language models a process hierarchically in its own Objects called Operations, modelling the process divisions: the Styrene Plant Operation and the Furnace, Reactor, Heat Recovery, Separator, and Feed Tankage SubOperations. Each Operation is organized into Pages for modelling distinct control functionalities.[1] The paper principally illustrates Procedures Pages, describing active control procedures.

Control Tasking and Sequencing

A statement language must list its statements to reflect distinct execution orderings. The proposed language can support: sequenced and looping order (as in conventional computer languages), or (as also required by real-time control activities) parallel, continuous (individually repeated each sample time), and state driven. The language uses iconic brackets (which may be nested) to distinguish execution orders. Figure 2 illustrates the usage; the legend defines the bracket forms. The diamond icons (including any internal State distinguishing numbers) define abnormal exits; similarly paired asterisks will later indicate normal exits. The icons replace keywords and highlight program structure.

When the Styrene Plant Operation is called, the plant is activated in a simple sequence. The outer (left most, thin lined) bracket represents this sequenced Activity, which first tests that all of the lower level units (SubOperations) have been shut down, prerequisite to full operation, invoked in nested Activities. The following nested bracket (two parallel lines) encloses two other Activities, to be carried out in parallel.

The first of these executes continuously (a solid continuous bracket), monitoring an operator console shutdown button state (Shutdown or Emergency Shutdown). The second (a dashed bracket) represents a state driven Activity, selecting a lower level Activity, depending on the current (Startup, Hold, Run, Shutdown, or Emergency Shutdown) system state. Normally, this activity proceeds through the Startup, Hold, and Run states to startup and run the plant.

The Startup State corresponds to a sequencing through the necessary Tasks: Prepare Startup, Purge (clearing oxygen from the system; slowly heating the furnace under Nitrogen), Steam (transitioning from a Nitrogen process atmosphere to a Steam atmosphere), and React (initiating a low Feed and reaction).

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[1] For example, the Definitions Page specifying the global Styrene Plant variables already described is:

STYRENE_PLANT Page: Definitions

NAME	IN	VALUE	MIN	MAX	UNITS	SET	HI	LO	DEV
FST	1	_	0	800	DGC	_	780	300	20
TRF	2	_	0	100	GPM	_	_	_	20
TFF	3	_	0	100	GPM	_	_	_	20
TF	_*1	_	0	100	GPM	_	_	_	20
POL	4	_	0	300	FT	_	30	10	20
WOL	5	_	0	300	FT	_	30	10	20

It groups process variables under a common user defined heading SuperVariable structure[7], replacing rigid I/O blocks of current practice with language structure. Note the **TF** related Footnote reference to a Details Page defining computation:

STYRENE_PLANT Page: Details

*1 TF TRF+TFF

Once the reactor is in operation, the State is changed to Hold, all Units called (activated), and intended final feed established. The system enters the Run state and operation continues normally until operator intervention calls for Shutdown or Emergency Shutdown.

The Emergency Shutdown consists of the sequenced Tasks: Prepare Emergency Shutdown (removing the feed from control and waiting 10 minutes for settling), Emergency Steam Shutdown (rapid steam rampdown, replacing with Nitrogen), and Final Shutdown (abruptly closing process valves).

The normal Shutdown consists of a more orderly sequencing of shutdown tasks: Shutdown Feed (ramping the feed down), Shutdown Temperature (ramping the temperature down to 350° over two hours), Shutdown Steam (ramping the steam down, replacing it with Nitrogen), and Final Shutdown.

Detailed Plant Level Notes

This section explains the language details according to the note numbers in the main Activity:

1. A Local Environment Declaration, its returned States control Case Statement-like conditional statements.[2]
2. This statement is executed if the Declaration returns **ACTIVE** (a system State), indicating Units still operating. In that case, the message is sent to the operator and the entire Activity terminated.
3. This is the assignment with States.[3] It sets the Styrene Plant Operation from the Console Shutdown variable.
4. A State Driven Activity starts in Null State, executing the first statement. This, in turn, assigns the Startup State. Thereafter, it executes those nested statements or Activities whose State Prefix[4] corresponds to the current assigned State of the State Driven Activity.
5. This Startup State Prefix applies to the following (Startup) Sequential Activity, calling for the execution of that Activity, until completion or change in State.
6. The normal Task call termination continues operation with the next statement. Abnormal exit (corresponding to the numbered diamond) terminates control (and the entire Styrene Plant Activity).
7. This Task call terminates normally only, continuing.
8. The **NEXTSTATE** command advances the State, terminating (to the level of the paired asterisks) the Activity.
9. Assignments and calls can include lists; in this case: **(FURNACE, REACTOR, HEAT_RECOVERY, SEPARATOR, FEED_TANKAGE)**. The terminating diamond indicates termination by any failed Operation.
10. A single statement continuous Activity terminated by operator action (tested by the **READY:** State Prefix) and **NEXTSTATE** command, to the level of the paired asterisks.
11. The normal State conditioned statement with its Prefix, followed by a statement which continues all control when the Run State is entered.
12. The normal Shutdown termination.

Plant Level (Global) Tasks

The above listing calls on a number of named Tasks to implement the details.

Prepare Startup Task; Outline Translation

The Prepare Startup Task (Figure 3) closes valves in the Furnace, Reactor, and Heat Recovery Operations, to configure the process for Startup. It tests Feed Tankage levels for adequate feed and Product tankage levels for adequate capacity.

Prepare Startup Task; Numbered Notes

1. A Task is a Named (above the Bracket) Activity.
2. A Scoping Prefix allows access to SubOperation Tasks and variables. Together with the List State assignment it allows the compact closing of the listed Furnace valves.
3. This Scoping Prefix is applied to an entire Activity.
4. This Declaration includes real variables, each with a comparison limit, and returned States **LO/EQUAL/HI**.
5. If either comparison in the above Declaration returns a State matching the **LO** State Prefix, the Task terminates. The paired diamonds with the **END** command represent an abnormal exit condition.

Purge Task; Outline Translation

The Purge Task (Figure 4) sequences, controlling the Heat Recovery Exchanger 2 (Level and Pressure), supporting initial product cooling and feed steam generation. Furnace, Reactor and outlet vent are connected by opening valves. The remaining steps are carried out in the Furnace. Nitrogen is placed under control and ramped to 5 CFS (in 2 minutes). Fuel ignition is started, and fuel ramped to 5% valve position. The igniter is stopped and the flame tested. If cold, the fuel valve is closed and the Task terminated. Otherwise, the Furnace Temperature is placed under control and ramped to 650° (in 6 hours), the operator so notified.

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[2] All conditions are based on (user) named States. If necessary, Details Page Truth Tables handle computed conditions, separating the condition computation from the conditional consequences. IF statement intertwinglement, dyslexia, and error is eliminated.

[3] State values and assignments allow natural language usage: variables naming both Real values and operating States.

[4] A State Prefix consists of a State name or expression followed by colon (e.g. **STARTUP:**), and precedes a statement (or Activity), executed conditionally on the application of that State. Other Prefixes modify the effect of their associated statements or Activities in other appropriate ways.

Purge Task; Numbered Notes

1. This statement initiates a continuous Task, allowing that Activity to continue execution without hanging up.

2. A Continuous non-terminating Task initiated as in 1.

3. Ramps[9] the already controlled Furnace Nitrogen Flow to 5 cubic feet per second in 2 minutes.

4. **END** statement and diamonds: an abnormal termination.

5. Without From phrase, ramping starts at current value.

Steam Task; Outline Translation

The Steam Task (Figure 5) continues the control of Heat Recovery Exchanger 2. And in the Furnace it requests opening the Furnace Steam Hand Valve, and brings the Furnace Temperature and Steam Flow under control, continuing the Nitrogen control. The Steam can now be ramped up as the Nitrogen is ramped down, both in 30 minutes, the Task terminating afterward.

Steam Task; Numbered Notes

1. The control of the Heat Reactor Exchanger 2, initiated in the previous call to Purge, continues at this point.

2. Normally continued from Purge, as in 1.

3. Initiating new control Task.

4. Normally continued from Purge, as in 1.

5. The two Ramp statements act together in parallel.

React Task; Outline Translation

The React Task (Figure 6), in Parallel, activates all SubOperations except the Heat Recovery, connects the Heat Recovery and initiates its control, ramps the total feed to 20 gallons per minute in 30 minutes, and terminates the Task. Notes 1 (paired diamonds) and 2 (**END** command with paired asterisks) distinguish abnormal and normal termination.

Prepare Emergency Shutdown: Translation:

The Prepare Emergency Shutdown Task (Figure 7) includes two parallel executed statements: the continued control of the Furnace Reactor, Feed Tankage, and Separator, and a ten minute wait to settle. The Task terminates normally at the end of the wait.

Prepared Emergency Shutdown: Detailed Notes

This section explains the language details according to the note numbers in the Task:

1. The list call statement continues the control of the four units. It does not show the end diamond because there is no point in ending a faulty unit, since the whole Task is carrying out an orderly shutdown.

2. This statement is a simple **WAIT** Theme statement with the obvious role. After the ten minute wait, the **END** statement terminates the Task, normally (the asterisks).

Emergency Steam Shutdown: Translation:

The Emergency Steam Shutdown Task (Figure 8) consists of Activities carried out in parallel in the Heat Recovery and Furnace Units. In the Heat Recovery Unit, the Heat Recovery Steam Vent Hand Valve is opened and the Product Hand and Water Valves are closed, isolating the reactor from the Heat Recovery Unit. In the Furnace, the Furnace Temperature, Steam Flow, and Nitrogen are maintained under control. The Steam flow is ramped down and the Nitrogen Flow is ramped up, both in 10 minutes. The Task is then terminated normally.

Emergency Steam Shutdown: Detailed Notes

This section explains the language details according to the note numbers in the Task:

1. In this example the **END** statement occurs after the two paralleled Ramp statements, rather than sequenced on just one of them. The effect is the same: the Task is terminated after the ramping actions have been completed.

Final Shutdown: Translation:

The Final Shutdown Task (Figure 9) sequences through a series of final valve closings, isolating everything. The final **END** statement is redundant for this Task, but included to allow the final system termination.

Final Shutdown: Detailed Notes

This section explains the language details according to the note numbers in the Task:

1. This End statement allows the Final Shutdown to shutdown the main Styrene Plant Activity; see the call from that Activity.

Shutdown Feed: Translation:

The Shutdown Feed Task (Figure 10) consists, in parallel, of the parallel continued control of all Units, and the ramping down of the total Tankage Feed Flow.

Shutdown Feed: Detailed Notes

This section explains the language details according to the note numbers in the Task:

1. The End statement is combined with the Ramp statement in a Sequential Activity inside the Scoping Prefix; it terminates the Activity only after the Ramp statement is completed.

Shutdown Temperature: Translation:

The Shutdown Temperature Task (Figure 11) is programmed as the parallel handling of several steps, including the continued control of Furnace, Heat Recovery, and Separator Units, the closing off of the Reactor heat exchanger steam flow, and the opening of the Reactor to the main steam flow. The Furnace Steam Temperature is ramped (down) to 350° in 2 hours.

Shutdown Temperature: Detailed Notes

This section explains the language details according to the note numbers in the Task:

1. Note that this ramp is timed in hours.

Shutdown Steam: Translation:

The Shutdown Steam Task (Figure 12) isolates the Reactor from the Heat Recovery Unit opening the Heat Recovery Steam Vent Hand Valve, and closing the Heat Recovery Hand Valve and Water Valve. In parallel, the Furnace Temperature, the Steam flow, and the Nitrogen control are continued. The Furnace Steam Flow is ramped down and the Furnace Nitrogen Flow is ramped up to 50% both in 30 minutes. When the ramping is completed the Task is terminated normally.

Furnace Operation Procedures

The main Plant Activity depends on the Furnace SubOperation (and Tasks).[5] The main Furnace SubOperation Activity (Figure 13) tests that the Furnace Steam Temperature and Pressure are high enough and then controls of the Furnace[6]. The associated Tasks are all Idiom Loop statement[8,10] Tasks, named for clarity.

Furnace Task; Numbered Notes

1. This is the Task name for the following Loop Statement.
2. Expresses the normal PID regulation of Furnace Steam Pressure by the Furnace Steam Valve.[7]

Reactor Operation Procedures

The Reactor Operation Activity (Figure 14) tests key reactor temperatures and calls the Control Reactor Task. This is a Continuous Task regulating the Reactor Steam Flow (as a ratio to Tankage Feed), Reactor 1 Product Inlet Temperature, Reactor Exchanger 1 Product Temperature, and Reactor Exchanger 2 Product Temperature. Other key variables are monitored manually.

Control Reactor Task; Numbered Notes

1. This loop includes a low outlet limit on the valve output.
2. This is a cascade loop, whose Temperature controller is redundantly specified for clarity (already specified in Control Furnace Temperature).

Heat Recovery Operation Procedures

The Heat Recovery Activity (Figure 15) tests several variables to initiate the Control Heat Recovery Task. The Heat Recovery loop Tasks, are phased separately in start-up and run, including two alternative loops for controlling a ratio-ed Heat Recovery Steam Flow.

Separator Operation Procedures

The Separator Activity (Figure 16) is more interesting; it starts pumps and tests/waits for the Separator Top Pressure to reach one atmosphere to initiate the Control Separator Task, and defines a redefined **ABORT** response. This includes an orderly shutdown whenever the Task is aborted from the outside.

Separator; Numbered Notes

1. Shorthand comparison; **END** terminates Activity only.

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[5] The corresponding Definitions Page is: The example shows

STYRENE_PLANT. FURNACE Page: Definitions

NAME	STATE	STATES	MANUAL_STATE
FSHV	_	OPEN/CLOSED	_
FSVHV	_	OPEN/CLOSED	_
FNHV	_	OPEN/CLOSED	_

NAME	DOUT	STATE	STATES
FFIg	1	_	START/STOP

NAME	DIN	STATE	STATES
FFFI	1	_	LIT/COLD

NAME	OUT	VALUE	MIN	MAX	UNITS	STATES
FSV	1	_	0	100	%	CLOSED=0 / OPEN=80
FNV	2	_	0	100	%	CLOSED=0 / OPEN=100
FFV	3	_	0	100	%	CLOSED=0 / OPEN=50

NAME	IN	VALUE	MIN	MAX	UNITS	SET	HI	LO	DEV
FSF	6	_	0	100	CFS	_	_	_	_
FFF	7	_	0	100	CFS	_	_	_	_
FNF	8	_	0	100	CFS	_	_	_	_
FSP	9	_	0	500	PSIG	_	_	_	_

the declaration of State value variables with the States declarations (**OPEN/CLOSED**), defining the allowed State values. The State and States declaration capability can be applied to real variables, for which a particular State may correspond to a particular real value (or range of values), (**CLOSED=0/ OPEN= 80**).

[6] A final non-terminating called Task hangs up the calling Task rather than allowing it to continue (directly terminating). A similar hang-up occurs in Figure 14; the **HOLD** command in Figure 15 expresses the same hang-up explicitly.

[7] The Loop Statement algebra defines the basic one degree of freedom process control loop including feed forward, cascading, and multivariable constraint control and fanout. It compiles to the necessary control function with parameter tables, and supports bumpless transfer between sequenced loops.

2. **ABORT** is a system State entered whenever the Task or Operation is terminated abnormally. A State Prefix keyed on it expresses a statement or Activity to be carried out before the completed Task or Operation termination, in this case the orderly shutdown of the Separator.

Feed Tankage Operation

In the similar Feed Tankage Page (Figure 17), Control Feed introduces multivariable control: The Split Range (**SPLR**) Idiom splits the output range of the Tankage Flow controller so that when the Tankage Feed Valve is full open or full closed, control is picked up with the Tankage Recycle Valve. This overrides its normal control role: regulating the Tankage Reflux Level (noted by the OVERRIDE Idiom operator and the asterisks in the two loop statements and diagrams).

Conclusions

Formal control technology emphasizes control feedback difficulties. But practice is difficult because of its complexity. This complexity could be mastered, if more knowledgable control people addressed computer science more deeply. Basic mastery requires the development of appropriate language frameworks.

Such frameworks can unify, simplify, and clarify the handling of all aspects of control, so that no control dimension is allowed to overwhelm a user or his program specification. This paper has taken a small but representative multi-unit process, and shown how its control could be unified by such a framework.

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Figure 1. Styrene Plant Process Diagram

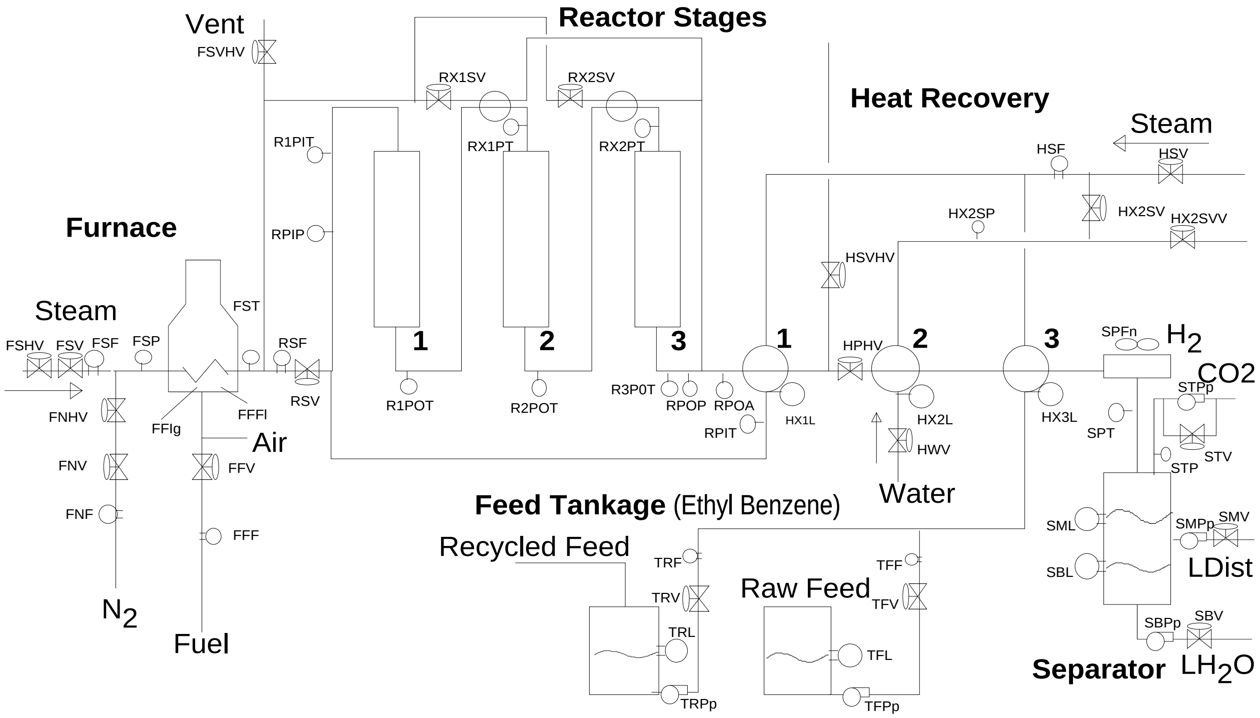
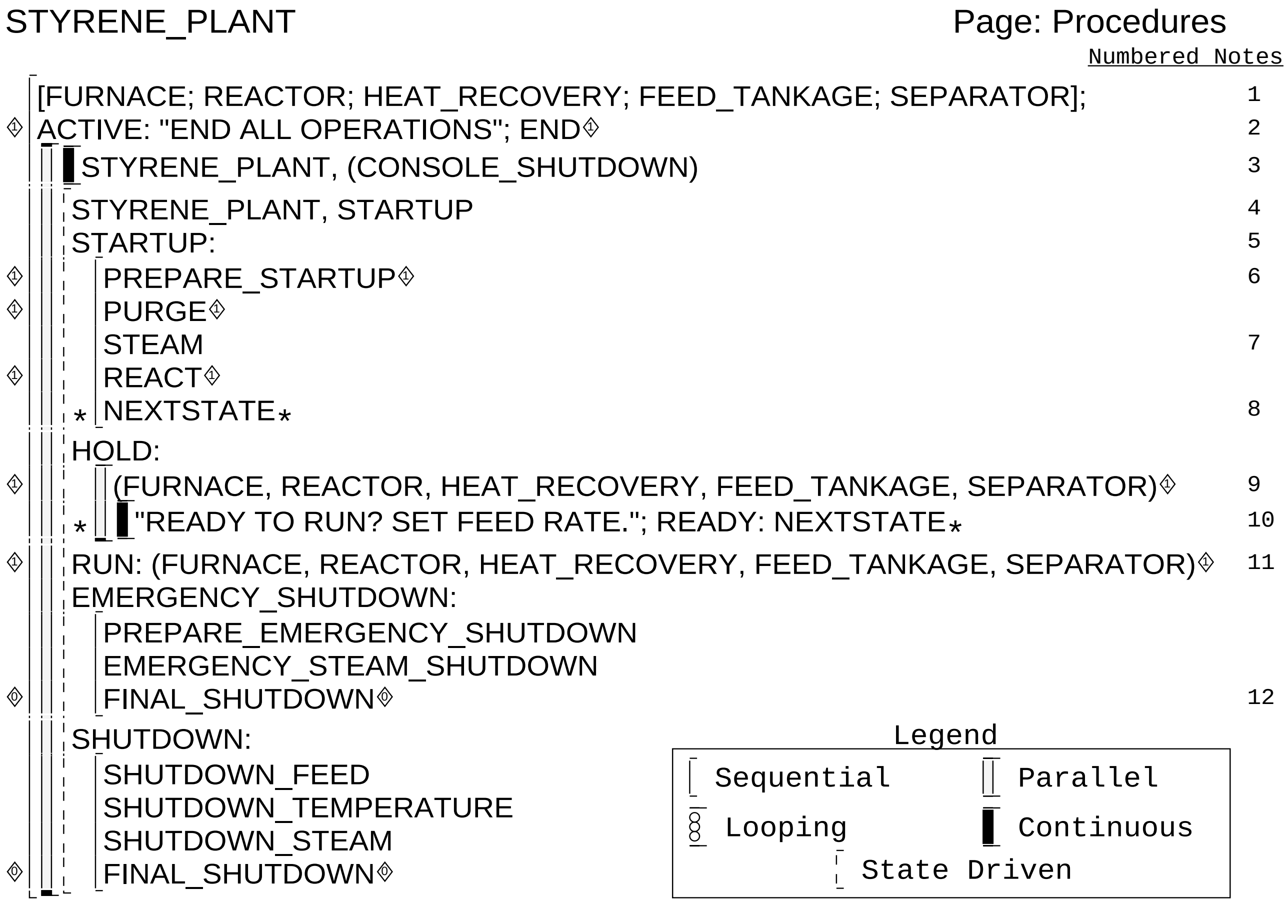


Figure 2. Styrene Plant Operation Main Activity

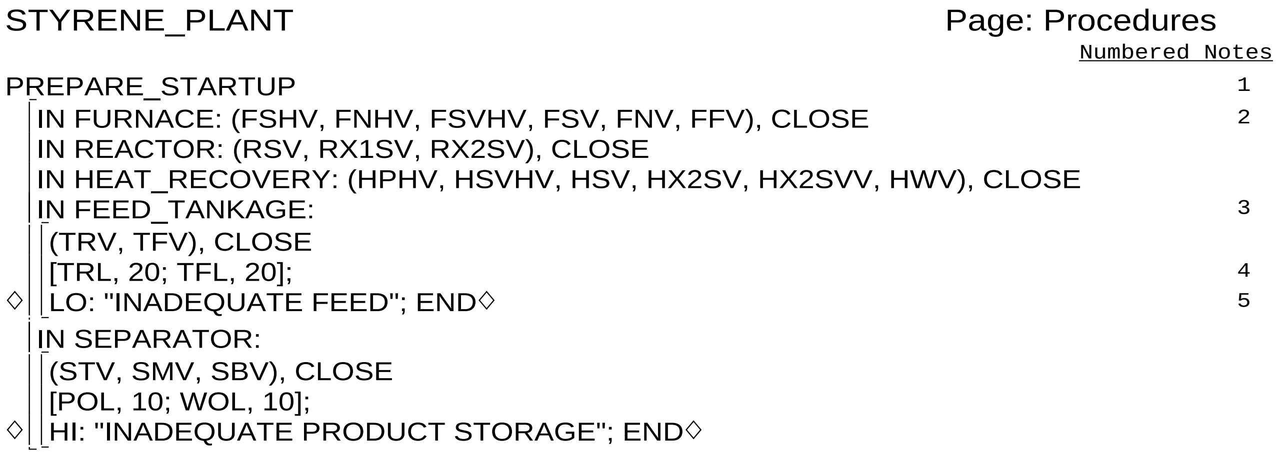


```
STYRENE_PLANT                                                  Page: Procedures
                                                                  Numbered Notes
 [FURNACE; REACTOR; HEAT_RECOVERY; FEED_TANKAGE; SEPARATOR];                  1
◊ACTIVE: "END ALL OPERATIONS"; END◊                                           2
   STYRENE_PLANT, (CONSOLE_SHUTDOWN)                                          3
    STYRENE_PLANT, STARTUP                                                    4
    STARTUP:                                                                  5
◊      PREPARE_STARTUP◊                                                       6
◊      PURGE◊
       STEAM                                                                  7
◊      REACT◊
    *  NEXTSTATE*                                                             8
    HOLD:
◊      (FURNACE, REACTOR, HEAT_RECOVERY, FEED_TANKAGE, SEPARATOR)◊            9
    *  "READY TO RUN? SET FEED RATE."; READY: NEXTSTATE*                      10
◊   RUN: (FURNACE, REACTOR, HEAT_RECOVERY, FEED_TANKAGE, SEPARATOR)◊          11
    EMERGENCY_SHUTDOWN:
       PREPARE_EMERGENCY_SHUTDOWN
       EMERGENCY_STEAM_SHUTDOWN
◊      FINAL_SHUTDOWN◊                                                        12
    SHUTDOWN:
       SHUTDOWN_FEED
       SHUTDOWN_TEMPERATURE
       SHUTDOWN_STEAM
◊      FINAL_SHUTDOWN◊
```

Legend

Sequential	Parallel
Looping	Continuous
State Driven	

Figure 3. Styrene Plant Prepare Startup Task



```
STYRENE_PLANT                                                  Page: Procedures
                                                                  Numbered Notes
PREPARE_STARTUP                                                               1
  IN FURNACE: (FSHV, FNHV, FSVHV, FSV, FNV, FFV), CLOSE                       2
  IN REACTOR: (RSV, RX1SV, RX2SV), CLOSE
  IN HEAT_RECOVERY: (HPHV, HSVHV, HSV, HX2SV, HX2SVV, HWV), CLOSE
  IN FEED_TANKAGE:                                                            3
    (TRV, TFV), CLOSE
    [TRL, 20; TFL, 20];                                                       4
◊   LO: "INADEQUATE FEED"; END◊                                               5
  IN SEPARATOR:
    (STV, SMV, SBV), CLOSE
    [POL, 10; WOL, 10];
◊   HI: "INADEQUATE PRODUCT STORAGE"; END◊
```

Figure 4. Styrene Plant Purge Task

```
STYRENE_PLANT                                      Page: Procedures
                                                     Numbered Notes
PURGE
  IN HEAT_RECOVERY: CONTROL_HX2                                   1
  IN REACTOR: RSV, OPEN
  IN HEAT_RECOVERY: HSVHV, OPEN
  IN FURNACE:
    CONTROL_NITROGEN                                              2
    RAMP FNF FROM 0 TO 5 CFS IN 2 MIN                             3
    FFIg, START
    RAMP FFV FROM 0 TO 5% IN 2 MIN
    FFIg, STOP
    [FFFI] COLD:
      "IGNITION FAILURE"
      FFV, CLOSE
◊     END◊                                                        4
    CONTROL FURNACE TEMPERATURE
    "FURNACE TEMPERATURE RAMPING TO 650, MONITOR R3POT."
    RAMP FST TO 650 IN 6 HR                                       5
```

Figure 5. Styrene Plant Steam Task

```
STYRENE_PLANT                                      Page: Procedures
                                                     Numbered Notes
STEAM
  IN HEAT_RECOVERY: CONTROL_HX2                                   1
  IN FURNACE:
    FSHV, OPEN
    CONTROL_FURNACE_TEMPERATURE                                   2
    CONTROL_STEAM_FLOW                                            3
    CONTROL_NITROGEN                                              4
      RAMP FSF FROM 0 TO 50 CFS IN 30 MIN                         5
      RAMP FNF TO 0 CFS IN 30 MIN
```

Figure 6. Styrene Plant React Task

```
STYRENE_PLANT                                        Page: Procedures
                                                       Numbered Notes
REACT
◊||(FURNACE, REACTOR, FEED_TANKAGE, SEPARATOR)◊                      1
 ||IN HEAT_RECOVERY:
 |||HPHV, OPEN
 |||HSVHV, CLOSE
 |||CONTROL_HX2
 |||CONTROL_STARTUP_VAPORIZED_FEED
*||IN FEED_TANKAGE: RAMP TF FROM 0 TO 20 GPM IN 30 MIN; END*         2
```

Figure 7. Styrene Plant Prepare Emergency Shutdown Task

```
STYRENE_PLANT                                        Page: Procedures
                                                       Numbered Notes
PREPARE_EMERGENCY_SHUTDOWN
 ||(FURNACE, REACTOR, FEED_TANKAGE, SEPARATOR)                       1
*||WAIT 10 MIN; END*                                                 2
```

Figure 8. Styrene Plant Emergency Steam Shutdown Task

```
STYRENE_PLANT                                        Page: Procedures
                                                       Numbered Notes
EMERGENCY_STEAM_SHUTDOWN
 ||IN HEAT_RECOVERY:
 |||HSVHV, OPEN
 |||(HPHV, HWV), CLOSE
 ||IN FURNACE:
 |||CONTROL_FURNACE_TEMPERATURE
 |||CONTROL_STEAM_FLOW
 |||CONTROL_NITROGEN
 |||||RAMP FSF TO 0 CFS IN 10 MIN
 |||||RAMP FNF TO 50 CFS IN 10 MIN
*|||END*                                                             1
```

Figure 9. Styrene Plant Final Shutdown Task

```
STYRENE_PLANT                                        Page: Procedures
                                                          Numbered Notes

FINAL_SHUTDOWN
   IN FURNACE:
      (FFV, FNV, FSV), CLOSE
      (FNHV, FSHV), CLOSE
   IN REACTOR: (RX1SV, RX2SV), CLOSE
   IN HEAT_RECOVERY: HSVHV, CLOSE
◊  END◊                                                         1
```

Figure 10. Styrene Plant Shutdown Feed Task

```
STYRENE_PLANT                                        Page: Procedures
                                                          Numbered Notes

SHUTDOWN_FEED
      (FURNACE, REACTOR, HEAT_RECOVERY, FEED_TANKAGE, SEPARATOR)
*     IN FEED_TANKAGE: RAMP TF TO 0 GPM IN 15 MIN; END*         1
```

Figure 11. Styrene Plant Shutdown Temperature Task

```
STYRENE_PLANT                                        Page: Procedures
                                                          Numbered Notes

SHUTDOWN_TEMPERATURE
      (FURNACE, HEAT_RECOVERY, SEPARATOR)
      IN REACTOR:
         (RX1SV, RX2SV), CLOSE
         RSV, OPEN
*     IN FURNACE: RAMP FST TO 350 IN 2 HR; END*                 1
```

Figure 12. Styrene Plant Shutdown Steam Task

```
STYRENE_PLANT                                        Page: Procedures

SHUTDOWN_STEAM
      IN HEAT_RECOVERY:
         HSVHV, OPEN
         (HPHV, HWV), CLOSE
      IN FURNACE:
         CONTROL_FURNACE_TEMPERATURE
         CONTROL_STEAM_FLOW
         CONTROL_NITROGEN
            RAMP FSF TO 0 CFS IN 30 MIN
            RAMP FNF TO 50 CFS IN 30 MIN
*        END*
```

Figure 13. Styrene Plant Furnace SubOperation Procedures Page

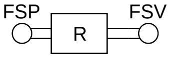
STYRENE_PLANT. FURNACE Page: Procedures

Numbered Notes

◊ [FST, 450; FSP, 100];
LO: END◊
CONTROL_FURNACE

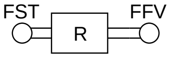
CONTROL_FURNACE 1

FSP $_{\text{REGULATE}}$ FSV 2



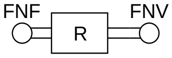
CONTROL_FURNACE_TEMPERATURE

FST $_{\text{REGULATE}}$ FFV



CONTROL_NITROGEN

FNF $_{\text{REGULATE}}$ FNV



CONTROL_STEAM_FLOW

FSF $_{\text{REGULATE}}$ FSV

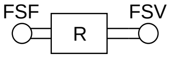


Figure 14. Styrene Plant Reactor SubOperation Procedures Page

STYRENE_PLANT. REACTOR Page: Procedures

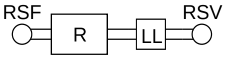
Numbered Notes

◊ [RSF, 20; R1PIT, 350; RX1PT, 350; RX2PT, 350];
LO: END◊
CONTROL_REACTOR

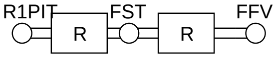
CONTROL_REACTOR

RSF = RSR*TF

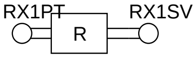
RSF $_{\text{REGULATE LOLIMIT}}$ RSV 1



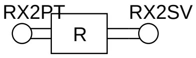
R1PIT $_{\text{REGULATE}}$ FST $_{\text{REGULATE}}$ FFV 2



RX1PT $_{\text{REGULATE}}$ RX1SV



RX2PT $_{\text{REGULATE}}$ RX2SV

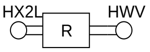


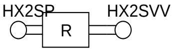
"MONITOR R1POT, R2POT, R3POT; RPOP, RPOA, RPIP. ADJUST RX1PT, RX2PT SETPOINTS AS NEEDED"

Figure 15. **Styrene Plant Heat Recovery SubOperation Procedures Page**

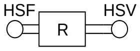
STYRENE_PLANT. HEAT RECOVERY Page: Procedures

```
  [HSF, 10; TF, 10; HX2SP, 200];
◊ LO: END◊
  CONTROL_HEAT_RECOVERY
  HOLD

CONTROL_HX2
  HX2L REGULATE HWV

  HX2SP REGULATE HX2SVV
```

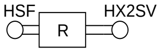




```
CONTROL_STARTUP_VAPORIZED_FEED
  HSF = HSR*TF
  HSF REGULATE HSV
```



```
CONTROL_VAPORIZED_FEED
  HSF = HSR*TF
  HSF REGULATE HX2SV
```



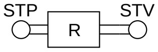
```
CONTROL_HEAT_RECOVERY
  CONTROL_HX2
  CONTROL_VAPORIZED_FEED
```

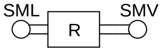
Figure 16. **Styrene Plant Separator SubOperation Procedures Page**

STYRENE_PLANT. SEPARATOR Page: Procedures

Numbered Notes

```
  (SPFn, STPp, SMPp, SBPp), START
  * [STP>1]: END*                          1
    CONTROL_SEPARATOR
    ABORT:                                 2
      (STPp, SMPp, SBPp), STOP
      (SPFn), STOP
      (STV, SMV, SBV), CLOSE
◊     END◊

CONTROL_SEPARATOR
  STP REGULATE STV

  SML REGULATE SMV

  SBL REGULATE SBV
```





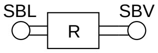
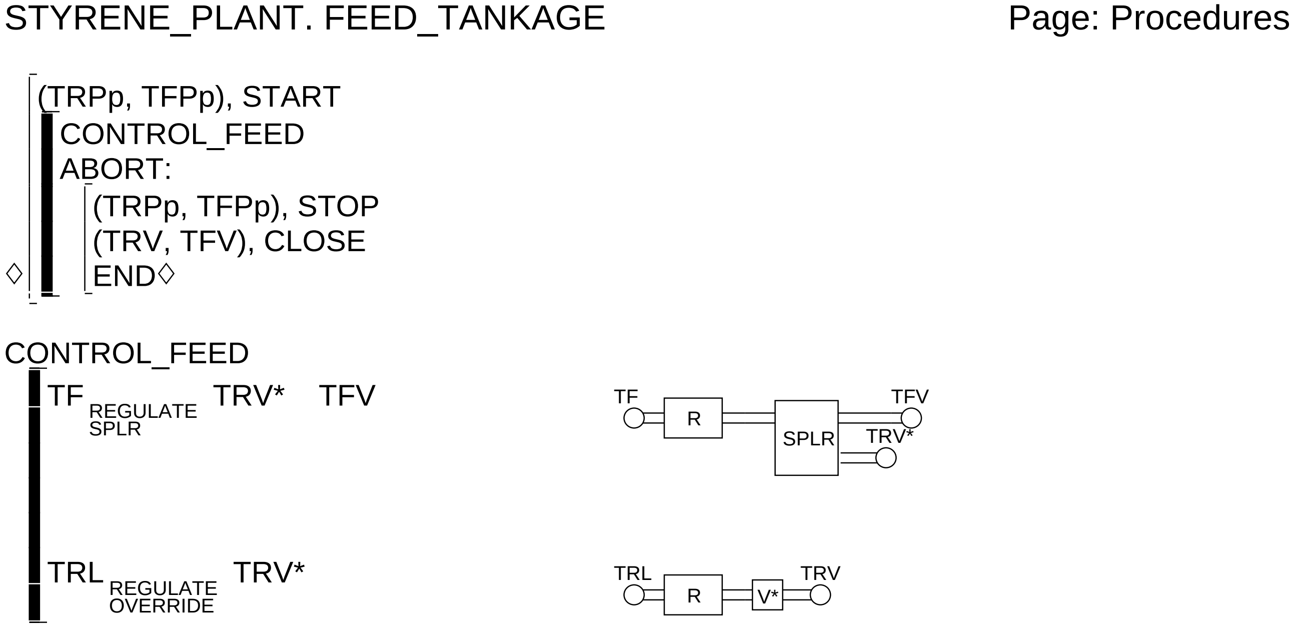


Figure 17. **Styrene Plant Feed Tankage SubOperation Procedures Page**



```
STYRENE_PLANT. FEED_TANKAGE                                   Page: Procedures

  (TRPp, TFPp), START
    CONTROL_FEED
    ABORT:
       (TRPp, TFPp), STOP
       (TRV, TFV), CLOSE
◊      END◊

CONTROL_FEED
   TF REGULATE SPLR  TRV*   TFV

   TRL REGULATE OVERRIDE  TRV*
```