EUROTHERM

CONTROLS
PROCESS AUTOMATION
RECORDERS

PC3000 USER GUIDE

Book 2
Languages

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INTRODUCTION

Edition 1

Contents

OVERVIEW

PC3000 is the first of a new generation of programmable process controllers which can be used to control both production and prototype processes. To develop control programs for the PC3000, Eurotherm Controls provide two advanced programming stations: the DOS based Programming Station which is fully described in this User Guide and the Microcell Programming Station which provides full graphical and spreadsheet programming along with integrated mimic screens and recipe management.

Both Programming Stations offer a full repetoire of facilities accessed by menus and user friendly screens.

These both provide the control and system engineer with a work station that is specifically designed to ease the task of developing control programs - through all phases from initial concept, development, commissioning to on-line operation. Each system also provides built-in help information so that descriptions of many functions and editors can be accessed directly from the screen.

In order to allow you to fully exploit the rich functionality of PC3000, further information is also provided by a suite of user guides and reference manuals.

PC3000 USER GUIDES

To help you use the PC3000 Programming Station, the user guides are arranged as a set of four books. Each book contains one or more manuals and is structured to answer specific basic questions :

Book 1 - PC3000 programming

"How do you use PC3000 ?"

Book 1 will tell you how to use all the facilities of the programming station to develop and commission your control programs.

Book 2 - PC3000 languages

"What facilities does PC3000 provide ?"

This user guide introduces the programming languages and concepts used by PC3000. It also provides some simple examples of the languages.

Book 3 - PC3000 in application

"Why are certain facilities provided and how can they be used ?"

This book contains a number of overviews on specific topics including :

PC3000 Communications overview

- introduces facilities and special function blocks which enable PC3000 to exchange control information and real-time data with other PC3000s and other proprietary equipment such as Programmable Controllers, SCADA, and Supervisory systems .

PC3000 Control overview

- describes some of the standard methods and techniques used for the control of processes using the PC3000 built-in and user-programmable function blocks, specically those concerned with PID.

PC3000 REFERENCES

In addition to the user guides, a number of reference manuals are provided to give detailed information on a wide range of topics. These manuals are not intended to be read cover-to-cover but are structured so that specific information can be located quickly.

The PC3000 Reference manuals include :

PC3000 real time operating system reference:

- provides a detailed description of the PC3000 real-time system and related topics including multi-tasking, performance, memory lay-out and fault detection.

PC3000 hardware reference

- provides detailed information on all the PC3000 hardware modules including calibration, wiring and physical configuration details.

PC3000 functions reference

- describes all the functions that can be called within the Structured Text (ST) language.

PC3000 function block reference

- describes the numerous function blocks available to be incorporated into your control program for PID control, Ramps, Counters, Filters, Timers etc.

Note: as it is the policy of Eurotherm Controls to continually refine and provide additional product information, the list and description of manuals provided for your system may differ slightly from those described.

ABOUT THIS GUIDE

You are advised read this guide before developing a PC3000 control program. PC3000 performance can be optimised and the integrity of the program ensured if a few simple principles are followed. This guide is written to supplement the PC3000 User Guide Book 1 Programmimg. It is envisaged that you may need to reference both user guides when developing programs for the first time.

Chapter 2 provides an overview of the PC3000 languages and concepts and is useful if you wish to quickly understand how the PC3000 can be programmed to solve control problems. A simple program example is described that depicts many of these concepts.

Chapter 3 provides a detailed description of the Structured Text language with examples.

Chapter 4 describes how to use the PC3000 Sequential Function Charts to program all the sequencing needs of both simple and complex control systems.

Chapter 5 is particularly important . You are advised to read Chapter 5 sections: Program Design Considerations and Program Development Stages, before starting a major programming project.

TERMINOLOGY AND ABBREVIATIONS

The following abbreviations are used in this user guide :

Actions	The Structured Text statements, including assignments that are evaluated when a specific step is active.
Assignment	A Structured Text statement that produces a value that is written to a specified function block parameter.
Boolean Expression	A Structured Text expression that produces a "true" or "false" result.
Chart	A Sequential Function Chart is a collection of graphically connected (wired) steps and transitions that form one or more sequences. It always has a single start step.
Expression	A Structured Text construct that produces a value of a specific data type.
Function Block Instance	A Function Block that has been created to be of a particular Function Block type and has a unique name.
Instantiation	The process of creating Function Blocks of a particular function block type.
PID	Proportional, Integral and Derivative control algorithm
SFC	Refers to the IEC Sequential Function Charts language and construction.
ST	Refers to the IEC Structured Text high level language
Statement	A Structured Text language statement is a collection of language keywords, operators and functions that performs a specific purpose and is terminated with a semicolon.
Step	A Step within the Sequential Function Chart that defines a particular process state or phase and is represented by a rectangular box.
Transition	A short horizontal line that represents the point where there is a change (ie. transition) from a step(s) to another step(s). It represents a decision point at some stage in the process. On meeting the condition control passes from the current step(s) to the next step(s).
Transition Condition	The condition that when "true" causes the transition between active steps. When using the PC3000 Programming Station, is defined as a boolean expression in Structured Text. On meeting the transition condition, control passes from the current set of steps to a new set of steps.

Chapter 2

PROGRAMMING CONCEPTS

Edition 2

Contents

OVERVIEW

The following programming concepts of the PC3000 are described in this chapter.

1. The design of PC3000 programming languages and how they are based on international standards.
2. How complex control programs can be built by connecting "soft instruments" or Function Blocks together by software.
3. The purpose of PC3000 Function Blocks and how they are described.
4. The advantages of using PC3000's multi-tasking system that allows different parts of the control program to run at different scan rates.
5. How you can use Function Blocks and Sequential Function Charts (SFCs) to operate together when building a control program.

Background

The PC3000 is a new generation, highly configurable Programmable Controller which is suitable for the automation of a wide range of industrial processes. Because PC3000 can easily be configured by having both modular hardware and software, it can be applied to both prototype and main-stream production processes.

The PC3000 programming languages have been designed to be compliant with the IEC 1131-3 Programmable Controller languages standard. The languages are suitable for programming the diverse range of applications for PC3000. These include, furnace control for heat treatment, cable manufacture, water treatment and fermentation through to advanced "hi-tech" applications, such as, super-plastic forming presses for aircraft turbine blades and molecular beam epitaxy (MBE) systems. In addition, the languages are ideal for creating control programs on small Personal Computer based programming stations.

A typical production process control system must handle a range of different control problems that include:

Interlocks that control the conditions under which certain activities or processes can operate. For example, a steam valve may not be activated unless sensors indicate that steam pressure is above a certain threshold value and steam is required by the process.

Alarms that are triggered when certain boundary conditions are exceeded. For example, an alarm signal that is triggered when a temperature of a process vessel exceeds normal working temperatures.

Closed Loop Control for ensuring that processes are run under optimal conditions. For example, PID loops can be used to ensure that a furnace temperature is kept to within an acceptable band, i.e. within particular high and low limits while the furnace is loaded.

Sequencing to facilitate the initiation and termination of key phases of a process under well defined conditions. For example, an ingot in a heat treatment furnace should be removed when the furnace has been at or above a prescribed temperature for a given period.

Long Loop Control where long term conditions are monitored and actions taken to optimise process yield. For example, the efficiency of a pump may gradually deteriorate due to impeller wear. This can be detected by monitoring the mean power consumption of the pump over a long period of time using Statistical Process Control techniques. The pump rate can then be adjusted to compensate for wear.

The languages adopted for PC3000 allow you to describe all of these aspects of the control program in a consistent and natural way. These languages are easy to read and maintain and are in a form that can be understood by people with different levels of computer expertise.

IEC 1131-3 PLC STANDARD

Figure 2-1 depicts the main components of a PC3000 program.

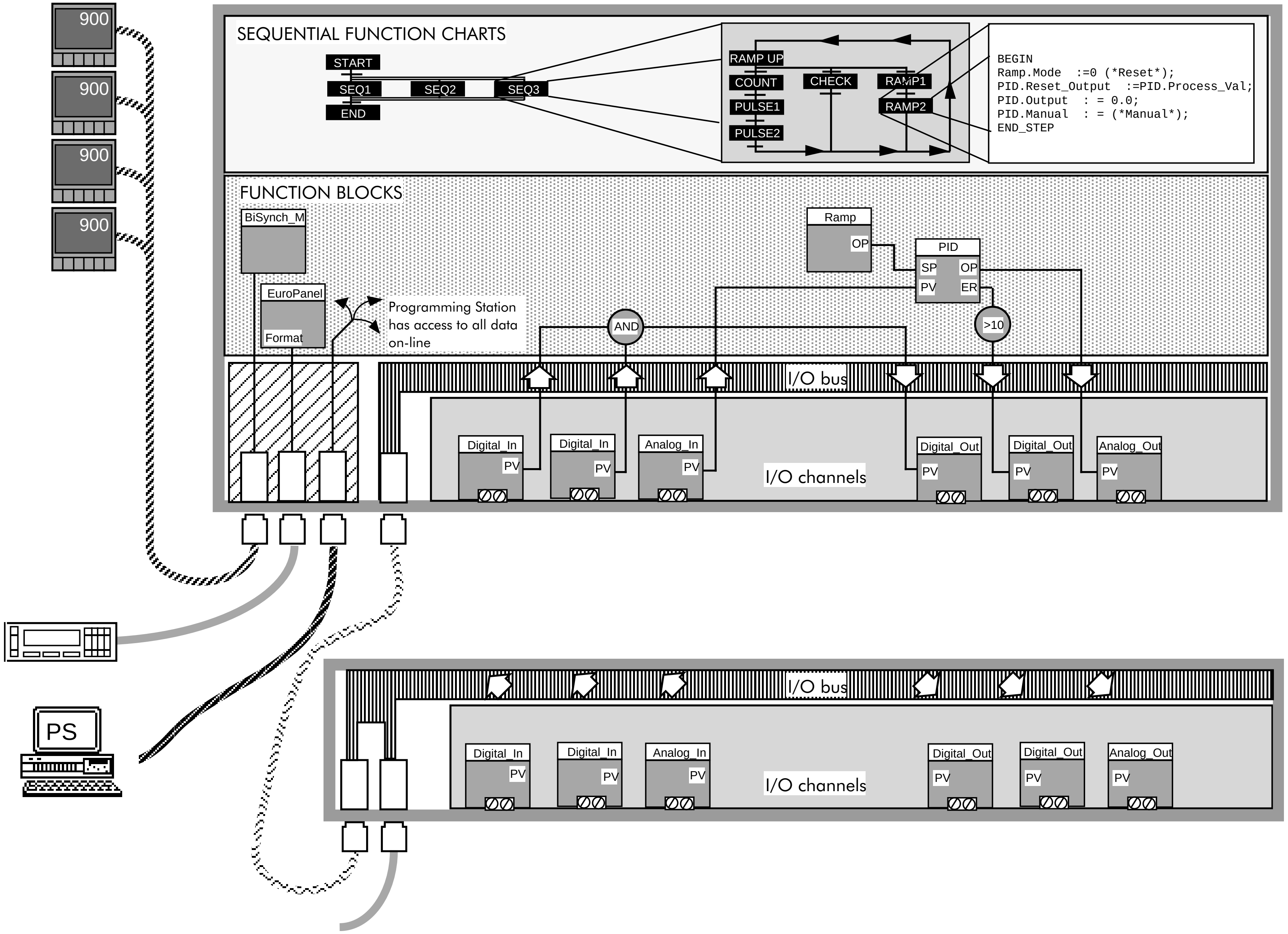
The International Electrotechnical Commission (IEC) have produced a set of standards for Programmable Controllers. identified as IEC 1131. Part 3 of this standard, termed IEC 1131-3, specifically addresses PLC languages and the way PLCs operate and run control programs. Many of the concepts of this standard are used both in PC3000 and also in other Eurotherm Controls products including the Production Orchestrator cell controller.

The following languages are available for programming the PC3000 :

Structured Text or ST - a high level language which can be used to express complex analogue and digital expressions. The language includes support for complex arithmetic operations, calculations involving times and dates and conditional expressions using constructs such as IF, THEN, and ELSE. There is also a comprehensive library that provides functions such as SQRT(), SIN(), MAX()

Sequential Function Chart or SFC - a graphical language which provides a diagramatic representation of sequences shown as a series of linked steps and transitions. SFC is based on the now well accepted Grafcet standard but with some additional features. It is provides a highly visible method for defining and, during operation, for analysing the behaviour of the control system, by showing the active states of the system in the context of all the possible alternative and parallel sequences.

Function Block Diagram or FBD - a graphical language which allows program elements called Function Blocks to be interconnected by simply drawing wires on the screen, i.e. in a form analogous to designing a circuit diagram using a CAD system.



```
BEGIN
Ramp.Mode  :=0 (*Reset*);
PID.Reset_Output  :=PID.Process_Val;
PID.Output  : = 0.0;
PID.Manual  : = (*Manual*);
END_STEP
```

Note: FBD programming is only provided by the Microcell Programming Station.

Multi-tasking

In accordance with IEC 1131-3, PC3000 allows the control program to be organised into tasks that run at different execution rates. Normally PC3000 has two tasks that run every 10ms and 100ms but extra tasks can be created or task execution rates can be modified to suit the particular process requirements. A task is a part of a program that is executed periodically.

Many PLCs have a very simple strategy where all the PLC program (normally ladder logic expressions) are scanned, i.e. executed, at a fixed scan rate. However, with PC3000, a program can use processing resources more efficiently if different parts of the program execute at different scan rates, as dictated by the responsiveness of the associated plant.

For example, some digital inputs dealing with fast mechanical interlocks may need to be scanned very rapidly, other digital inputs concerned with say, over temperature sensors can be scanned more slowly. Typically, analogue inputs are scanned more slowly than digital inputs. There may also be parts of the application required to analyse long term trends. In such cases, tasks can be configured to execute at much slower rates, such as every 5 minutes or longer.

Deterministic performance

Unlike many PLCs, PC3000 provides tasks that have fixed scan rates. For example, providing certain performance considerations are followed, it is possible to build a control system in which function blocks assigned to run in a 100 ms task will always execute every 100 ms. Deterministic Performance is important for stable and predictable control system behaviour.

If too many function blocks are assigned to a task, PC3000 may overrun, i.e. the task scan time has to be extended to ensure that the task completes correctly. This is regarded as an exceptional situation that requires modification of the function block task assignments.

Further information on using tasks is provided in the PC3000 Real Time Operating System Reference.

FUNCTION BLOCKS

Traditionally, control systems have been constructed by physically wiring together a number of discrete instruments, such as, temperature controllers, timers, displays and so on. However, systems of this type are costly to install and are extremely inflexible.

In constrast, PC3000 allows control programs to be built-up from "soft instruments" called function blocks. This powerful concept, formalised by the IEC 1131-3 standard, allows proven software components with functionality similar to real instruments to be connected together to form complex control systems simply by software - a concept called **"soft-wiring"**.

A function block contains an "encapsulated" program or algorithm which can be accessed and controlled externally by a set of parameters. It is "encapsulated" so that the systems engineer need not be aware of the way the function block has been designed internally. In fact, the only access to the function block is via a set of formal parameters provided by the original designer.

Normally a function block will have a set of input parameters which can be used to connect (or soft-wire) to other function blocks. Input parameters can be driven from live control signals originating from the plant or assigned values by external devices such as operator stations and supervisory systems.

The input parameters can be used to modify the function block's behaviour . Each time a function block executes, which depends on the task it is associated with, it is run using the current input parameters and other internally stored data. The internal algorithm then updates the output parameters.

Function blocks in some form, have been used in control instrumentation for many years. For example, the PID algorithms that run is discrete instruments such as Eurotherm Controls 818 and 900 EPC instruments behave as function blocks. The PC3000 has an extensive library of function blocks from which the systems and control engineer can build complex applications. The library includes PID and Valve Positioner function blocks with auto and adaptive tune, Timers, Counters, Filters and Bistables. There are also blocks for specific applications, for example, for building Recipe Management systems, for communicating with other proprietary devices such as PLCs and for real-time Statistical Process Control (SPC). With function blocks you are able to "plug and play" and develop new and novel solutions to process problems.

Function block example

Figure 2-2 depicts a Ramp Function Block which can be used wherever there is a requirement to generate a value that increases at a constant rate. The **Ramp** function block will ramp the output parameter (actually called **Output**) towards the value of the **Setpoint** input parameter at rate determined by the **Rate** input parameter.

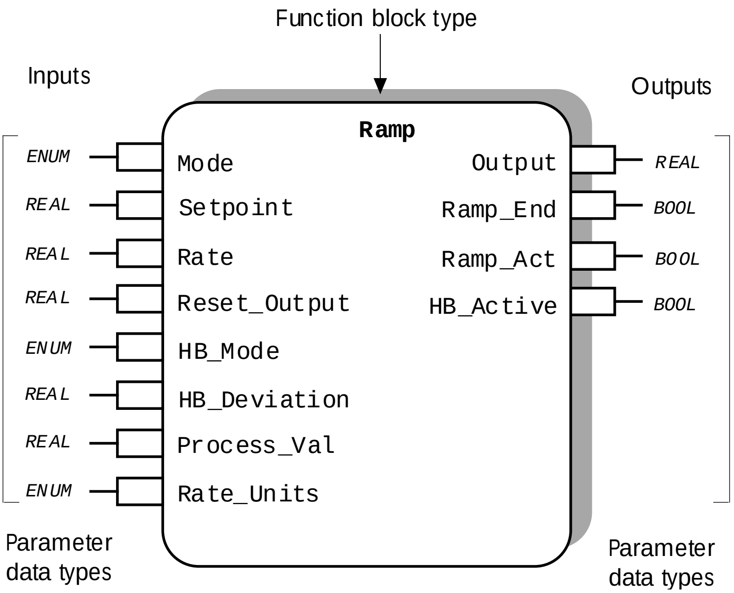


Figure 2-2 Function Block Example

The function block also supports a hold-back mode whereby the Output can track the value of the process value, i.e. the **Process_Val** parameter, within a given deviation. This may be useful for example, when ramping a furnace temperature when the difference between the furnace setpoint temperature and actual temperature should stay within certain limits.

Each function block parameter is associated with a particular **data type** which defines the type and range of values that the parameter can store. A wide range of data types are provided including REAL parameters which are used for decimal (floating point) values such as 12.54, 0.0541, - 1220.1 ; BOOL parameters which have two states such as ON/OFF, TRUE/FALSE, UP/DOWN ; ENUM parameters which can have a number of named or enumerated states, for example the Mode parameter of the Ramp function block has states Reset, Run and Hold. Other data types are provided for holding counts, messages and dates and times.

Full details on Data types are given in chapter 3.

In PC3000 it is possible to create many copies of the same function block type. For example, you may wish to have three ramp function blocks to control three different control variables such as, pump rate, temperature and pressure. The copies can be given unique names e.g. RampPump, RampTemp, RampPres . Copies of a particular type of function block are referred to as function block **Instances**. When a new copy of a function block is created, all input parameters are given a standard set of default values. In many cases, these values can be left unchanged where the default values suit your application or if a particular feature of the function block is not required.

All values assigned to input parameters as constants, e.g. setting a PID Prop_Band parameter to 6.00 %, are used to reset the function block when it is initialised, i.e. used for **Cold Start** values.

When PC3000 runs, each function block copy or instance, runs entirely independantly of any other instance. For example, RampPump could be in Hold state, while RampTemp and RampPres are ramping to different setpoint values.

When a function block executes, the output values will, in many cases, change for each execution, even when the value of all the function block's input parameters are left unchanged. This is because the function block has internally stored variables that are used to accummulate values for counters, integrated values etc. For example, while the Ramp function block is in Run mode, the Output will increase on each subsequent function block execution until the ramp setpoint is reached although all the input parameters remain unchanged.

I/O Function blocks

For consistency, the gathering of input values from sensors and delivering output signals to actuators, heaters etc. is handled by input/output (I/O) function blocks. For example, the analogue input function block **Analog_In** provides a range of input parameters that configure the sensor type, and scale the input value to handle a wide range of input sensor types including most types of thermocouple. The input sensor value is provided by the function block's **Process_Val** output parameter in process units such as degrees C, millibars etc. Note that this function block also provides a test facility to override the current plant input value with a test value.

Each I/O function block is associated with a particular hardware I/O channel defined by an input parameter called **IO_Address.** This defines the I/O channel's physical location by rack number, module number and channel.

For example an I/O channel function block for the second channel of a hardware module in position 3 of rack 1 has an I/O address : 1:03:02

I/O addresses are automatically given by the PC3000 Programming Station when a channel is assigned. It is not possible to directly change the value of the I/O address parameter, but the I/O channel function block can be moved to a different hardware module.

For further information on the Ramp and Analog_In function blocks refer to the PC3000 Function Block Reference.

PROGRAM EXECUTION PRINCIPLES

The PC3000 user program for a particular control application, consists of a number of inter-connected function blocks to provide the continuous control aspects of the system and one or more Sequential Function Charts (SFCs) to define the sequential aspects. The SFCs contain actions that can modify the values of function block input parameters in response to certain events. SFCs are therefore able modify the system behaviour according to well defined changes in specific process conditions, such as reaching operating temperature, or emptying a reactor vessel.

The function blocks are partitioned into tasks that execute at fixed scan rates. The default task configuration which is suitable for a large number of PC3000 applications, has two tasks named Task_1 and Task_2,which execute every 10 ms and 100 ms respectively. Most function blocks associated with analogue I/O and analogue control are run every 100 ms; this includes the PID function blocks. The rest, i.e. those associated with digital signals and therefore requiring a faster system response are run every 10 ms. The Sequential Function Charts (SFCs) by default are run in the slower 100 ms task .

Task Name	Task Scan Rate	Purpose
Task_2	100 ms	All analogue related function blocks Most analogue I/O function blocks All Sequential Function Charts
Task_1	10 ms	All digital related function blocks All digital I/O function blocks Fast analogue I/O function blocks

Table 2-1 Default Task Configuration

However, the default task configuration can be modified if the control problem has some special requirements. All function blocks including those for I/O can be assigned to run at other scan rates by changing the task scan times or by creating additional tasks. This may be necessary, for example, when there is a need to increase the responsiveness of certain inputs by shortening the task scan times or alternatively a need to reduce system overheads by increasing the scan rates of certain function blocks.

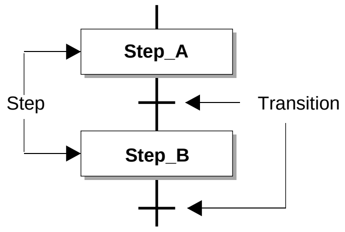
Caution:

Care should be taken when modifying task configuration parameters or task assignments as this may affect the control system responsiveness or produce unexpected side-effects. The PC3000 Programming Station automatically assigns function blocks to the two default tasks. Therefore modification to the task configuration is not normally required.

Refer to the PC3000 Real Time Operating System Reference, Chapter Real Time Task Scheduler for details on configuring tasks.

SEQUENTIAL FUNCTION CHARTS

Sequential Function Charts (SFCs) consist of two basic constructs, steps and transitions as depicted in Figure 2.3.



A **Step** defines a set of actions that are performed when the control program is in a certain state. A step remains active until a following **Transition** becomes true. A transition is defined by a test condition which must result in a true or false result; for example, that a particular digital input from a micro-switch is "on".

Figure 2-3 Sequential Function Charts Constructs

In Figure 2-3 , if Step_A is active, then Step_B will become active and Step_A inactive when the condition for the Transition from Step_A to Step_B becomes true.

When the SFCs are evaluated (normally by default every 100 ms), only the conditions of transitions from active steps are tested. In a well designed program, it is generally found that only a small number of steps are actually active at any time. As a consequence, PC3000 is able to execute complex programs, having SFCs with a large number of steps and transitions, without any significant performance overhead.

Actions within steps can be defined in Structured Text (ST) or in terms of further SFCs. Examples of ST statements to define actions within steps are :

```
loop1.Setpoint := 400.0;
tempRamp.Mode := 1 (* Run *);
vacpump.Process_Val := vacpump.Process_Val
           + 12.50 ;
```

Each Transition is defined by a condition expressed in Structured Text such as,

```
pumpswt.Process_Val = 1 (* On *) AND
      O2valve.Process_Val = 1 (* Open *);
```

In this example, two digital inputs pumpswt and O2valve provide the states of two digital process variables. So the transition condition can be read as "pump switch is on and oxygen valve is open"

For further details refer to Chapter 3 Structured Text. and Chapter 4 SFC Programming.

Note: On the Microcell Programming Station alternative graphical programming methods are provided including Spreadsheets and Function Block Diagrams.

SOFTWARE OVERVIEW

An application program for PC3000 consists of two main sections, 1) Function Blocks and their associated wiring to provide the continuous control and logic functions and 2) Sequential Function Charts to handle sequencing.

Figure 2.1 shows how these program sections interact with the PC3000 hardware that provides the interfaces to I/O sensors and actuators and communications with external devices. The figure shows a few examples of the many different types of function blocks provided with PC3000.

The interfaces to I/O is provided by I/O function blocks such as Digital_In and Analog_Out. The PC3000 I/OBus provides a two-way information exchange between these function blocks within the PC3000 application program and the I/O channels of the hardware I/O modules.

The PC3000 Programming Station (and MicroCell) has access to all Function Block parameters while the PC3000 is running using the Eurotherm communications protocol Bisync. This facility is referred to as "default communications" and is always available for diagnostic and program development purposes.

Communications with other external devices is provided by communications driver function blocks such as Bisync_M and Euro_Panel. In figure 2-1, the Bisync_M function block is associated with a communications port linked to a number of multi-dropped instruments; in this case, using the Eurotherm Bisync protocol. The figure also shows an operator panel connected using the EuroPanel function block. A wide range Function Blocks for other protocols such as JBus/Modbus are also provided. This allows a large number of different types communicating devices to be connected to PC3000.

Refer to the PC3000 Communications Overview document for further information on communicating with external devices.

PROGRAM EXAMPLE

Figure 2.4 depicts a simple program example that demonstrates many the PC3000 programming concepts. The program uses a single PID control loop to drive a heat process and changes the setpoint for the control loop by a small sequence program.

This program is used to introduce the PC3000 programming techniques and is therefore intentionally simplistic but it will function.

Continuous Control

The single channel control loop is constructed by "soft-wiring" an analogue input channel function block (Temp1) to a PID block (Loop1) which in turn, then provides an output signal to an analogue output channel function block (Heat1).

The configuration parameters which are required to customise the input and output channel blocks to match the sensor and actuator characteristics and the PID tuning parameters are not shown in figure 2.4 to aid clarity.

To construct the "continous control" part of the program, the main actions are :

1. Allocate hardware modules and channels for the analogue input and output using the hardware configuration screen; for example, using modules such as AI4 and AO4 .

In this example, the analogue input is driven by channel 1 of module 2, and the output drives channel 2 of module 4, both in rack 1.

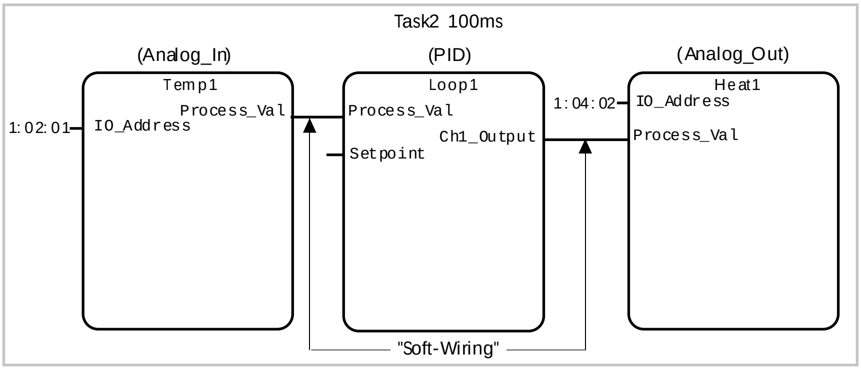
2 . Assign values for the configuration parameters to customize the input and output. The analogue input channel will normally require values for the following parameters :

Input_type e.g. Range_3. Check the Data sheet for the range supported by a particular hardware module. In this case, Range_3, selects -10 to 50mV operation.

Lin_Type to set the linearisation type e.g. J for a type J thermocouple

CJC_Type to set the type of Cold Junction Compensation e.g. intern for internal.

Pre_Scaler, Pre_Offset , Post_Scaler, Post_Offset to set the scalers to scale and offset the input signal before and after linearisation. These parameters are used in conjunction with **PV_Max** and **PV_Min** to produce the required engineering units.(ie. 0 to 100 degrees C). The values 1.0 and 0.0 for both scalers and offsets should be suitable for this example. E.g. Post_Scaler to 9/5 and Post_Offset to 32 would produce a value in degrees F. With Post_Scaler set to 1 and Post_Offset to 0 will produce a value in degrees C.



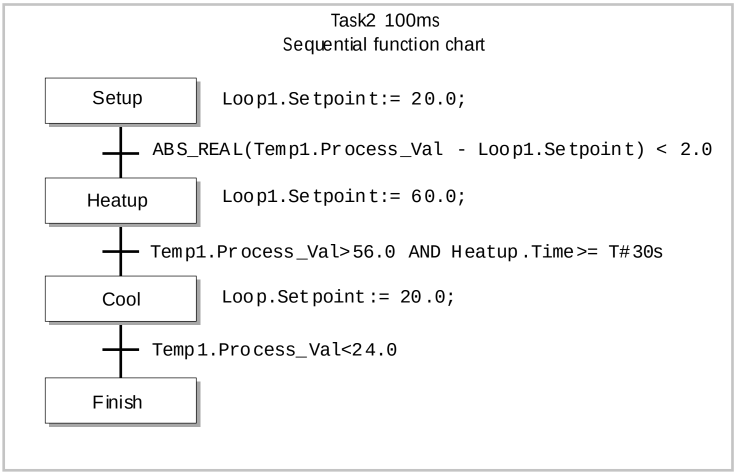

Task2 100ms
Sequential function chart
Setup
Loop1.Setpoint:= 20.0;
ABS_REAL(Temp1.Process_Val - Loop1.Setpoint) < 2.0
Heatup
Loop1.Setpoint:= 60.0;
Temp1.Process_Val>56.0 AND Heatup.Time>= T#30s
Cool
Loop.Setpoint := 20.0;
Temp1.Process_Val<24.0
Finish

Figure 2-4 Simple Program Example

PV_Max, PV_Min set these to define the acceptable range of values for the input eg. 0 to 100.

> **Note:** If PV_Max is left at 0, the analogue input status **Act_Status** may be set to NOGO because the input value is out-of-range.

The analogue output channel function block requires a value for **Output_type** to define the range of the output actuator, or drive e.g. mA4_20 for 4 to 20 milliamps.

3. The PID function block also requires the following configuration parameters :

Span_High, Span_low set these to match the range of the analogue input.

Output_High,Output_Low ensure these are set to 100 and 0 percent. If Output_Low is set to -100 percent, the PID will function in dual channel mode (heat/cool).

Prop_Band, Integral and **Derivative** set these as required by the controlled process.

Manual set to Auto to switch the PID into automatic mode.

4. Construct the "soft-wiring" to link the three function blocks, i.e. :

Loop1.Process_Val := Temp1.Process_Val;

and

Heat1.Process_Val := Loop1.Ch1_Output;

When using the PC3000 Programming Station, these statements are attached to the input parameter of the function block to receive the value; in this case Loop1 and Heat1.

> **Note:** Wiring statements are created at the DESTINATION parameter

Further details on hardware configuration may be found in the PC3000 Hardware Reference handbook.

The continuous control part of this simple example is now complete and if this program is now compiled, built and downloaded into the PC3000, the three functions blocks will behave as a simple single loop controller. The loop setpoint can be set by changing the PID input parameter, Loop1.Setpoint .

Sequencing

The control loop is sequenced by a small SFC with steps; Setup, Heatup, Cool and Finish.The Structured Text for each Step and Transition is shown alongside the SFC in figure 2-4. The Setup step establishes an initial setpoint of 20.0 and waits for the process value to settle. During the Heatup step, the process is driven to a higher setpoint of 60.0. The Heatup step continues until the process value has reached a threshold value of 56.0 and has been active for period of more than 30 minutes. The Cool step is then activated which changes the setpoint back to 20.0. When the process value has cooled to below 24.0, the SFC terminates by entering the Finish step.

To program the SFC using the Programming Station the following actions are required :

1. Use the SFC editor to create a four step SFC in the main chart. The first step should be defined as a "start" step and given the name Setup. Also name the other steps Heatup, Cool and Finish. The Finish step should be defined as an "end" step.

2. All three steps should be defined as "single shot" implying that they will only execute once when the steps are first entered.

3. Enter the Structured Text for each step and transition as shown in figure 2-4. Note that the transition from Start to Heat uses the function ABS_REAL which is used to calculate the absolute value of the PID error parameter.

The condition for the second transition uses the AND operator to check that

a) the process value is greater then 56.0 and

b) the Heatup step has been active for longer than 30 minutes.

The duration of any active step is provided by the step's **Time** (abbreviated .T) output parameter.

To test the program - compile, build and download the program into the PC3000. With the PC3000 switched into RUNNING mode, the program will execute by sequencing through steps Setup to Finish setting the PID setpoint. Note that on reaching the Finish step, the SFC terminates with no further active steps. However, the function blocks for the control loop continue to execute. With this simple example, it is necessary to RESET the PC3000 and then switch the PC3000 back into RUNNING mode to re-start the SFC. It is possible to construct the SFC so that it always re-starts, this is discussed in Chapter 4 SFC Programming.

The PC3000 mode is displayed on the main menu of the PC3000 Programming Station when in on-line mode. Use the command RUN to switch the PC3000 into the RUNNING mode.

All the function blocks in this example are associated with analogue control and all execute in Task2 which by default runs every 100 ms. The SFC also executes in the same task but remember that only the active step and it's associated transition conditions are evaluated every 100 ms.

For further system details on timing and execution of SFCs and function blocks refer to PC3000 Real Time Operating System Manual.

Digital Logic

To complete this example, figure 2-5 shows how a simple alarm condition can be added by using digital function blocks. These are inter-connected using soft wiring in exactly the same way as the analogue blocks. The example assumes that an alarm signal is required to switch off power to the process, whenever either of two doors (Door1 and Door2) are opened and the temperature of the process is greater than 50.0.

I/O channel function blocks for digital inputs Door1 and Door2 provide the state of doors, for example, by connecting the hardware digital inputs to micro-switches. The alarm output signal is driven by a digital output function block, Alarm.

The Alarm Process_Val input parameter is "soft-wired" using an ST expression that involves both the process value of the digital input function block and the Temp1 function block. Soft-wiring can either provide direct point-to-point links as used to construct the control loop, or can involve complex expressions with both digital and analogue function block parameters.

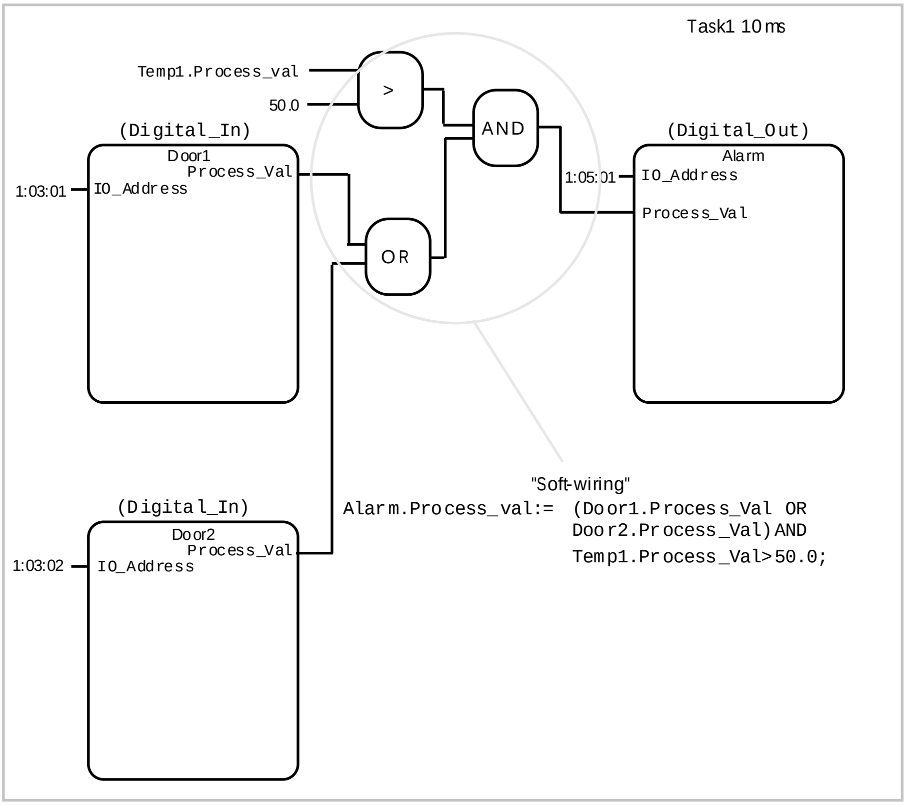


Figure 2-5 Digital Logic Example

To create these function blocks and soft-wiring, the following actions are required:

1. Create two I/O digital input channel function blocks named Door1 and Door2 using a hardware module such as DI14_CON. There are no channel configuration parameters to set-up. Ensure that the **Test_Enable** parameter for each block is Off, i.e. the default value.

2. Create a digital output channel function block named Alarm using a hardware module such as DO12_RLY. Ensure that the **Test_Enable** parameter is Off, i.e. the default value.

3. Select the **Alarm.Process_Val** parameter and attach the soft-wiring Structured Text statement as shown in figure 2-5 .

The digital function blocks are assigned to Task 1 which runs every 10 ms. The soft-wiring connected to the process value of the output function block Alarm, is also evaluated every 10 ms i.e. the same as the Alarm function block.

The example program is now complete and can be compiled, built and downloaded into the PC3000. The control loop and alarm digital logic are executed continously while PC3000 is in RUNNING mode. The sequencing will proceed through the four steps starting from Setup. Table 2-2 depicts the execution order that is automatically created by the Programming Station to run the program. In most cases, detailed knowledge of the execution order is not required.

Every 10 milliseconds -	
	Read the hardware digital input channels Door1 and Door2
	Execute the digital I/O channel function blocks and the alarm digital logic soft-wiring.
	Write the Alarm output value to the digital hardware channel.
Every 100 milliseconds -	
	Read the hardware analogue input channel Temp1
	Execute function blocks Temp1, Loop1 and Heat1 and the soft-wiring forming the control loop.
	Execute active SFC steps and evaluate transition conditions following active steps.
	Write out the output value to the analogue hardware channel.

Table 2-2 Example Program Execution Order

SOFT-WIRING PERFORMANCE CONSIDERATIONS

When designing large PC3000 programs it is important to appreciate that a large number of soft-wiring statements can present a significant performance overhead.

> **Note:** Each soft-wiring ST statement is executed at the same rate and in the same task,as the function block receiving the value produced by the soft-wiring.

Care should therefore be taken to minimise the number and complexity of soft-wiring statements assigned to function blocks that have a high scan rate, particularly digital function blocks. Soft-wiring containing a large number of operations involving floating point values, such as comparing Temp1.Process_val with 50.0 used in the previous program example, presents a significant performance overhead. With good program design, the number of floating point calculations can be reduced.

In contrast, a large number of operations involving digital parameters, such as the OR of door1.Process_val and door2.Process_val used in this example, can be executed without any significant overhead.

More guidance on good program design is given in Chapter 5 Program Development. Detailed information on performance is also given in the PC3000 Real Time Operating System Reference Appendix C.

Chapter 3

STRUCTURED TEXT

Edition 1

Contents

OVERVIEW

This Chapter discusses :

- The features of the Structured Text language
- Where Structured Text can be used in PC3000 programs
- How different types of data can be handled in Structured Text
- How to use functions within Structured Text
- Good Programming style for Structured Text

Introduction to structured text

Structured Text (abbreviated as ST) is a high level textual language which has been formalised by the IEC 1131-3 PLC Programming Languages standard for use in programming controllers for industrial manufacturing processes. ST provides a wide range of features that make it particularly suitable for programming the control of industrial processes.:

- All variables used within the language can be given meaningful names such as:

```
pumpRate.Setpoint
heat1.Output_Type
```

- Both simple and complex expressions for mathematical calculations can be clearly expressed, e.g.

```
FlowRate.Val := FanSpeed.Process_Val * 3.5;
```

- Conditional expressions, i.e. for values that are derived from tests of some form, are well supported. For example, to deal with requirements such as: "The motor speed is 200 r.p.m. when the casting is less than 5 Metres from the tool-head otherwise the speed is 20 r.p.m." can be expressed as:

```
IF Position.Val < 5.0 THEN
          Motor.Process_Val := 200;
ELSE
          Motor.Process_Val := 20.0;
END_IF;
```

- A wide range of different types of data can be used including floating point and digital values, times, time of day and dates. There is also provision for handling textual messages.
- Expressions involving different types of data are possible, e.g:

```
gas.Process_Val := Zone1.Process_Val > 310.4
```

- A wide range of range of standard built-in operators are provided such as :

```
+,-,*,>,<,AND,OR,NOT
```

- The language has built-in safe-guards to prevent illogical operations between different types of data. For example, it is not possible use mathematical operations with digital input values, or logical operators such as AND with analogue values.
- Functions can be used to ease, otherwise complex program expressions, eg:

```
position.Val := SQRT(X.Val*X.Val + Y.Val*Y.Val);
```

```
position.Val := SQRT(X.Val*X.Val + Y.Val*Y.Val);
```

In general, fairly simple Structured Text statements are adequate when programming the majority of PC3000 control applications. However, the PC3000 Programming Station does allow large complex pieces Structured Text to be created if required. There are limits to the maximum size of an individual piece of ST but this is sufficiently generous that normally it is of no practical significance.

When programming PC3000, ST is used to describe :

a) "soft-wiring" to inter-connect function blocks,

b) the actions within SFC steps

c) the conditions for SFC transitions.

Certain restrictions apply to ST when used for these different purposes; these are discussed in more detail later in this chapter.

Comments

To aid readibility, comments can be freely added to ST statements by enclosing text with the characters (* and *). Examples are :

```
(* This step starts up reactor 2 *)
(* Modified to optimise energy usage *)
```

DATA TYPES

PC3000 supports a range of data types within Structured Text that cover most of the processing requirements for production process control. Writing ST expressions that use these different types of data is discussed in later sections of this chapter.

Note: throughout this user guide, where an informal data type decription is given, the formal IEC data type name is sometimes given in parenthesis.

Floating Point (REAL)

Range	Size in Bits	Purpose
$\pm 10^{\pm 38}$	32	Gerneral purpose data type for all floating point i.e. decimal values

This data type is used for storing all analogue floating point values both positive and negative values, and large and very small fractional values, e.g. 100.56, 100245.21, -0.000233

Integer (DINT)

Range	Size in Bits	Purpose
-2147483648 to +2147483647	32	Gerneral purpose data type for holding integer values, eg. for counters.

This is used for holding integer values , i.e. whole numbers and is used for counts, batch numbers etc. A large range of positive and negative values can be stored e.g. 12, 1235687, - 100040.

Enumerated Integer (DINT)

Range	Size in Bits	Purpose
-2147483648 to +2147483647	32	Gerneral purpose data type for holding integer values that have a defined set of named values, eg. for modes, status

This data type (sometimes abbreviated as ENUM) uses the same storage size as a the integer (DINT) but has names associated with a defined set of values. These names are displayed on the PC3000 Programming Station and are provided to aid readability.

For example, the PcsSTATE function block which defines the current state of the PC3000 control system has an output parameter Battery_Cond (battery condition) that is an enumerated integer. This has named states :

```
Good   (0)
Low    (1)
Faulty (2)
```

The appropriate name is displayed on the PC3000 Programming Station when the value of the parameter is viewed.

Enumerated integers can be freely used together with normal integers in ST expressions.

Boolean (BOOL)

Range	Size in Bits	Purpose
0 or 1	1	Gerneral purpose data type for storing boolean values, i.e. 0 or 1.

This data type is used to store boolean values, such as those associated with digital inputs for switch contacts, which can have two states of value 0 and 1. Normally 0 is associated with "Off" or "False" and 1 is associated with "On" or "True". The PC3000 Programming Station however allows boolean values to be given alternative sense names if required. The sense names are used to aid program readibility.

Examples are :

```
Down (0)
Up (1)

In (0)
Out (1)
```

Duration (TIME)

Range	Size in Bits	Purpose
Up to 49 days	32	Used specifically for storing time durations, such as job durations, PID time constants

This data type is used to store time durations accurately to the nearest millisecond. Any duration for up to 49 days can be stored. When viewed on the Programming Station, durations are displayed using the IEC format. Examples are:

```
T#2d_01h_30m  (* 2 days, 1 hour, 30 minutes *)
T#3s200ms  (* 3 seconds and 200 milliseconds *)
```

The use of the prefix T# in ST indicates that these are constants of TIME data type. The prefix is automatically inserted by the Programming Station.

Time of day (TIME_OF_DAY)

Range	Size in Bits	Purpose
00:00:00 to 23:59:59	32	Used specifically for storing values for the time of day i.e. 24 hour clock.

This data type is used wherever there is a need to store the time of day. For example, to define the time of day to start a particular job or task. Values are stored to an accuracy of one second and displayed on the Programming Station in 24 hour clock format .

Examples are :

```
TOD#09:30  (* 9:30 in the morning *)
TOD#13:45  (* 1.45 in the afternoon *)
```

The use of the prefix TOD# in ST indicates that these are TIME_OF_DAY constants. The prefix is automatically inserted by the Programming Station.

Calendar Date (DATE)

Range	Size in Bits	Purpose
01-Jan-1970 to 01-Jan-2136	32	Used specifically for storing values for calendar dates

This data type is used for storing calendar dates. A wide range of dates are supported.

Examples are :

```
D#28-Jul-1992
D#01-Jan-1993
```

The use of the prefix D# in ST indicates that these are date constants. The prefix is automatically inserted by the Programming Station.

Calendar Date and Time of day (DATE_AND_TIME)

Range	Size in Bits	Purpose
01-Jan-1970-00:00:00 to 01-Jan-2136-23:59:59	32	Used specifically for storing values for calendar dates combined with time of day

This data type is used for storing calendar dates along with time of day and is typically used to store "time stamps" for key events such as when jobs start, when alarms are raised, when operator shifts are changed etc.

Examples are :

```
DT#02-Sep-1992-20:30:00
DT#25-Jan-1991-23:00:30
```

The use of the prefix DT# in ST indicates that these are date DATE_AND_TIME constants.The prefix is automatically inserted by the Programming Station.

Textual strings (STRING)

Range	Size	Purpose
Each character can hold any character from the ASCII code set. Non ASCII codes from hexadecimal values $80 to $FF are also supported.	The length of a textual string is variable - see description	General purpose data type used for storing textual information consisting of a string of characters.

This data type is used for holding textual information such as operator messages, printer report messages, communication addresses, batch descriptions etc. The length of the string, i.e. the maximum number of letters and digits (characters) that can be stored depends on usage.

For example, the String User Variable function block can store textual strings of up to 80 characters, whereas the Long_String User Variable function block can be used for strings up to 255 characters.

For further information on User Variable function blocks refer to the PC3000 Function Block Reference.

Examples of textual strings are :

```
'Batch 723XA' (* Current Batch Identity *)
'0A01 PV' (* Address Port 0A, instrument 1 PV *)
'ADD REAGENT X1' (* Operator Message *)
```

Strings in ST are enclosed between apostrophe characters. These characters are automatically inserted by the Programming Station when a string constant is created.

It is possible to insert a non-printable character into a string by typing a dollar $ sign followed by the ASCII code in hexadecimal. E.g. to insert the bell character that will produce an audible sound on some operator stations type $07. The full ASCII code is given in the PC3000 Function Block Reference. Non-printable characters may be required to format textual messages to be issued to a printer.

Additional Integer Data Types

The majority of integers used in PC3000 function blocks and functions are of the DINT data type. However in a few rare cases parameters can be defined using integer data types listed in table 3-1.

IEC Data Type	Description	Size in Bits	Range
SINT	Unsigned Short Integer	8	-128 to 127
USINT	Unsigned Short Integer	8	0 to 255
INT	Unsigned Integer	16	32768 to -32767
UDINT	Unsigned Double Integer	32	0 to 42944967296

Table 3-1 Additional Integer Data Types for Function Block Parameters

The Table 3-1, data types described as "unsigned" imply that only positive values can be stored.

Caution

Care should be taken when assigning integer values created by ST expressions, to integer parameters that are not of the normal DINT data type. The range of the integer value created by the ST must be within the range of the data type of the parameter to receive the value. If the value is out-of-range an incorrect value may be assigned, e.g. assigning the DINT value 300 to a USINT will fail because the USINT maximum value is 255.

Note: These additional integer data types are not used in any of the standard PC3000 function blocks or functions with the exception of the string functions LEN, LEFT, RIGHT,MID, INSERT, DELETE, REPLACE, FIND, JUSTIFY_LEFT, JUSTIFY_RIGHT, JUSTIFY_CENTRE which have some USINT integer parameters.

Descriptions of functions and function blocks in the PC3000 Functions and Function Blocks References include the data type of each parameter.

IO Address

The I/O Address data type is used to store the physical position of an I/O channel function block. This is a special PC3000 data type which is not defined by the IEC standard. It is not possible to manipulate parameters of this type in ST since this would serve no practical purpose.

Note that I/O channel function blocks can be assigned to different physical addresses by using facilities provided by the Programming Station on the Hardware Definition screen.

I/O Address parameters are discussed in Chapter 2, PC3000 Programming Concepts.

Data Type Conversion

A wide range of functions are provided to convert between data types; refer to the PC3000 Functions Reference, Chapter Type Conversion Functions for the full list.

For example, a count held as an integer may be required in an expression to calculate the value of an analogue output. In this case, the function DINT_TO_REAL can be used to convert the integer value into a floating point (REAL) value, i.e.

```
height.Process_val :=
          DINT_TO_REAL(count) * 100.5;
```

WHERE TO USE STRUCTURED TEXT

Structured Text can be used for three different purposes in a PC3000 program but in each case, the basic structure of the language is the same.

Usage	Purpose	Language Constructs
Soft-wiring	Inter-connection of Function Blocks	Assignments Expressions
Step Actions	Assigning new values to Function Block Parameters	Assignments Expressions Statements Conditional Statements
Transition conditions	Defining a condition that when "true" causes a new step (or steps) to be active	Expressions

Table 3-2 Use of Structured Text

Structured Text provides a few, simple easy-to-learn, constructs - Assignments, Statements, Expressions and Conditional Statements which when used together, result in a flexible and expressive language. In order to produce efficient PC3000 programs, you are advised to become familiar with the following language constructs.

ASSIGNMENTS

Structured Text assignments allow new values to be written to Function Block input parameters. These values can be constants, the value of other parameters, or derived from other parameters using expressions. Assignments are used to inter-connect function blocks, i.e. in soft-wiring, and to define new parameter values in SFC steps.

Examples are :

```
loop1.Setpoint := 30.5;
count1.Process_Val := 300;
pulse3.Prog_Time := T#1s;
heat1.Process_Val := loop1.Output;
speed.Process_Val := rate.Process_Val * 20;
```

An assignment always starts with the name of the Function Block input parameter on the left-hand side followed by the symbol ":=".

The value of the right-hand side (i.e. following the ":=" symbol) should result in a value of the same data type as the function block input parameter. The assignment text is always terminated by a semicolon ";".

When creating "soft-wiring" assignments, the Programming Station automatically inserts the ":=" and ";" symbols.

Note: The Programming Station will report "Error Invalid ST" if an assignment is made to any function block output parameter. Assignments to input/output parameters are allowed.

When an assignment is used to inter-connect or "soft-wire" function blocks as part of the continous control strategy, remember that the assignment will be evaluated continously. That is, at the task scan rate of the function block to which the asignment is being made.

Expressions

A wide range of expressions can be created using the standard ST operators so that derived values can be calculated from parameters of the various ST data types. Expressions are used in the right-hand side of assignments and in conditional expressions. A typical simple expression involves one or two parameters or constants and an operator.

Examples of simple expressions :

```
123 + 34.6
10000 * count.Process_Val - loop1.Setpoint
NOT switch.Process_Val
```

Examples using simple expressions in assignments :

```
(* Add 120.0 degrees to the current soak
temperature *)
soakTemp.Setpoint := soakTemp.Setpoint + 120.0;


(* The line rate is 2 M/S plus 50% the conveyor
speed *)
lineRate.Process_Val := 2.0 +
         conveyor.Process_Val * 0.5;


(*Valve is ON if O2 supply is OFF and H2 is ON*)
valve.Process_Val := NOT O2.Process_Val AND
                                  H2.Process_Val;
```

Complex expressions

In some cases it may be necessary to build-up complex expressions involving many parameters and operators. A complex expression is composed of many sub-expressions each of which , in turn, may be composed of further sub-expressions or simple expressions. To clarify the execution order of complex expressions, round brackets "(", ")" can be used to identify the sub-expressions.

Examples :

```
(( airPress.Val * 13.54 )
         + ( gasPress.Val * 34.32 )
         - ( vapPress.Val * 0.5 ))


(switch.Process_Val AND dig3.Process_Val)
         OR
         (overpress.Process_Val AND  noAlarm.Val)
```

STATEMENTS

A section of Structured Text is composed of a number of statements. An assignment is one example of a simple ST statement. Conditional Statements are more complex and allow sets of ST statements to be selectively executed - as described in the next section.

In an SFC step, a variety of statements can be used to set up the values of function block input parameters as required for the particular process phase or state.

Example :

```
BEGIN
          heater1.Process_Val := 123.0;
          heater2.Process_Val := 130.0;
          fan.Process_Val := 1 (* ON *);
END
```

Note : The keywords BEGIN and END are automatically added by the Programming Station when Structured Text for a step is created. They indicate that the ST defines step actions

Conditional statements

A set of statements can be conditionally evaluated using a conditional statement structure. The PC3000 Structured Text provides the IF, THEN, ELSIF, ELSE and END_IF keywords to allow you to conditionally select statements according to certain control criteria.

In the simplest form, IF, THEN and END_IF can be used to conditionally select a set of statements.

Example:

```
IF switch.Process_Val = 1 (* COOL *) THEN
          fan.Process_Val := 1 (* ON *);
          fanSpeed.Process_Val := 230.0;
END_IF;
```

The expression between the IF and THEN keywords can be either simple or complex but must result in a boolean (BOOL) result, i.e. the expression must generate a value that can only be "True" (1) or "False" (0). This is known as a boolean expression.

In the example, the assignments to fan.Process_Val and fanSpeed.Process_Val only occur when switch.Process_Val has the value 1, otherwise the assignments are ignored. All the ST between the IF and the END_IF is known as a conditional IF statement and like other statements, it must be terminated with semicolon ";".

Using the ELSE keyword, alternative statements can be evaluated.

Example:

```
IF switch.Process_Val THEN
          gasFlow.Process_Val := 100.0;
          almEnable.Val := 1 (* ON *);
ELSE
          gasFlow.Process_Val := 30.0;
          almEnable.Val := 0 (* OFF *);
          report.Val := 'STANDBY';
END_IF;
```

In this example, the assignments to gasFlow.Process_Val, almEnable.Val and report.Val are only evaluated if the switch.Process_Val is off.

Because switch.Process_Val produces a boolean value, it can be used as the conditional expression in the IF...THEN construct.

The ELSIF ... THEN construct can be used to select one or more further sets of alternative statements.

Example:

```
IF count = 0 THEN
          speed.Process_Val := 20.0;
          door1.Process_Val := 0 (* SHUT *);
ELSIF count < 10 THEN
          speed.Process_Val := 40.0;
          door2.Process_Val := 0 (* SHUT *);
ELSE
          speed.Process_Val := 60.0;
          door3.Process_Val := 0 (* SHUT *);
END_IF;
```

In this case, if count is zero, the first set of assignments are made, if the count is less than 10 but not zero, the second set of assignments are made. Otherwise, the last set are made.

Where there is an IF... THEN construct followed by multiple ELSIF ... THEN constructs, only the set of statements associated with the first true conditional expression is evaluated.

Note: It is good practice to ensure that multiple ELSIF constructs have mutually exclusive conditions to ease program readability.

Further conditional statements can be used within any set of statements of a conditional statement. In other words, statements using IF constructs can be used within other IF constructs. This allows very complex conditional statements to be constructed. Each "nested" IF statement must be terminated with "END_IF ;"

Example:

```
IF zone1.Process_Val > 300 THEN
          timer.Prog_Time := T#4s;
          cool.Output.High := 90.0;
          IF zone1.Process_Val > 310 THEN
             boost.Process_Val := 400.0;
          ELSE
             boost.Process_Val := 350.0;
          END_IF;
END_IF;
```

OPERATORS

The operators shown in Tables 3-3, 3-4 and 3-5 can be used in PC3000 Structured Text expressions.

Arithemetic operation

Operation	Symbol	Data Types
Addition	+	Floating point(REAL), Integer(DINT)
Subtraction	-	Floating point(REAL), Integer(DINT) Note 1
Multiplication	*	Floating point(REAL), Integer(DINT)
Division	/	Floating point(REAL) Integer(DINT) Note 2
Modulo Note 3	MOD	Integer(DINT)

Table 3-3 Structured Text Arithmetic Operators

Note 1. The "-" symbol can also be used for negation, i.e. to convert a value to the opposite sign.

For example :

```
loop.Setpoint := - SPlow.Val;
```

Note 2. The division operator can be used with two integer data type parameters or constants. The result is always integer and any fractional part of the result is discarded.

For example :

```
12 / 5
(* This will yield 2 as the integer result.*)
```

Note 3. The modulus operator produces the remainder of an integer division. It can be only be used with integer data types and is typically used to count to a certain modulus.

Examples :

```
12 MOD 4  (* Result is 0 *)
14 MOD 4  (* Result is 2 *)
-4 MOD 3  (* Result is -1 *)
gearPos.Val := (gearPos.Val + pulses.Val) MOD 7;
(* The value of gearPos.Val is always between 0
and 6 for any value of pulses.Val *)
```

Comparison operators

Operation	Symbol	Data Types
Greater than	>	Floating point(REAL), Integer(DINT), All time and date data types
Less than	<	Floating point(REAL), Integer(DINT), All time and date data types
Equal	=	Floating point(REAL) Note 1, Integer(DINT), All time and date data types
Not-equal	<>	Floating point(REAL) Note 1, Integer(DINT), All time and date data types
Greater than or equal	>=	Floating point(REAL) Integer(DINT), All time and date data types
Less than or equal to	<=	Floating point(REAL) Integer(DINT), All time and date data types

Table 3-4 Structured Text Comparison Operators

Note 1. It is normally not advisable to test equality of floating point values as smalling rounding errors can cause the test to fail unexpectedly, e.g. (3.43212 * 2 = 6.86424) may be false.

These operators can be used to compare the values of floating point, integer and time and date data types, i.e. the IEC data types REAL, DINT, TIME, TIME_OF_DAY, DATE, DATE_AND_TIME. The two values being compared must be the same data type. These operators always return a result of boolean (BOOL) data type and are typically used to define process boundary conditions.

Examples:

```
purge.Time >= T#4m  (* Purge step duration
      greater than or equal to 4 minutes ? *)
loop1.Setpoint > 300.0 (* Loop Setpoint
                                   over 300.0 ? *)
```

Boolean operators

Operation	Symbol	Data Types
Boolean AND	AND	Boolean (BOOL)
Boolean OR	OR	Boolean (BOOL)
Boolean Exclusive OR	XOR	Boolean (BOOL) Note 1
Inverse or contrary Boolean sense.	NOT	Boolean (BOOL) Note 2

Table 3-5 Structured Text Boolean Operators

Note 1. The exclusive OR operator (XOR) is useful where it is necessary to evaluate whether only one of two parameters are "on" or "true", but not both. It produces a false result if both parameters are true.

Note 2. The NOT operator is used with a single boolean value or expression to negate the boolean sense. This operator can be used after, and inconjunction with, other boolean operators (see earlier boolean operator examples).

These operators are used to create expressions involving boolean (BOOL) data types. Although they are primarily used with digital inputs and outputs, they are also useful when used with comparison operators to create expressions that describe complex conditions.

Examples:

```
vent.Process_Val := switch1.Process_Val AND
          heatFlag.Val OR overPres.Val;
alarm.Val := NOT pressure.Val AND
              NOT airValve.Process_Val AND
              ( zone1.Process_Val > 500.0 ) ;
```

Example :

```
out1.Process_Val := (( in1.Val XOR in2.Val ) AND
                         NOT in3.Val ) OR in3.Val;
(* out1.Process_Val is set to 1 "ON" when only
one of the parameters in1.Val, in2.Val or in3.Val
are 1 "ON" *)
```

Operator precedence

Operators have different precedence to ensure that where there are complex expressions involving many operators, the order of evaluation is consistent.

Example:

```
total.Val := a.Val * 10 + b.Val * 20;
```

When this expression is evaluated, a.Val is multiplied by 10, b.Val is multiplied by 20 and the two values are added together. In other words, the multiplication occurs first and has higher precedence than the addition operator. Operators of equal precedence are evaluated left to right.

The precedence can be modified by inserting brackets "(",")" round expressions that should be evaluated first.

Example

```
total.Val := a.Val * ( 10 + b.Val * 20 );
```

In this case, b.Val is multiplied by 20, 10 is then added and the result is multiplied by a.Val.

If you have any doubts about evaluation order, insert brackets round expressions that you expect to be evaluated together.

Operator	Symbol	Precedence
Parenthesization	(...)	HIGHEST
Negation Complement	- NOT	
Multiply Divide Modulo	* / MOD	
Add Substract	+ -	
Comparison	<,>,<=,>=	
Equality Inequality	= <>	
Boolean AND	AND	
Boolean Exclusive OR	XOR	
Boolean OR	OR	LOWEST

Table 3-6 ST Operator Precedence

BOOLEAN EXPRESSIONS

Boolean Expressions always produce a boolean (BOOL) result, i.e. the value is either 1 for "true" or 0 for "false". This type of expression can be used to describe process boundary conditions or events within conditional statements or SFC transitions. A boolean expression can involve any of ST operators and functions but must result in a final boolean value.

Examples

```
gasFlow.Process_Val >= (valvePos.Process_val
                            + 300.0 ) * flow.Val

digin1.Process_Val AND (heat1.Process_Val<250.0)
                        AND ( soak.Time>= T#40m)

valve.Process_Val > SQRT ( IN :=
                    loadSize.Process_val * 1.234 )
```

FUNCTIONS

PC3000 provides a wide range of standard functions which can be used in ST expressions to simplify complex operations. You are advised to become familiar with the types of functions that are available; remember that functions can often simplify and minimise the ST required to solve a particular problem. A function has one or more parameters and always returns a single result of a particular data type.

Function categories are listed in tables 3-7 and 3-8.

Category	Purpose	Examples
Numerical	Provides a wide range of common mathematical functions including trignometric and logarithmic	ABS_REAL, SQRT, LOG, EXP, SIN, ACOS
Selection	Used to select values depending on a condition	SEL_BOOL, SEL_REAL, SEL_DATE, MAX_REAL
String	Comprehensive set of functions for manipulating textual strings, including joining strings, inserting text	EQUAL, LEFT, CONCAT, REPLACE, JUSTIFY_RIGHT

Table 3-7 ST Function Categories

Category	Purpose	Examples
Type Conversion	Conversion between data types	DINT_TO_REAL, REAL_TO_TIME, TIME_TO_UDINT
String Conversion	Conversion of values of various data types to and from textual string format	STRING_TO_DINT, STRING_TO_REAL, DINT_TO_STRING, DATE_TO_US_STRING
Time Arithmetic	Used to add and subtract times, dates, date and times	ADD_DATE_AND_TIME_T, SUB_DATE_AND_TIME_T, ADD_TOD_TIME
Compact	Functions allow multiple values to be compacted to and from long strings for serial communication.	EXT_REAL_FROM_STR, REP_REAL_IN_STR, EXT_TIME_FROM_STR, REP_TIME_IN_STR

Table 3-8 ST Function Categories Continued

Many of the mathematical functions involve complex floating point arithmetic and therefore, in order to minimise performance overheads, these functions should only be used sparingly in "soft-wiring" associated with function blocks running at high scan rates, e.g. in "soft-wiring" to digital function blocks.

A full list of functions is provided in the PC3000 Functions Reference.

Examples of ST using functions :

```
light.Process_Val := EXPT ( BASE := 2.0,
                         POWER := rate.Val );

(* light is given by raising two to the power of
"rate" *)


upTime.Val :=  UDINT_TO_TIME (
                 IN := pulses.Val * spaces.Val);
(* pulses scaled by spaces gives milliseconds
upTime *)
```

The function parameter names are inserted automatically by the Programming Station when a function is inserted.

The values provided to function parameters may involve complex ST expressions providing the result of the expression is the same data type as the particular function parameter. The Programming Station will check that the expressions generate the correct data type for the function parameters.

VALUE SELECTION

Two methods are provided to allow alternative values to be selected in ST assignments and expressions.

Selection functions

This type of function allows one of two alternative values IN0 and IN1 to be selected depending on the value of a boolean (BOOL) input G. The result is the value of IN0 if the value of G is 0 "false", otherwise the result is the value of IN1, if the value of G is 1 "true". Selection functions for all the PC3000 data types are provided. The selection input G can take a value derived from any boolean expression.

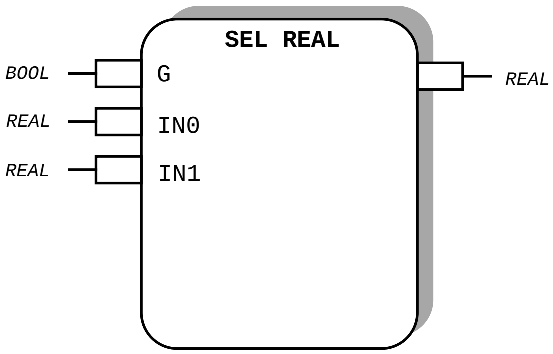


Figure 3-1 Selection Function Example

Examples:

```
speed.Val := SEL_REAL( G:= sensor.Val,
                                 IN0 := -20.0  ,
                                 IN1 := 30.0  );
         (* If sensor.Val is true value is 30.0,
         otherwise the value it is -20.0 *)

pulse.Prog_Time := SEL_TIME(G := rate.Val>100.0,
                              IN0 := T#5s      ,
                              IN1 := T#2s500ms);
(* pulse is 2.5 seconds for rate greater than
         100.0 otherwise pulse is 5 seconds *)
```

Selection Functions are defined within the IEC 1131-3 standard and are particularly useful in "soft-wiring" where there is a requirement to change the assigned value depending on some special condition.

Example:

```
loop1.Process_Val := SEL_REAL(G:= input1.Status,
                     IN0:= input2.Process_Val  ,
                     IN1:= input1.Process_Val);
```

In this example, the PID loop1 is connected to analogue input1 while the status of input1 is 1 i.e. "GO". However, if input1 develops a fault such as a sensor break, the status changes to 0 i.e. "NOGO" and loop1 continues with the process value from input2.

Value selection using IF construct

A second method, which is not compliant with the IEC 1131-3 standard, provides value selection using the IF...THEN construct to aid program readibility. Use of this construct is not recommended if any part of the program is intended to be used on a fully IEC 1131-3 compliant system in the future.

The previous example can be expressed as :

```
loop1.Process_Val := IF input1.Status THEN
                                input1.Process_Val
                            ELSE
                                input2.Process_Val
                            END_IF;
```

The IF...THEN requires a boolean expression which when 1 i.e. "true", causes the parameter on the left-hand side of the assignment to be assigned the first value otherwise it is assigned the second value. Like the selection function, the boolean expression can be complex. The alternate values can be provided by complex expressions as long as they yield a value which is the same data type as the assigned parameter.

Note. In the Structured Text, the value that is assigned when the boolean expression is 1 "true" comes after the value assigned when 0 "false" when using the selection function, but this order is reversed when using the IF...THEN construct.

RULES FOR WRITING VALID STRUCTURED TEXT

The Programming Station checks that all Structured Text statements have the correct structure (i.e. syntax) and in some cases that data types used in expressions are consistent.. However, it is good practice to always write correctly structured ST and use the operators with the correct data types. The main points to be considered are :

1. Ensure that each statement is terminated with a semi-colon ";", including each conditional statement.
2. Check that constructs such as IF ... THEN are correctly structured and terminate with END_IF.
3. Expressions should deal with consistent data types.
4. Operators should be used correctly. For example, all operators except "-" and "NOT" should be between two parameters, constants or expressions. Examples of invalid expressions :

`switch.Val := a.Val AND OR b.Val ;`
`heat.Val := * 100.0 / O2flow.Val ;`
	✗

5. Use operators with matched data types. This may require the use of TYPE_CONVERSION functions to ensure that parameters or expressions are converted to the correct data type.

Chapter 4

SEQUENTIAL FUNCTION CHARTS

Edition 2

Contents

OVERVIEW

This Chapter describes the following :

- The reasons for using Sequential Function Charts (SFCs)
- The main SFC concepts
- Using Structured Text to define SFC steps and transitions
- The relationship between SFC execution and the execution of function blocks for continuous control
- Safe and unsafe SFC design.

Introduction to sequential function charts

Sequential Function Chart (abbreviated SFC) is a graphical programming language formalised by the IEC 1131-3 standard for describing the sequential aspects of a control program in terms of discrete steps and transitions.

A sequence is built-up by graphically linking two basic program elements, steps and transitions, as shown in figure 4-1. The graphical links are analogous to the "Soft-wiring" used to connect function blocks .

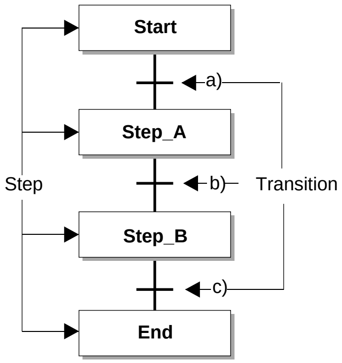


Figure 4-1 Basic SFC Elements

A **Step**, which is depicted as a box surrounding a step name, defines a set of actions that are performed when the controlled plant or machine is in a defined state The step remains active until the condition associated with a following **Transition** which is depicted by a short horizontal line, becomes "true".

For example, when controlling a furnace, a step could establish setpoint temperatures for PID control loops and the following transition could have a condition that waits for the control loops to be stable.

A series of of steps and transitions are linked by lines as shown in figure 1 to form a sequence. When a sequence is executed, the first step, in this case step "Start", is activated. It remains active until the condition for the following transition is true, i.e. transition a). When the condition for transition a) is true, the following step "Step_A" is activated and step "Start" is deactivated. In the same way, sequence will process through all the linked steps. In this example, only one step is active at any time.

Typically, a step contains actions that change the values of function block input parameters in order to modify the behaviour of the continuous control part of the program. A step usually defines actions in Structured Text but can represent another SFC using the "Macro Step" concept as discussed later in this chapter.

The condition associated with a transition is defined using a boolean expression written in the Structured Text language; see Chapter 3 Structured Text. A condition can define any time related process event or boundary condition. Figure 4.2 depicts an example of simple sequence and its associated step actions and transitions defined using ST; this is taken from the example program discussed in Chapter 2 .

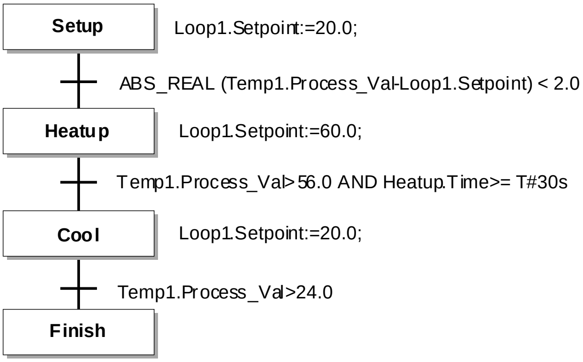


Figure 4-2 Example of a Sequence with ST

In Figure 4-2, assuming that the step Setup is active, the Heatup step is activated when the transition condition "`ABS_REAL(Temp1.Process_Val - Loop1.Setpoint) < 2.0`" becomes true i.e. the absolute value of the PID control loop error is less than 2.0. As soon a s Heatup is activated, the Setup step is deactivated and its associated transition is no longer evaluated.

> **Note:** It is only necessary for the condition of a transition, that follows an active step, to be evaluated as "true" once in order to cause the succeeding step to be activated.

SELECTING ALTERNATIVE SEQUENCES

Alternative parts of a sequence can be selected by having multiple transitions from a step as shown in the figure 4-3 example a). From Step "Load" there are three possible alternative steps that can be activated. The selection depends on which one of the three transitions is "true" first while "Load" is active.

Examples where alternative sequences are useful :

- When the process phases need to vary depending on the type of product being made - such as depicted in the figure 4-3.
- Where a special set of actions are needed following a process failure - i.e. fault recovery.
- Where it is necessary to repeat a set of steps a number of times and then enter an alternative sequence when the end condition is reached.

The PC3000 operating system evaluates transitions from left-to-right. In this example, if all three transition conditions are "true", only the "Heat" step will be selected.

Note : Where there are alternative transitions, only one of the successive steps will be activated even when more than one transition condition is "true".

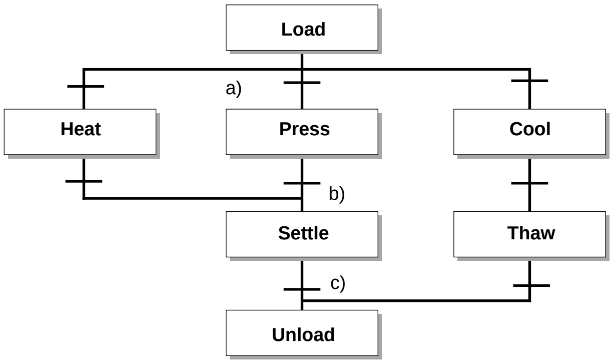


Figure 4-3 Alternative Sequence Selection

Alternative sequences can re-join other sequences by linking the transition of the last step to a step in a different sequence, see figure 4-3b) and c).

PARALLEL SEQUENCES

Sequences to run in parallel can be defined by linking them with a double horizontal line which follows a single transition, see Figure 4-4 a).

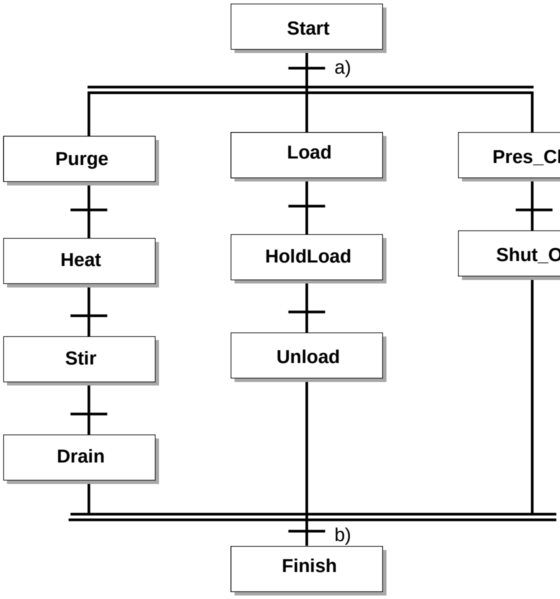


Figure 4-4 Parallel Sequences

In figure 4-4, when step "Start" is active and the condition for transition at a) is "true", steps "Purge", "Load" and "Pres_Chk" are activated simultaneously. This initiates three sequences to run in parallel.

Parallel sequences may be required where there are a number of process operations that can proceed independently. Figure 4-4 shows three sequences to control a reactor vessel, a job loading mechanism and pressure checks.

The Programming Station allows up to 12 parallel sequences to be initiated from one transition. Other transitions can initiate further parallel sequences on the same chart if required.

In many control applications there is often the need to wait for a number of parallel sequences to end before proceeding with the next part of the main sequence. This can be achieved using a parallel sequence **rendezvous** as depicted in figure 4-4b) by a double horizontal line joining a number of parallel sequences. A rendezvous is always followed by a single transition.

Note: The condition for the rendezvous transition is only evaluated when all connected preceding steps are active. When it is "true", all preceding steps are deactivated, and the following step (or steps) is activated.

A rendezvous may be required where several sequences must be finished before proceeding. For example, you may need to ensure that a reactor vessel is drained, the product has been unloaded, and pressure checks have been shut off before opening a vessel door.

MACRO STEPS AND MACRO CHARTS

The Programming Station allows complex sequences to be built-up from a hierarchy of Sequential Function **Charts**. The top level chart is displayed when the SFC editor is first viewed on the Programming Station and is referred to as the **Main** chart. A step can be created as a **Macro** step by assigning the "Macro" attribute. This implies that the step represents a lower level macro chart.

Each macro chart must have a single step identified as the start step. When a macro step is activated, it causes the start step of the lower level macro step to become active.

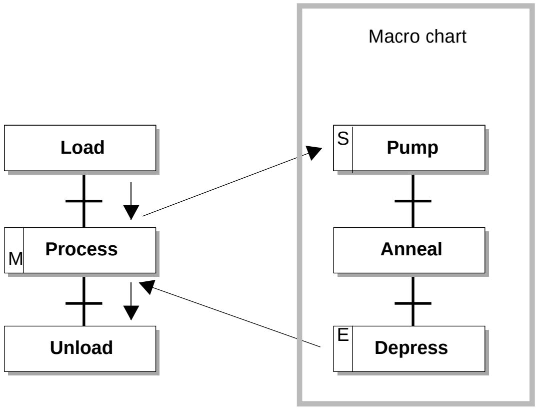


Figure 4-5 Calling a Macro Chart from a Macro Step

Figure 4-5 shows a simple example of a macro Step "Process" that represents a lower level macro chart. The sequence transfers from step "Load" on the higher level chart to the start step "Pump" on the macro chart when the transition from "Load" to "Process" becomes "true". The transition from "Process" to "Unload" is only evaluated when the macro chart end step "Depress" is reached. When this transition is "true" and step "Depress" is active, the sequence returns to the top level chart at step "Unload".

Macro charts can call further macro charts to a level of 20 so that complex hierarchies of sequences can be created.

Note: It is good practice to ensure that the main chart only depicts the primary process steps. Typically the primary steps will be macro steps which represent lower level charts.

Abortable macro steps

An **Abortable Macro** Step provides a mechanism to deactivate all steps in lower level macro charts. When an abortable macro step is active the lower level macro chart is activated from the start step (i.e. as for a normal macro step). However, in this case, transition following the macro step is continually evaluated. If the transition condition becomes "true", <u>all</u> steps in the lower level macro chart (including those in yet lower level macro charts arising from macro steps) are deactivated.

This can be useful where a complex sequence needs to be cleared-down rapidly, for example, to shut-down an automatic load sequence when a manual switch is depressed.

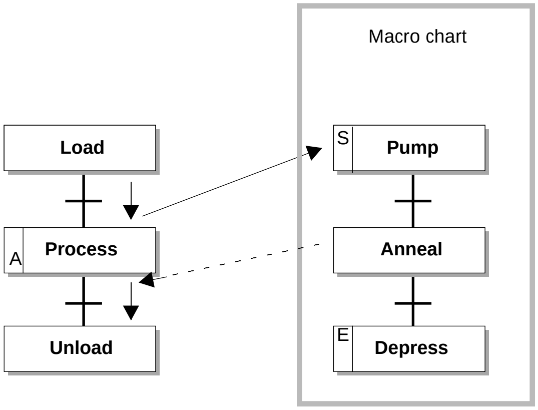


Figure 4-6 Using an Abortable Macro Step

In figure 4-6, "Process" is an abortable macro step. When "Process" is activated,the macro chart is entered from the start step "Pump" . The condition for the transition from "Process" is continually evaluated while the macro chart sequence is active. The dotted line depicts the case, where the step "Anneal" is aborted because the transition from "Process" has become "true". The sequence in the upper level chart continues from the step "Unload" that follows "Process".

It is possible for an end step to be an abortable macro. In which case, it is the transition(s) of the macro step in the next higher level chart that is tested and when "true" aborts the lower level chart.

Deactivating steps

When steps are deactivated as a result of aborting a macro chart, actions of a step are always executed completely. That is, it is never possible for a step to be deactivated while actions are being executed.

A single-shot step is deactivated after executing all the actions once.

A continuous step is deactivated after the actions have been executed at least once. The actions are executed one further time after the step has been deactivated. During this last execution of the continuous step the step's **.Executing** parameter is false. This is described in more detail in the following text.

EXECUTION OF STEP ACTIONS

The actions within any step that is described in ST can be executed in two modes i.e. single shot or continuous.

Single shot step

This is the normal default execution mode where all the actions within the step are executed once when the step is first activated.

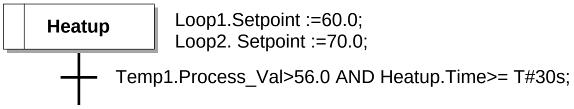


Figure 4-7 Single Shot Step

Figure 4-7 depicts a single shot step "Heatup". The assignments to Loop1.Setpoint and Loop2.Setpoint only occur when the step is first activated. The transition condition waits for the step to be active for at least 30 seconds. However, although the step remains active, the assignments are only made at the beginning and have no effect for the rest of this time.

This execution mode is suitable for the majority of steps where there is a requirement to simply set-up function block parameters for a particular process state or operation.

Note: This mode is equivalent to the Action Qualifier **P**ulse defined in the IEC 1131-3 standard .

Continuous step

This execution mode which can be set by the continuous step attribute, causes the step actions to be repetitively executed while the step is active. This may be required where for example there is a need to monitor input values for a period of time, or continuously modify output values. In effect, a continuous step behaves as a piece of temporary "soft-wiring".

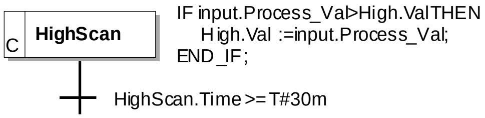

C
HighScan
IF input.Process_Val>High.ValTHEN
High.Val :=input.Process_Val;
END_IF;
HighScan.Time >= T#30m

Figure 4-8 Continuous Step

In figure 4.8, a continuous step is used to monitor the value of an analogue input over a period of 30 minutes and record the highest value reached in parameter High.Val.

Note: The actions of a continuous step are executed one further time after the step's following transition becomes "true"; this is discussed in the next section.

STEP EXECUTION TIMING

All the charts are scanned repetitively at the scan rate set by the task assigned to the SFC. All active steps are evaluated and the associated step actions are executed according to each step's execution mode.

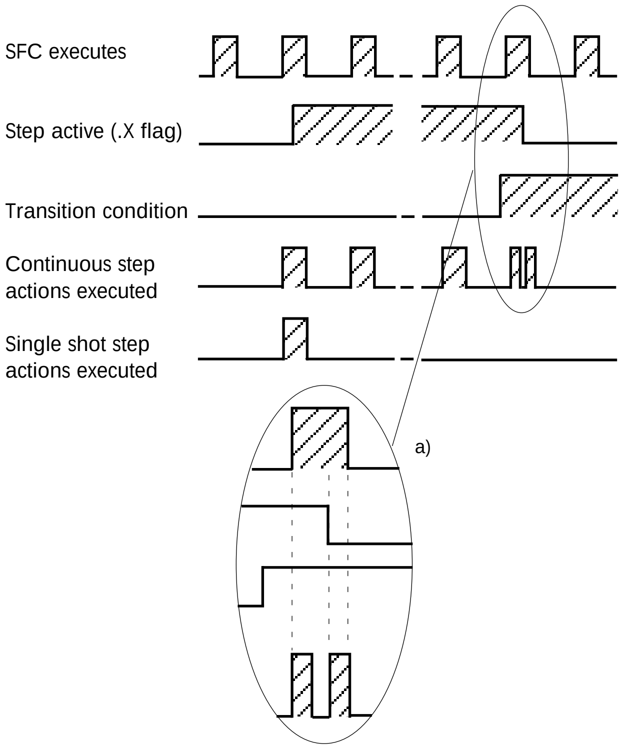

SFC executes
Step active (.X flag)
Transition condition
Continuous step actions executed
Single shot step actions executed
a)

Figure 4-9 Step Execution Timing

Figure 4-9 is a timing diagram that depicts the differences between single shot and continuous step execution. A step is active until a following transition becomes "true"; it is then deactivated. The step's **Executing** parameter remains "true" while the step is active (also see section Step and Macro Function Blocks)

The actions of a single shot step are executed once when the step first becomes active.

In contrast, the actions of an active continuous step are executed every time the SFC is scanned. However note, that actions are also executed <u>once more</u> after the step has been deactivated, see figure 4-10 This facility is provided so that continuous steps can have actions to close-down certain functions on exit.

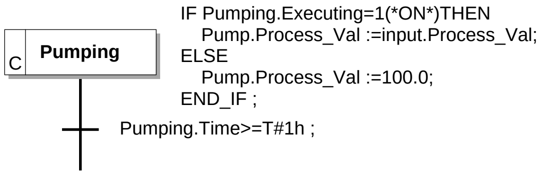

C
Pumping
IF Pumping.Executing=1(*ON*)THEN
Pump.Process_Val :=input.Process_Val;
ELSE
Pump.Process_Val :=100.0;
END_IF ;
Pumping.Time>=T#1h ;

Figure 4-10 Execution of Continuous Step Actions on Exit

Figure 4-10 depicts an example of a continuous step where an assignment is made when the step is deactivated. While the step "Pumping" is active, the `Pump.Process_Val` is continually updated from `input.Process_Val.` However, when the step is deactivated, the Pump.Process_val is reset to 100.0. The step parameter, **Executing** (abbreviated X), is used to select actions to occur when the step is active, and those that occur once when the step is deactivated, i.e. when it is off (also see Step and Macro Function Blocks).

Timing actions within continuous steps

The **.Time** parameter of a Continuous step is continually updated while the Continuous step is active. This can be used to cause certain actions to occur at various times after the step has started.

Example :

```
IF shutdown.Time < T#1m THEN
  pump1.Process_Val := 30;
ELSE
  pump1.Process_Val := 0;
END_IF;


Valve1.Process_Val := (shutdown.Time > T#2m);
```

In this example assume that shutdown is a Continuous step that is active for say, 4 minutes, timed by the step's following transition. The Structure Text statements for the step actions ensure that process value of pump1 is set to 30 during the first minute, thereafter set to 0. The Valve1.`process val` is "true", i.e. the valve is switched "ON" after two minutes.

Seq. Function Charts

SFC AND FUNCTION BLOCK INTERACTION

Care should be taken in cases where function block parameter values are set-up in a step that is immediately followed by a transition that tests whether the function block has completed a particular operation. Remember that a particular function block may not have time to execute between setting values in the step and testing the result in the transition.

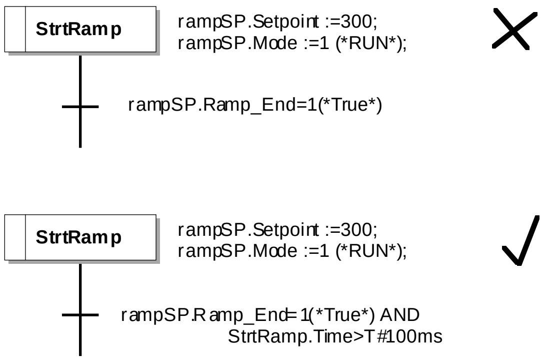


Figure 4-11 SFC and Function Block Interaction

Figure 4-11 depicts a common problem that can occur. The step actions set-up a ramp function block "rampSP" to ramp to a particular setpoint. The transition is required to wait for the ramp to complete.

In the first example, the transition may fail to detect the end of the ramp because the transition may to be "true" immediately after the step is active. This is due to the rampSP.Ramp_End parameter still being "true" from a previous execution of the rampSP function block.

In the second case, the transition condition has been modified to ensure that the rampSP executes as least once before testing the Ramp_End parameter. This example assumes that the rampSP function block is in a 100 ms task.

Note: Always ensure that time is allowed for function blocks to execute after setting input parameters and then testing the values of function block output parameters .

STEP ATTRIBUTES

Start	Specifies that the step will be made active when the chart that contains it becomes active.
End	Normally the last step of a macro step. The condition of the transition following a macro step will be tested when the End step in the associated macro chart becomes active.If the transition condition is "true", the End step becomes inactive and the macro chart that contains it completes execution. However the End step of the MAIN chart is a special case which when active, executes once and the entire SFC is then completed. A normal (non-abortable) macro must contain one end step. An abortable chart may contain one or zero end steps
(Normal default)	This is the default attribute which is not explicitly set on the Programming Station, implies that the step is neither a start nor an end step.

Table 4-1 Step Attributes

Macro	Specifies that the step activates a non-abortable macro chart. The transition(s) that follows a macro step will only be tested when the associated macro chart has reached the end step.
Abortable Macro	Specifies that the step activates an abortable macro chart. The transition(s) that follow an abortable macro step are tested continuously while the macro chart is active. If one of the transitions have a condition that is "true", the entire macro chart is deactivated.
One-shot *(default)*	Specifies that the actions of the step are only executed once when the step is first activated.
Continuous	Specifies that the actions of the step are continually executed while the step is active. The actions are executed one further time after the step has been deactivated.

Table 4-2 Step Attributes

When setting step attributes, a step may have one attribute from table 4-1 and one attribute from table 4-2.

Examples are :

Start + One-shot

Normal + Continuous

Normal+ Abortable Macro

End + Macro

STEP AND MACRO FUNCTION BLOCKS

Each step, macro and abortable macro step is represented in the PC3000 system as a function block. This allows parameters that give the state and step duration to be used in ST .i.e. in "soft-wiring", step actions and transition conditions.

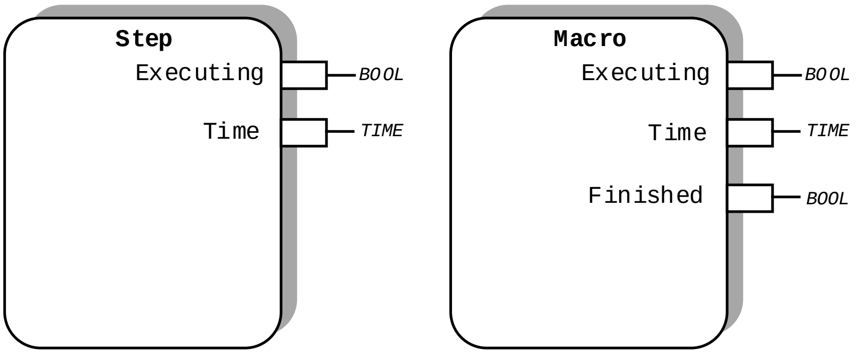


Figure 4-12 Step and Macro Function Blocks

The macro function block is used for macro and abortable macro steps. Both blocks have Executing and Time parameters.

The **Executing** parameter (abbreviated .X) is set whenever the step or macro is active.

The **Time** parameter (abbreviated .T) provides the duration of the step or macro. The value of this parameter is reset when the step is first activated and then increases while the step is active. When the step is deactivated, the value is frozen. This parameter can be used to time the duration of a step. It is also a useful diagnostic aid because it records the length of time a program was in a given step the last time it ran.

The **Finished** parameter (abbreviated .F) provided with the Macro function block is set when the macro chart reaches the end step. It is always cleared when the macro step is not active. It can be used in transition conditions to test whether a particular macro chart has finished.

SFC PROGRAMMING RULES

Rules for using charts

The following points always apply to charts :

1. The top chart called MAIN provides the top level overview of the entire sequence program.
2. A lower level chart is associated with a macro step or an abortable macro step in the next higher level chart.

3. A chart may contain a number of steps and transitions connected by wiring (i.e. graphical lines) that define the flow of control from one set of active steps and their associated transitions to the next.
4. A chart must have exactly one start step.
5. A chart must have one or zero end steps.
6. An active chart is one that has one or more active steps.

Rules for using Steps

The following points always apply to steps :

1. A step may be a Macro that represents another SFC chart, or it may be defined as a set of actions using the ST language.
2. A step normally has one or more following transitions except;

   a) End steps which never have a following transition and

   b) a step may optionally have no succeeding transitions if it is always required to stay active once reached.

   A Continuous step with no following transition stays active.
3. A step cannot be immediately followed by another step without an intervening transition.
4. A step may have an attribute that defines how it is executed.

Rules for using transitions

The following points always apply to transitions :

1. Every transition must always have one or more preceding steps and one or more succeeding steps.
2. A transition can never be connected to another transition.
3. A transition represents a condition that must be fulfilled before its associated preceding step(s) are deactivated.
4. A transition condition is described using a boolean expression in ST.

UNSAFE SFC DESIGN

The Programming Station checks each chart and ensures that the basic construction of each SFC is correct before allowing a program to be built. e.g. that each chart must have a start step. However, it is possible to construct a chart that can behave incorrectly for two main reasons:

1. There may be steps that can never be activated.
2. Steps or sequences may unintentionally remain active. This can occur when re-entering a sequence especially if it involves parallel sequences that do not terminate at a rendezvous correctly.

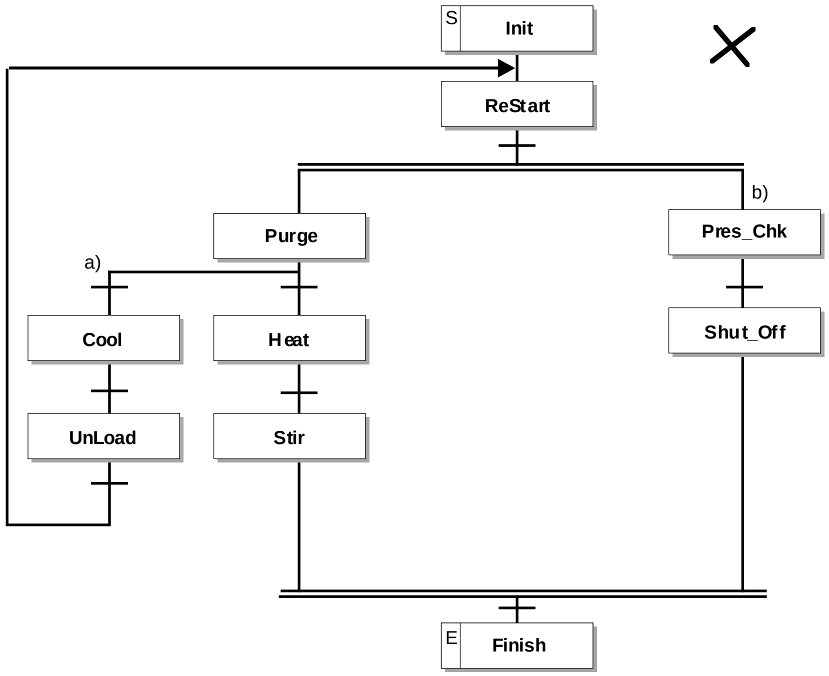


Figure 4-13 Unsafe SFC Construction

Figure 4-13 depicts an unsafe SFC because if sequence a) is selected, it is possible that steps "Pres_Chk" or "Shut_off" remain active when step "ReStart" is re-activated.

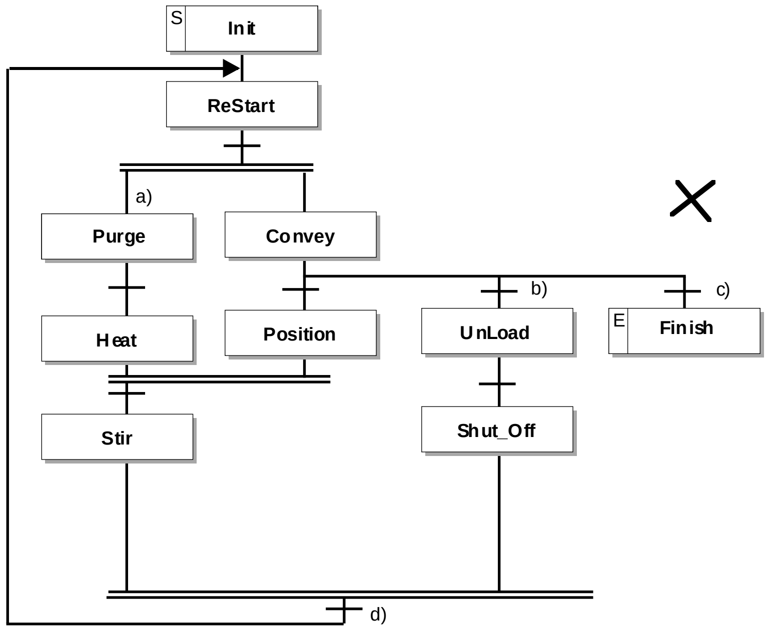


Figure 4-14 Unreachable rendezvous

Figure 4-14 depicts another example of an unsafe chart; assume that the chart has been called by a macro step. The rendezvous at d) may never be reached if sequence at b) or the end step c) are selected. Because the step "Position" is not activated, the step "Stir" will never be reached.

It is also possible for the end-step "Finish" to be reached while other steps are still active, i.e. steps "Purge" or "Heat". This may result in returning to the macro step in the higher level chart with steps still active.

> **Note:** On macro charts always ensure that all parallel sequences rendezvous before reaching the end step.

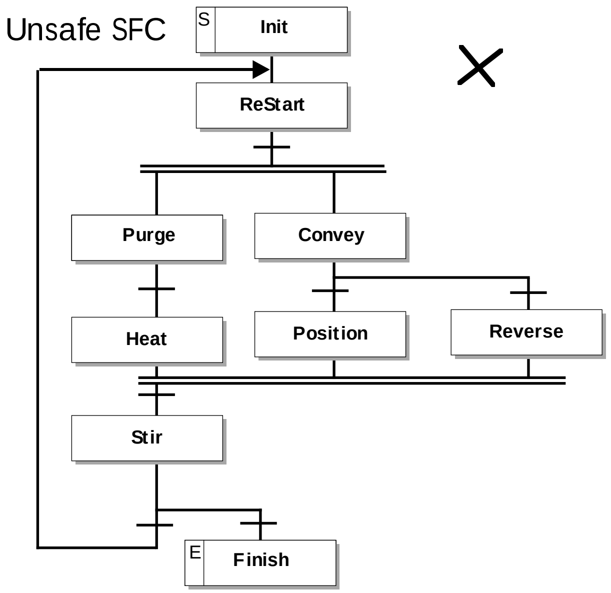


Figure 4-15a Incomplete Rendezvous

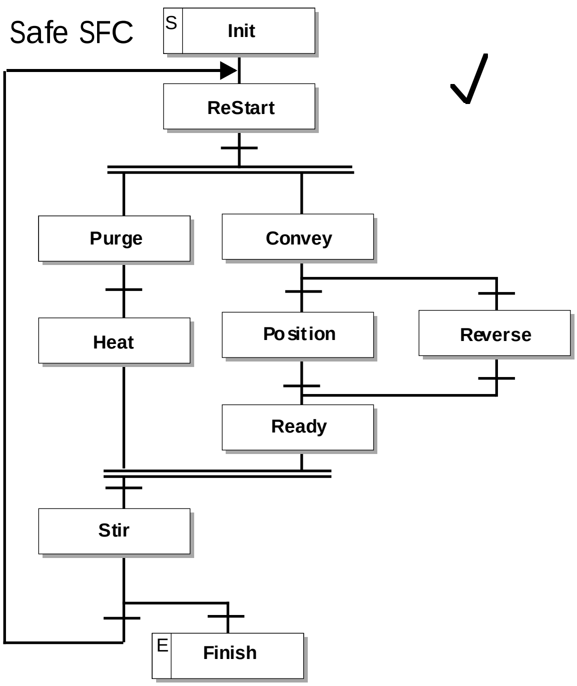


Figure 4-15b Complete Rendezvous

Figure 4-15a depicts an unsafe SFC and an equivalent safe SFC in figure 4-15b. In the unsafe SFC, the rendezvous transition before step "Stir" will never be evaluated because it will wait for all steps "Heat", "Position" and "Reverse" to be active. This can never occur because steps "Position" and "Reverse" are alternatives.

Chapter 5

PROGRAM DEVELOPMENT

Edition 2

Contents

OVERVIEW

This Chapter describes the following aspects of program development for the PC3000:

- How to structure a PC3000 program by analysing the different requirements of a control system
- Good programming practice
- How to use the PC3000 control system efficiently
- How to develop programs that are easy to read and maintain
- How to commission PC3000 programs
- How to use function blocks together with SFC to solve control problems

PROGRAM DESIGN CONSIDERATIONS

A PC3000 program, like any piece of software, needs to be carefully designed to ensure that the program functions correctly and makes best use of the PC3000 resources and performance. If the program is being used to control a production process, it is also important that the program is easy to read and understood by commissioning and maintenance engineers.

Although, PC3000 is a flexible control system which allows programs to be built-up piecemeal, it is recommended that all the aspects of the control system application are understood and considered before starting program development.

It is recommended that the following procedures are adhered to:

1. Produce a complete inventory of all inputs and outputs required by the system. It is recommended that some extra inputs and outputs are added for contingencies and for future enhancements.
2. Analyse all the analogue inputs and outputs and identify those associated with PID control loops. Identify any digital outputs to be used for time proportional outputs.
3. Identify the response times, range and accuracy of all analogue inputs and outputs.
4. Identify the response times required for digital inputs and outputs.
5. Identify aspects of the control strategy that are always applicable and are therefore part of the continuous control strategy, e.g. PID control loops, interlocks, alarm monitoring.
6. Identify the main sequential control phases - process initialisation, calibration, shut-down, standby are examples of clearly separate control phases.
7. Identify control phases that can operate in parallel and do not directly interact. For example, handling an operator display and ramping control loop setpoints could be controlled by sequences that run in parallel.

8. Identify all requirements for communications with external equipment including SCADA systems, other PC3000s, PLCs and Eurotherm discrete instruments and drives.
9. Identify key parameter values of the control system that may need to be modified when the control system is being commissioned.

Performance optimisation through sequencing

It is important to consider all the sequencing aspects of the control program. You should avoid having unnecessary "soft-wiring" in the continuous control strategy as this may present a significant performance overhead. In constrast, the control strategy provided by actions within SFC steps only present a performance overhead while particular steps are active.

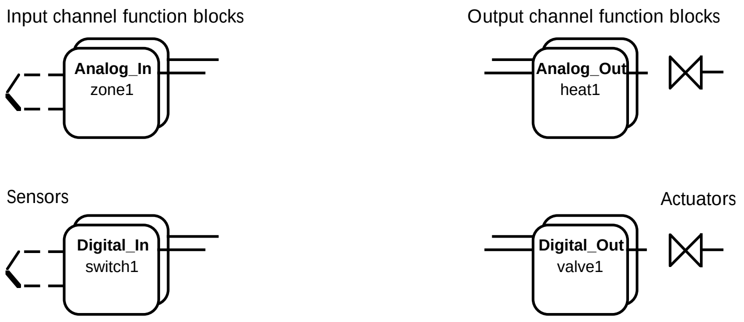
Note: Unlike PLC ladder programming where sequencing and continuous control are combined. PC3000 allows sequencing and continuous control to be separated. This reduces the performance requirements and makes the control program easier to develop, commission and maintain.

PROGRAM DEVELOPMENT STAGES

It is recommended that a PC3000 program is developed in a number of clear stages. However, remember that these stages are only advisory and you are free to develop any part of the program at any time. The program example given in chapter 2 follows these guidelines.

The stages recommended to develop a PC3000 program using the PC3000 Programming Station are summarised as follows :

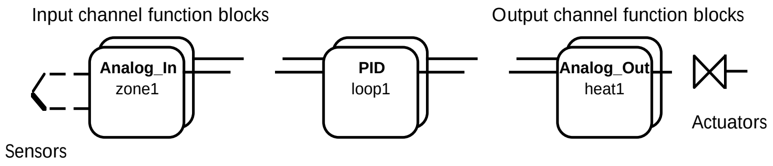
Stage 1:Select and configure the I/O channels



The main actions required are :

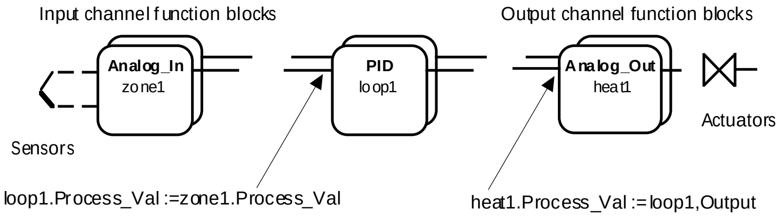
1. Using the PC3000 Programming Station, select the hardware modules required based on the I/O inventory. If several racks are required, the I/O throughput can be optimized by ensuring that digital inputs are in separate racks to digital outputs. Also where possible, avoid having digital and analogue modules in the same rack.
2. Assign names to all I/O channels. Use names that are meaningful and not arbitary. Ideally use names that appear on wiring or control diagrams.
3. Set up the channel ranges, offsets and scaling. In some cases, this may be left until the system is being commissioned.
4. Remember that specialist modules such as the ICM and AIO8 can only be positioned in the first 5 slots in the first rack. So leave these slots free if any of these modules are to be added later.

Stage 2:Configure the continuous analogue control



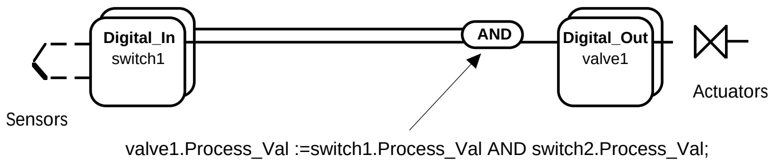
The main actions required are :

1. Create PID function blocks to handle each control loop.
2. Configure the operating mode for each PID e.g. dual channel (heat/cool), valve positioner, auto-tune.
3. Use Structured Text "soft-wiring" to connect the process value of analogue output channels (or of time proportional digital output channels) and the output of PID function blocks.


Input channel function blocks
Output channel function blocks
Analog_In
zone1
PID
loop1
Analog_Out
heat1
Actuators
Sensors
loop1.Process_Val :=zone1.Process_Val
heat1.Process_Val := loop1,Output

4. Also "soft-wire" the process value of each PID function block to the appropriate analogue input process value.
5. Create other function blocks and use "soft-wiring" to create other aspects of the continuous analogue control.

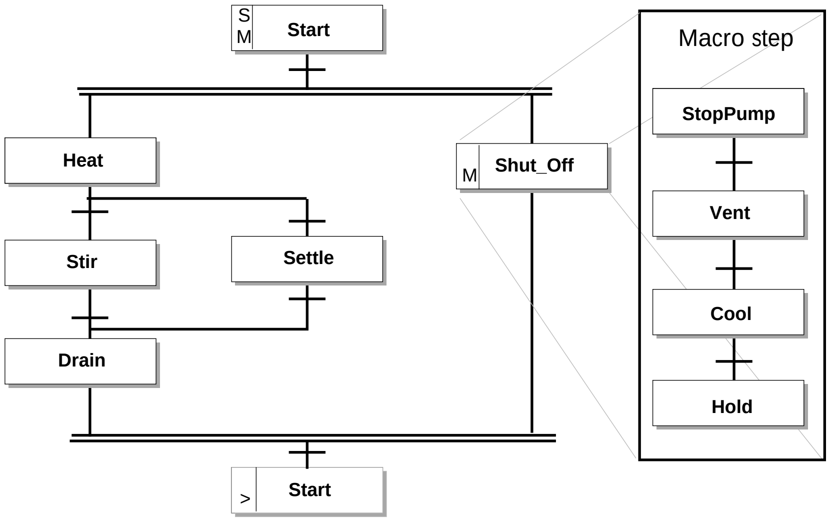
Stage 3:Configure the continuous digital control


Digital_In
switch1
AND
Digital_Out
valve1
Sensors
Actuators
valve1.Process_Val :=switch1.Process_Val AND switch2.Process_Val;

The main actions are :

1. Use "soft-wiring" to create the digital continuous control strategy, i.e. the digital logic.
2. Try to avoid ST, that involves numerous floating point (REAL) expressions or functions, in "soft-wiring" to digital function blocks. This will lessen the digital "soft-wiring" performance overhead which normally runs in the task that scans at the highest frequency.

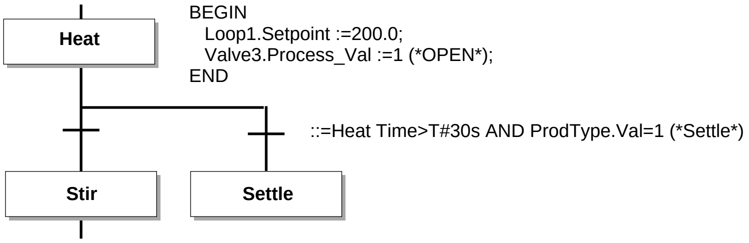
Stage 4:Create sequencing control strategy



The main actions are :

1. Create the Main (top-level) SFC. Each step should represent a primary process phase. Typically steps in the Main chart are defined as macro steps. This allows the important process phases to be clearly visible - this is especially useful during commissioning.
2. Decompose each macro step into yet lower-level macros and finally steps, to complete the sequence program.

Stage 5:Create transitions and step actions


Heat
BEGIN
Loop1.Setpoint :=200.0;
Valve3.Process_Val :=1 (*OPEN*);
END
::=Heat Time>T#30s AND ProdType.Val=1 (*Settle*)
Stir
Settle

The main actions are:

1. Create the ST for the transition conditions.

   Note: Transitions that are not defined will default to 1 .i.e. "true" or "on".

2. Create the step actions.

   Note: For timing reasons, it is acceptable to have steps with no ST actions . For example, a null step can be used as a "wait", if it is followed by a transition condition that waits for the step to be active for a defined duration.

DESIGN OF THE MAIN SFC

It is good programming practice to follow "top-down" design principles. This implies that the Main SFC should represent the main process phases or primary control sequences.

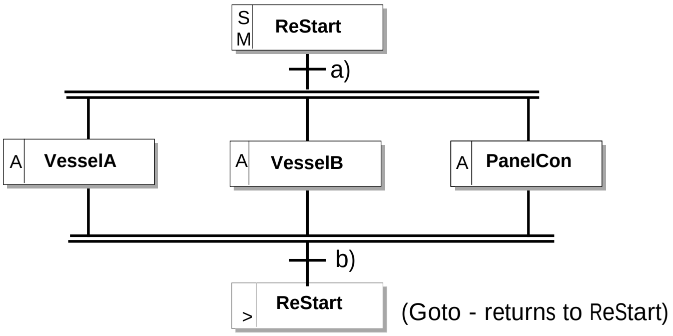


Figure 5-1 Main SFC Example

Figure 5-1 is an example of a Main (top-level) SFC for a control program that handles two reactor vessels. Each of which are independantly controlled by two abortable macro steps "VesselA" and "VesselB". A third abortable macro step "PanelCon" controls a operator panel that provides a real-time display of selected control parameters for both vessels. These steps run in parallel and have no direct interaction. The control program is initialised by macro step "ReStart" that sets up the control loop setpoints etc.

The transition a) waits for the operator to acknowledge that process can re-start by typing in a command on the operator panel.

The condition for the transition at b) tests a digital input that is connected to a manual shut-off key. On detecting that the key is "made", this transition causes all three parallel steps to be aborted. The sequence then returns via a "goto" to the start step "ReStart".

FEEDBACK IN FUNCTION BLOCK SOFT-WIRING

Normally the function block execution order in any scan is such that function blocks associated with parameters in "soft-wiring" assignments always execute ahead of the function block to receive the "soft-wiring" value.

There are situations as depicted in figure 5-2 where it is necessary to "soft-wire" function blocks together to form a feedback loop. In such cases, the function block execution order can be modified by identifying one of the soft-wiring expressions forming the loop as being the "feedback soft-wiring".

Programming Station Wiring Editor provides a Mark Feedback function key that allows any ST wiring assignment to be marked by inserting the text "feedback" as a comment. When the program is compiled and built, this causes the function block being assigned the feedback "soft-wiring" to be executed <u>before</u> the function blocks referenced in the right-hand side of the "soft-wiring" assignment.

> **Note:** A function block receiving a value from a Soft-wiring assignment marked as "feedback" always executes before function blocks whose parameters are referenced in the right-hand side of the assignment.

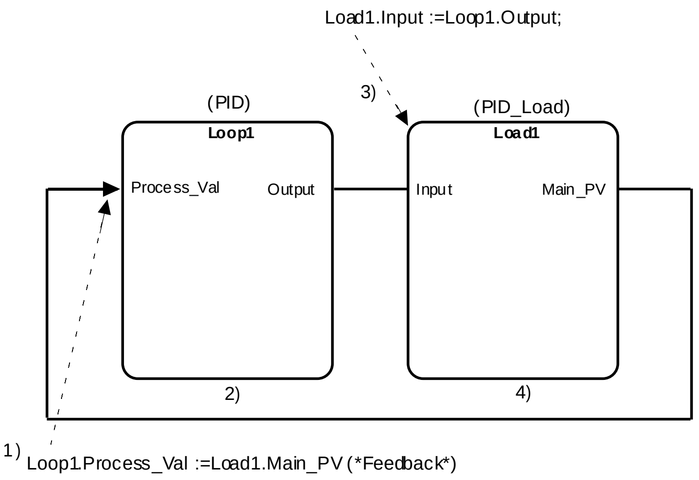

Load1.Input :=Loop1.Output;
3)
(PID)
Loop1
Process_Val
Output
(PID_Load)
Load1
Input
Main_PV
2)
4)
1)
Loop1.Process_Val :=Load1.Main_PV (*Feedback*)

Figure 5-2 Feedback in Function Block Soft-wiring

Figure 5-2 depicts an example where a PID control loop (Loop1) is connected to a PID_Load (Load1) that simulates various plant control loads. To complete the simulation, the process value (**Main_PV**) from the Load1 is fed back as the process value (**Process_Val**) to the Loop1 PID block using soft-wiring marked as "feedback".

This results in the following execution order being created when the program is built:

1. Execute soft-wiring to create new value of `Loop1.Process_Val` using the value of `Load1.Main_PV` from the last scan.
2. Execute Loop1 PID control block and update Loop1.Output.
3. Execute soft-wiring to create new value for `Load1.Input` from `Loop1.Output` created in current scan.
4. Execute the Load1 block and update the Main_PV parameter.

Any ST soft-wiring assignment that is marked as "feedback" when it is not actually part of a feedback loop will cause the Programming Station to issue a "Redundant Feedback Mark" error message when the program is compiled.

The positioning of feedback mark in soft-wiring does not normally have a significant effect when constructing analogue feedback loops. Especially in control situations where time constants are significantly longer than the task scan times.

However, with digital logic, care is required when positioning the feedback soft-wiring as this can sometimes have a significant effect.

CHANGING TASK CONFIGURATION

For the majority of PC3000 programs, the default task configuration is suitable. This provides two tasks - Task_1 running at a 10ms scan rate for digital function blocks and Task_2 running at a 100ms scan rate for analogue function blocks and SFC execution.

The default tasks provide digital input to output response times (throughput latency) of between 15 ms and 25 ms. Up to 32 PID control loops can be configured each running at a 100 ms scan rate and capable of controlling loads with primary time constants of greater than 10 seconds.

An alternative task configuration should be considered if :

a) a digital input to output response less than 25 ms is required,

b) there is a requirement to run more than 32 PID control loops,

c) there is a requirement to run PID control loops for loads with primary time constants shorter than 10 seconds,

d) the sequencing is required to respond more rapidly than every 100 ms,

e) the program requires a large number of function blocks or has complex "soft-wiring" which results in either of the tasks overrunning. That is, a task is unable to complete the execution of all function blocks and "soft-wiring" within the task scan time.

You are advised to refer to the chapter Real Time Task Scheduler and Appendix D Example Task Configurations in the PC3000 Real Time Operating System Reference for further details on task configuration.

Caution

An incorrect task configuration can have have a detrimental effect on the performance and integrity of the PC3000 control system.

TYPES OF FUNCTION BLOCK

A wide range of different types of function block can be instantiated and inter-connected to solve both simple and complex control problems. In many cases, this allows completely new and novel control strategies to be developed.

For a full description of the standard function blocks provided by the Programming Station, refer to the PC3000 Function Block Reference handbook.

The function blocks types are organised into different classes to ease selection as shown in the following table:

Class	Purpose	Examples
SYSTEM	Provides Function Blocks that interface with the PC3000 Real Time Operating System, including the Real Time Clock and the task management	PcsSTATE, Task, RT_Clock
COMMS	Provides communications driver Function Blocks for protocols including JBus, EI_Bisync and Euro_Panel	EI_Bisync_M, EI_Bisync_S, JBus_M, JBus_S, Euro_Panel
MODULES	Function Blocks to support intelligent hardware modules	PPM, PIM2
INPUTS	Function Blocks that represent input channels. Note1	Digital_In, Analog_In
OUTPUTS	Function Blocks that represent output channels. Note 1	Digital_Out, Analog_Out
CONTROL	Control Loop Function Blocks including PID and Valve Positioner and versions with auto-tuning	PID, VP, PID_Auto, VP_Auto
TIMERS	Provides Function Blocks for various timing purposes including pulse generation, delay timing and stopwatch	Pulse_Timer, On_Delay, Off_Delay, Stopwatch
USER_VAR	User variable Function Blocks are provided to hold internal values - all data types including floating point, integer, time and string are available.	Boolean, Real, Integer, Time, String
REMOTE_VARS	Remote variables allow parameters of various data types to be read from external equipment using specific communications drivers.	Remote_Bool, Remote_Real, Remote_Str
SLAVE_VARS	Slave Variables provide values that are addressable by specific communications protocols, i.e. by external equipment.	Slave_Bool, Slave_Real, Slave_Int, Slave_Real_8
RECIPE	Recipe Function Blocks provide recipe storage and selection facilities.	RecipeMan, StageMan, Name_1x128, Real_16x128

Class	Purpose	Examples
STEPS	The steps Function Blocks are created automatically when a SFC is developed. There are two types Step, Macro	Macro, Step
COUNTERS	Provides Function Blocks for counting both up, down and up/down	Up_Counter, Dn_Counter, Up_Dn_Count
SELECT	The select Function Blocks allow one of a set of values to be selected by a single integer input. A variety of data types are provided.	Select_Real, Select_Int, Select_Time, Select_Bool, Select_Str
FILTERS	Provides Function Blocks for frequency filtering of analogue signals.	Lag1
LOADS	These Function Blocks provide simulutaions of different types of control loads. Used with PID blocks to simulate control loops.	PID_Load, VP_Load
OTHERS	Provides a variety of miscellaneous Function Blocks including shift register, ramp, alarm control, bistable	Shift_16, Rate_Limit, Ramp, Shift_Real, Alarm_Cntrl, Bistable_SD

Table 5-1 Function Block Type Classes

Note 1 : The channel input and output function blocks are created via the hardware configuration screens.

Assignment of function blocks to tasks

Bistable_RD Bistable_SD Boolean Debounce_In Digital_In Digital_Out Dn_Counter EI_Bisync_M EI_Bisync_S JBus_M JBus_S Off_Delay On_Delay Pulse_timer Select_Bool Shift_16 Siemens_M_S Stopwatch Toshiba_M Up_Counter Up_Dn_Count	Table 5-2 lists the standard Function Blocks that are assigned to Task_1 by default. The rest of the function blocks in the standard library are assigned to Task_2. By default Task_1 scans every 10ms, Task_2 scans every 100ms. Do not modify these task assignments without understanding the performance implications. Before modifying the task configuration, you are advised to refer to the chapter Real Time Task Scheduler and Appendix D Example Task Configurations in the PC3000 Real Time Operating System. It is always possible to see which task a function block is assigned to by viewing the function block Instance List menu on the Programming Station.

Table 5-2 Default assignment of Function Blocks to Task_1

BUILDING A RAMP-DWELL PROGRAMMER

This section describes how a simple ramp-dwell programmer can be constructed from standard function blocks and controlled by a few steps in a Sequential Function Chart. The example provides a ramp-dwell programmer that can have up to 16 segments. Each segment can be either a ramp or a dwell and the number of segments in the program can be set from 1 to 16. During a ramping segment , a Ramp function block is used to increment an output to a setpoint value, at a prescribed rate. A dwelling segment holds the current output from the Ramp function block for a prescribed duration.

Steps in a SFC use values generated by select function blocks to set up the Ramp function block to create the ramp and dwell functions. The output of the Ramp, (in the example, parameter **ramp1.Output**) provides the ramp/dwell profiled value that can be used to drive physical outputs or PID setpoints etc. For example, by "soft-wiring" a number of different PID setpoints to this parameter, it is possible to construct a multi-zone programmer.

The techniques described here can be extended to provide other features, such as, more segments, further segment parameters etc.

Figure 5-3 depicts the function blocks and "soft-wiring" required to create the ramp-dwell programmer. Some of the parameters that are not relevant to this example are not shown for clarity.

Instance Name	Type	Purpose
setpoint	Select_Real	Provides a setpoint value for each segment.
rate	Select_Real	Provides a rate value for each segment.
dwell	Select_Time	Provides the dwell duration for a dwell segment.
segno	Integer	Stores the current segment number
segmax	Integer	Stores the maximum segments in use.
ramp1	Ramp	Provides the ramping function when in RUN mode.

Table 5-3 Ramp Dwell Programmer Function Blocks

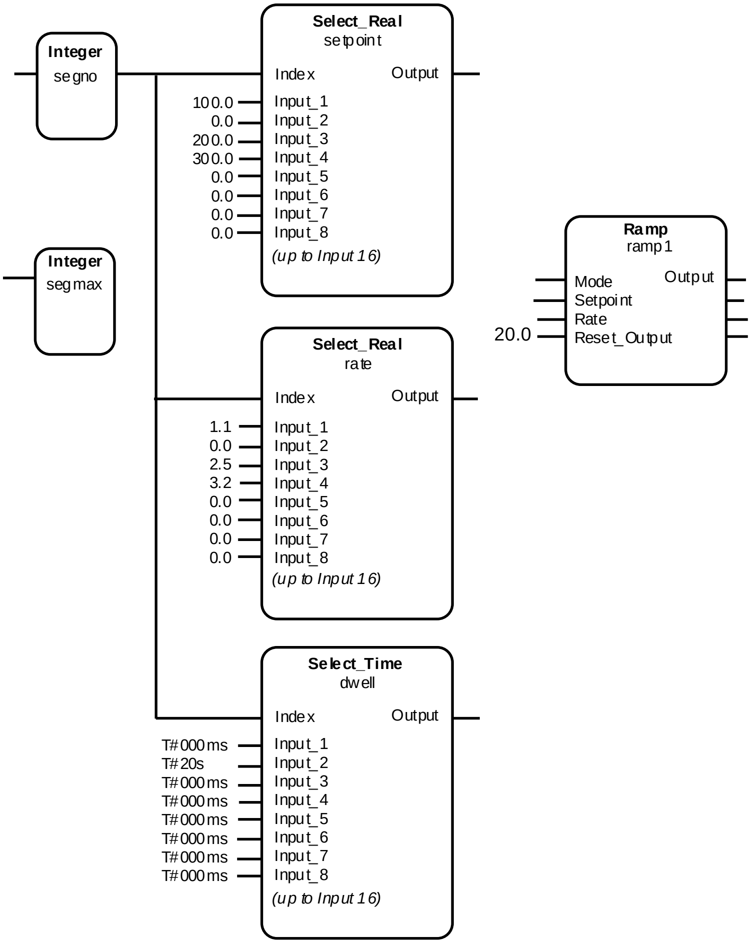


Figure 5-3 Ramp Dwell Programmer Function Block Diagram

The ST "soft-wiring" assignments required are :

setpoint.Index := segno.Val;

rate.Index := segno.Val;

dwell.Index := segno.Val;

The index parameter of the select functions are all driven by the "segno" integer user variable. By setting a given segment number in "segno", the outputs of the select blocks provide the setpoint, ramp rate and dwell values for a selected segment. A dwell segment is characterised by the "rate" Select_Real function block producing an output of 0.0, i.e.a null ramp rate. In figure 5-3, the select function blocks are set up to have 4 segments :

Segment 1 - Ramp to 100 at 1.1 units/seconds

Segment 2 - Dwell for 20 seconds

Segment 3 - Ramp to 200 at 2.5 units/seconds

Segment 4 - Ramp to 300 at 3.2 units/seconds

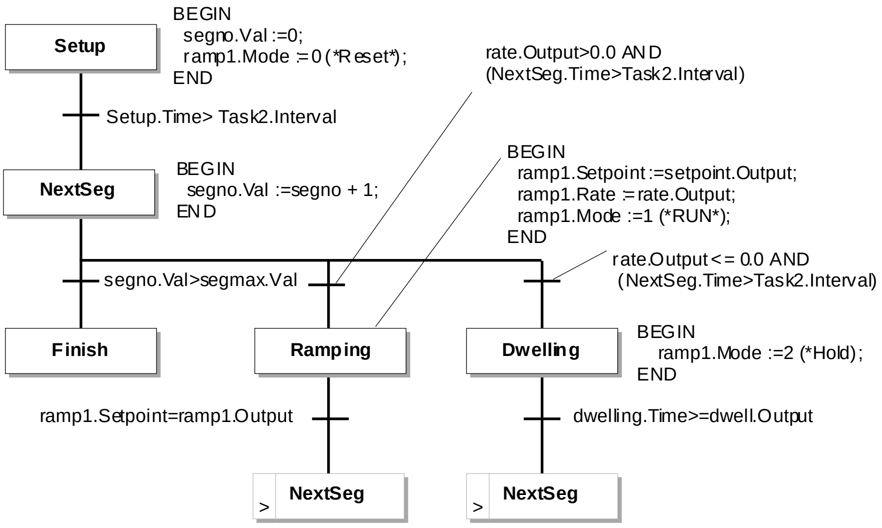

Setup
BEGIN
segno.Val :=0;
ramp1.Mode := 0 (*Reset*);
END
Setup.Time> Task2.Interval
NextSeg
BEGIN
segno.Val :=segno + 1;
END
rate.Output>0.0 AND
(NextSeg.Time>Task2.Interval)
BEGIN
ramp1.Setpoint :=setpoint.Output;
ramp1.Rate := rate.Output;
ramp1.Mode :=1 (*RUN*);
END
segno.Val>segmax.Val
rate.Output <= 0.0 AND
(NextSeg.Time>Task2.Interval)
Finish
Ramping
Dwelling
BEGIN
ramp1.Mode :=2 (*Hold);
END
ramp1.Setpoint=ramp1.Output
dwelling.Time>=dwell.Output
NextSeg
NextSeg

Figure 5-4 Ramp-dwell Programmer SFC

Figure 5-4 depicts the steps and transitions required to control the ramp-dwell programmer and should be regarded as part of a larger SFC.

The "Setup" step resets the segment number to zero and puts the "ramp1" function block into RESET mode. At this point the output of "ramp1" function block will be reset to the value of the **Reset_Output** parameter which, in this example, has the value 20.0.

The transition from the "Setup" step waits for the step to be active for one task scan to ensure that the function blocks have executed before proceeding. This example assumes that the SFC is executed in Task_2 (the normal default). In which case, the step should wait for the duration of one scan of Task_2. The task scan time is provided by the parameter **Task_2.Interval**.

In step "NextSeg", the segment number held in user variable "segno" is incremented.

Following "NextSeg" there are transitions to three alternative steps. Remember that the transitions are evaluated from left-to-right. The left-most transition checks whether the end segment has been reached by comparing the segment number with the user variable "segmax".

The other two transitions wait for "Nextseg" step to be active for one task scan to allow the select function blocks to execute to produce the correct outputs for the current segment.

The middle transition then checks whether the currently selected segment has a non-zero rate in order to select the "ramping" step.

The right-most transition checks whether the rate is zero in order to select the "dwelling" step.

The "ramping" step sets up the "ramp1" function block to increment its output to the setpoint and rate as produced by the select function blocks. The "ramp1" function block is then switched into RUN mode.

The transition from the "Ramping" step simply waits for the output of the ramp function block to reach the setpoint value and then returns to "NextSeg" for the next segment.

The "dwelling" step switches the "ramp1" function block into HOLD mode so that the output remains unchanged.

The transition from this step waits for the "dwelling" step to last for the segment dwell time and then returns to "NextSeg".

GOOD PROGRAMMING STYLE

When developing programs the following points should be considered to improve program readibility and consequently make the program easier to commission and maintain:

1. Where possible use meaningful names for function blocks and steps.
2. Use meaningful sense names for digital values, e.g. "UP"/"DOWN", "SHUT/OPEN". This is particularly important if a digital input or output has inverted logic such as 1 meaning "OFF".
3. Insert comments to describe complex pieces of Structured Text.
4. Use a top-down approach to the SFC structure, with the Main chart depicting the primary process states.
5. Use sequences wherever possible in place of state machines built from logic in continuous "soft-wiring". For example, use a step in place of setting a boolean user variable to define that a machine or process is in a certain state.
6. Avoid having constants in ST that may need to be changed when the system is commissioned. Instead, use User Variable function blocks to hold the constant

values. It is then possible to change the values when the system is being commissioned.

7. Become acquainted with the functionality of all the different types of function blocks and functions. In many cases, complex problems can be solved using existing functionality.

COMMISSIONING PROGRAMS

The PC3000 Programming Station provides on-line access to all function block parameters. This allows the PC3000 control program to be monitored as it operates in real-time. The various Sequence Function Charts can be viewed to identify active steps and macro steps. This provides a good indication of the process or machine state.

Sequence held-up

If a particular sequence is held-up at a certain step, view the ST defining the condition of each transition that follows the step. This will allow the reason to be rapidly located. Identify the ST boolean expression that you would expect to be "true".

On the PC3000 Programming Station, the live value of each function block parameter used in the expression is displayed on the bottom line of the Transition ST screen.

If the sequence is held-up by a macro step, view the lower-level macro chart until the faulty step is located. If this is also a macro step, continue down the chart hierarchy until the step that is held-up is located then check each of its transition conditions.

If a rendezvous transition fails to cause its following step to be activated, check that each step leading into the rendezvous, i.e. entering the double horizontal lines is active.

User screens

User Screens can be created on the Programming Station, while the PC3000 is running, to view selected parameters. This allows critical parameters to viewed simultaneously for diagnostic and commissioning purposes. User screens can also be used to provide an operator interface for applications where a simple man-machine interface is adequate.

Plant simulation

During system commissioning it is unlikely that all plant I/O is available for program testing. In some cases, it may be inconvenient or even dangerous to drive the physical outputs. PC3000 provides facilities to test programs without being directly connected to the plant or controlled machine.

Most PC3000 input channels have a test mode which allows the value of the physical input to be replaced by a test value. It is also possible to replace the channel status with a test status. Consequently, the behaviour of the program can be tested by simulating different plant input values and fault conditions such as, overrange sensor readings . A part of the sequence program (typically running as another parallel sequence) can be used to provide multiple test values to the I/O channels to build a plant simulation test-bed that exercises the control program. This can be removed when the program is fully commissioned.

Output Testing

By placing output channel function blocks in a test mode it is possible to directly provide test values to the physical outputs, irrespective of the state of the normal PC3000 control program. This can be useful when testing physical wiring and the connection between hardware channels and the physical actuators.

When output channels are in the test mode, the values written to the channel function blocks by the program are not written out to the physical outputs.

Caution

Ensure that all test enable parameters of all input and output channel function blocks are set to "off" in PC3000 programs that are running production processes.

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