

DEP SPECIFICATION

BASELAYER CONTROL APPLICATIONS

DEP 32.30.20.16-Gen.

February 2017

ECCN EAR99

DESIGN AND ENGINEERING PRACTICE



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1. INTRODUCTION

1.1 SCOPE

This DEP specifies rules, policies and guidelines for configuration of selected complex process control loops.

A control loop is defined as complex when its objectives or functionality cannot unambiguously be determined by inspection from a DCS display, PEFS, or PFS. Classification of control loops as either complex or basic is important because complex control loops have additional documentation and testing requirements.

The applications described in this DEP are complex process control loops that comprise part of the basic process control system (BPCS). Implementation of the schemes described in this DEP will be different depending on the host control computer. Hence, the descriptions in this DEP are written in a generic format that can be adapted to the DCS or PLC of any given Manufacturer/Supplier.

The statements in this DEP regarding operator HMIs are intended to be recommendations only. Local project standards for HMIs should be followed.

This DEP applies to the control system design, narratives, functional logic diagrams and PEFS for the application for which it has been specified by the Principal.

Control standards for fired equipment are described in DEP 32.24.20.44-Gen. Details such as control systems, IPF narratives, cause and effect diagram and functional logic diagram for a dual fuel fired, forced draft and single burner furnace/boiler are available upon request from the Process Automation, Control and Optimisation discipline.

This is a revision of the DEP of the same number dated February 2014; see (1.5) regarding the changes.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

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This DEP is intended for use in facilities related to oil and gas production, gas handling, oil refining, chemical processing, gasification, distribution and supply/marketing. This DEP may also be applied in other similar facilities.

When DEPs are applied, a Management of Change (MOC) process shall be implemented; this is of particular importance when existing facilities are to be modified.

If national and/or local regulations exist in which some of the requirements could be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable with regards to the safety, environmental, economic and legal aspects. In all cases, the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned, the objective being to obtain agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party that carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party that manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party that initiates the project and ultimately pays for it. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

The word **may** indicates a permitted option.

1.3.2 Specific definitions

Term	Definition
Engineer Authority	An industry term commonly used to refer to a higher level of authentication required to make certain changes on a process control system.
MAC Toolkit	a set of work processes, procedures and library of product standards and implementation configuration templates developed by the MAC. The MAC's Toolkit contains both its standard documents as well as Shell specific addenda.
Main Automation Contractor (MAC)	the DCS Manufacturer responsible for delivery of total automation solutions, comprising Distributed Control System, Instrumented Protective System, Fire and Gas System, Asset Management System, Sequence of Event Recorder and Operator Training Simulator.
Prototype complex loop	Complex loops that are built without the aid of existing templates, guidelines or testing procedures
Transition range	The overlap between the full scale value of the low-range transmitter and the minimum reliable value of the high-range transmitter

1.3.3 Abbreviations

Term	Definition
AUTO	AUTOMATIC mode
BFW	Boiler Feed Water
CAS	CASCADE mode
CASC	Compressor Anti-Surge Control
DCS	Distributed Control System. Also referred to as BPCS (Basic Process Control System)
ERFB	External Reset FeedBack
EU	Engineering Units
FAT	Factory Acceptance Test
FB	FeedBack (as in feedback control)
FF	Feed-Forward (as in feed-forward control)
FF/FB	Feed-Forward (and) Feedback control
HC	Hand Controller or Manual Loader Station
HMI	Human-Machine Interface
IGV	Inlet Guide Vane
IPS	Instrument Protective System (the safeguarding system)
MAC	Main Automation Contractor
MAN	Manual mode
MCB	Motor Control Block
OP	Output
P&ID	Process and instrumentation diagram (equivalent to PEFS)
PACE	Platform for Advanced Control and Estimation
PC	Pressure Controller
PEFS	Process Engineering Flow Scheme (equivalent to P&IDs)
PFD	Process Flow Diagram (identical to PFS)
PFS	Process Flow Scheme (identical to PFD)
PI	Proportional Integral

Term	Definition
PID	Proportional Integral Derivative
PLC	Programmable Logic Controller
PROG	PROGram mode
PV	Process Value
SAT	Site Acceptance Test
SCL	Surge Control Line
SI	International System of units, or Separation Index
SMOCPro	Shell Multivariable Optimising Controller
SP	Set Point
SRL	Surge Reference Line
SRV	Surge Reference Value
SSVCPro	Shell Surge Volume Controller
TC	Temperature Controller
VFD	Variable Frequency Drive
VPC	Valve Position Controller

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section or clause number is shown in brackets (). Other documents referenced by this DEP are listed in (4).

1.5 SUMMARY OF MAIN CHANGES

This DEP is a full revision of the DEP of the same number dated February 2014. The following are the main, non-editorial changes.

Section/Clause	Change
the entire DEP	Numerous updates in order to improve the overall quality of the DEP statements

1.6 COMMENTS ON THIS DEP

Comments on this DEP may be submitted to the Administrator using one of the following options:

Shell DEPs Online (Users with access to Shell DEPs Online)	Enter the Shell DEPs Online system at https://www.shelldeps.com Select a DEP and then go to the details screen for that DEP. Click on the "Give feedback" link, fill in the online form and submit.
DEP Feedback System (Users with access to Shell Wide Web)	Enter comments directly in the DEP Feedback System which is accessible from the Technical Standards Portal http://swwww.shell.com/standards . Select "Submit DEP Feedback", fill in the online form and submit.
DEP Standard Form (other users)	Use DEP Standard Form 00.00.05.80-Gen. to record feedback and email the form to the Administrator at standards@shell.com .

Feedback that has been registered in the DEP Feedback System by using one of the above options will be reviewed by the DEP Custodian for potential improvements to the DEP.

1.7 DUAL UNITS

This DEP contains both the International System (SI) units, as well as the corresponding US Customary (USC) units, which are given following the SI units in brackets. When agreed by the Principal, the indicated USC values/units may be used.

1.8 NON NORMATIVE TEXT (COMMENTARY)

Text shown in italic style in this DEP indicates text that is non-normative and is provided as explanation or background information only.

Non-normative text is normally indented slightly to the right of the relevant DEP clause.

2. CONFIGURATION OF PROCESS CONTROL LOOPS

2.1 GENERAL

1. This DEP shall be used as the basis for control system design, narratives, functional logic diagrams and PEFS for the application for which it has been specified by the Principal.
2. The control narratives shall include all details required for flawless installation and commissioning.
3. Unless stated otherwise, no standard or emergency alarms should be implemented for any of the applications described in this DEP.

The decision on which alarms to add is application dependent.

4. The decision on which alarms to add shall be handled by the Principal in accordance with applicable Alarm Management standards.

2.2 STANDARD DCS TOOLKITS

1. For capital projects, the MAC shall implement the configuration of process control loops using the Shell MAC toolkit, if one exists, as the basis for the loops implemented.
2. All schemes listed in (3) shall be implemented within each MAC's DCS toolkit.
3. For each capital project, the MAC should ensure that the control scheme functional specification is implemented using toolkit typicals wherever possible.
4. During PEFS development, the MAC, Contractor and the Principal's Control Systems Engineer shall agree on the toolkit typical to be utilized, or agree that a prototype complex control loop will need to be developed.

2.3 PROTOTYPE DCS TOOLKITS

1. If a loop typical does not exist in the Shell MAC toolkit, then refer to (3) for the requirements to develop a prototype complex loop for the project.
2. The prototype complex loop shall be subject to approval by the Principal prior to implementation on the project.
3. The project prototype complex loop should be considered for inclusion in the MAC's toolkit as a typical.
4. Each MAC's established procedure shall be followed in making updates to its toolkit.

2.4 COMPLEX CONTROLS

1. For complex controls which are not described in (3), nor included within the MAC's existing toolkit, the MAC shall consult the Principal for implementation guidance.
2. The MAC shall implement the narratives, configuration, and testing in accordance with the toolkits and other general and project-specific standards as agreed with the Principal.

Requirements and recommendations for documentation and testing of complex control loops are included in (3.20).

3. MEASUREMENT/SIGNAL CONDITIONING/CONTROL SCHEMES**3.1 DUAL RANGE TRANSMITTERS****3.1.1 General**

1. The algorithm in this section is used when flow measurements from two differently ranged transmitters need to be combined into a single measurement spanning the unified range of the transmitters.

Refer to the control block diagram in Figure 1.

It is assumed that both transmitters are reporting flow in the same engineering units [EU].

2. A unit conversion in the DCS should be used to align the engineering units.
3. There shall be one flow transmitter with a 'low' calibrated range (FI01A) and one with a 'high' calibrated range (FI01B).
4. There shall be an overlap between the full scale value of the low-range transmitter and the minimum reliable value of the high-range transmitter.

This overlap is called the transition range.

The transition range maximum is specified by the parameter F_{max} .

5. The transition range maximum should be selected as the full scale reading in [EU] of the low-range transmitter, FI01A.

The transition range minimum is specified by the parameter F_{min} .

6. The transition range minimum should be selected as the minimum reliable value in [EU] of the high-range transmitter, FI01B.
7. If density compensation is being applied to the measurement, it should be applied to the individual flows unless the calibration conditions of the two flows are identical.
8. If the calibration conditions are identical, compensation may be applied to the calculated flow instead.

3.1.2 Calculations

1. Equations 1, 2, and 3, should be used to compute the total flow, F01.PV, in [EU]:

$$F01.PV = Y01.OP \quad \text{Equation 1}$$

$$Y01.OP = (1 - k) \cdot FI01A.PV + k \cdot FI01B.PV \quad \text{Equation 2}$$

$$k = \min \left(\max \left(0, \left(\frac{FI01A.PV - F_{min}}{F_{max} - F_{min}} \right) \right), 1 \right) \quad \text{Equation 3}$$

Where:

k Calculated weighting factor.

F_{min} Transition range minimum, [EU].

F_{max} Transition range maximum, [EU].

3.1.3 Initialisation

No initialisation of dual range transmitters is required.

3.1.4 Operational modes

1. The calculated flow PV status shall be determined from Table 1 based on the status of the measured inputs.

Table 1 Operational modes of dual range transmitters

Mode of Operation	Scenario	Automatic Action	Operator Action
Start-up	No special requirements		
Normal Operation	No special requirements		
Uncertain Input(s)	No special requirements. Equations 1 through 3 will compute a value for F01.PV and assign a PV Status of Uncertain.		
Bad Inputs	If both input transmitter PVs are Bad, then F01.PV is Bad.		
Crippled Mode	Low range transmitter FI01A has Bad PV status.	Use logic to set $F1.PV$: If $(FI01B.PV > F_{min})$ Then $(F01.PV = FI01B.PV)$ Else: Set the status of F01.PV to Bad PV.	-
Crippled Mode	High range transmitter FI01B has Bad PV status.	Use logic to set $F01.PV$: If $(FI01A.PV < F_{max})$ Then $(F01.PV = FI01A.PV)$ Else: Set the status of F01.PV to Bad PV.	-

3.1.5 Operator interface

1. On Level 1, 2 and 3 graphics, only the calculated flow result, F01.PV, should be shown.
2. On Level 4 graphics:
 - a. the raw flow indications from both transmitters and the calculated flow should be shown;
 - b. an additional symbol should be used to indicate which of the indicators has been selected;
 - c. in the transition range, both raw indicators should be shown as selected.

3.1.6 Start-up/shutdown

No special provision for dual range transmitters is required.

3.2 PRESSURE COMPENSATED TEMPERATURE

3.2.1 General

Pressure compensation is not required in all temperature control applications.

1. Pressure compensation should be implemented when temperature control is being used to infer the composition of a hydrocarbon mixture at a particular stage of a distillation operation.
2. Pressure compensated temperature should only be implemented when specified by the Principal.

Figure 2 shows a typical control block diagram for a pressure compensated temperature application.

3. The pressure at the temperature measurement point (P_{Act}) may be an absolute pressure measurement ($P_{Act} = P_{Meas}$) or a calculation based on an absolute pressure measurement and a pressure drop measurement ($P_{Act} = P_{Meas} + dP_{Meas}$).

The minimum required set of process measurements is an estimate of the absolute pressure (P_{Act}) at the temperature measurement point (T_{Meas}).

4. An upper pressure limit (P_{max}) and lower pressure limit (P_{min}) shall be used to define the validity range of P_{Act} :
 - a. if P_{Act} is greater than P_{max} then P_{Act} is set to P_{max} and the PV status of P_{Act} is set to Uncertain;
 - b. if P_{Act} is less than P_{min} then P_{Act} is set to P_{min} and the PV status of P_{Act} is set to Uncertain.
5. If the PV status of P_{Act} is Bad, then the pressure used to calculate T_{Comp} should automatically switch from P_{Act} to one of the following alternatives:
 - a. the normal operating pressure specified for this application, or
 - b. the last good pressure measurement if this is available and considered reliable.
6. For either of the alternatives described in (3.2.1, Item 5), the PV status of T_{Comp} should be set to Uncertain.
7. The PV status of T_{Comp} shall be the same as the PV status for T_{Meas} .

The pressure compensated temperature calculation is always active and cannot be switched off by the operator.

8. There should be an option provided to apply a first order digital filter to the pressure measurement used by the compensation algorithm (P_{Act}).
9. The calculation block Y01 in Figure 2 represents the logic required to meet all of the requirements in (3.2.1, Item 3) through (3.2.1, Item 9).

There are two possible equation forms that can be specified by the Principal to calculate pressure compensated temperatures:

- Type I: Linear (refer to (3.2.2.1));
- Type II: Modified Clausius-Clapeyron (refer to (3.2.2.2)).

Either of the equation forms can be selected to calculate the pressure compensated temperature. If the Principal does not specify the equation form to be used, the Linear equation form can be assumed to apply.

3.2.2 Calculations

The formulae in (3.2.2.1) and (3.2.2.2) are given in units of absolute pressure and temperature because the compensation coefficients are expressed in absolute units. Input and output unit conversions from standard units to absolute units will normally be required.

3.2.2.1 Type I: Linear

The calculated value for T_{Comp} is given by Equation 4:

$$T_{Comp} = T_{Meas} + k \cdot (P_{Ref} - P_{Act}) \quad \text{Equation 4}$$

Where:

T_{Comp} = Pressure compensated temperature, [K] or [R]

k = Linear compensation factor, [K/kPaa] or [R/psia]

T_{Meas} = Measured temperature, [K] or [R]

P_{Ref} = Reference pressure in absolute units, [kPaa] or [psia]

P_{Act} = Actual pressure in absolute units, [kPaa] or [psia]

3.2.2.2 Type II: Modified Clausius-Clapeyron

The calculated value for T_{Comp} is given by Equation 5:

$$T_{Comp} = \frac{b}{\frac{b}{T_{Meas}} - \ln\left(\frac{P_{Ref}}{P_{Act}}\right)} \quad \text{Equation 5}$$

Where:

T_{Comp} = Pressure compensated temperature, [K] or [R]

b = Pressure compensation coefficient, [K] or [R]

T_{Meas} = Measured temperature, [K] or [R]

P_{Ref} = Reference pressure in absolute units, [kPaa] or [psia]

P_{Act} = Actual pressure in absolute units, [kPaa] or [psia]

3.2.3 Initialisation

No special initialization is required for pressure compensated temperature applications.

3.2.4 Operational modes

1. Table 2 indicates the operational modes for pressure compensated temperature applications.

Table 2 Operational modes of pressure compensated temperature

Mode of Operation	Scenario	Automatic Action	Operator Action
Normal Operation	No special requirements.		
Uncertain Input(s)	No special requirements.		
Crippled Mode	Failure of Temperature transmitter. The PV status of T_{Meas} is Bad.	The PV status of T_{Comp} shall be set to Bad.	-
Crippled Mode	Failure of Pressure transmitter. The PV status of P_{Meas} is Bad.	The compensation calculation should use the vessel operating design pressure or the last good measured pressure. The PV status of T_{Comp} should be set to Uncertain.	-
Crippled Mode	Pressure outside validity limits	The limit closest to the pressure should be used to calculate the compensated temperature. The compensated temperature quality should be set to Uncertain.	-

3.2.5 Operator interface

1. The raw temperature value and the compensated temperature should be available to the operator.
2. The operator should have read-only access to all parameters.

3.2.6 Start-up/shutdown

There are no special start-up or shutdown requirements for pressure compensated temperature applications.

3.3 MOTOR OPERATED VALVE (MOV)**3.3.1 General**

1. The open/closed limit switches, valve positioner or position transmitter should be used to indicate the valve position on operating displays.
2. The following digital commands should be made available to the operator: Open, Close and Stop.
3. The stop command should stop the valve movement on demand at its current position.
4. In applications where switching between local and remote control is possible in the field, a remote/local mode indicator should be shown on the operator display.

5. The use of MOV for closed-loop control shall be subject to approval by the Principal.
6. If an MOV is used for closed-loop control the following conditions should apply:
 - a. in Automatic mode, the valve should be moved only if the change in PID output is greater than a prescribed threshold value;
 - b. if the PID output change is less than the threshold amount, it should be accumulated;

Once the cumulative change exceeds the threshold value it sent to the MOV, and the cumulative amount is reset to zero.
 - c. in Manual mode, it should be possible to set the position of the valve using the controller output.

There is no minimum move threshold applicable in manual mode.
7. Any rate of change constraints on MOVs shall be applied in the MOV, not in the process control computer (DCS or PLC).
8. Refer to DEP 32.30.20.15-Gen. Section 7.2 for information regarding the digital input and output requirements for MOVs.

3.4 SURGE VOLUME CONTROL

3.4.1 General

1. When surge volume control is specified by the Principal:
 - a. when a stand-alone level controller is required to have surge volume control capability, the first choice should be a standard PID implementation with a suitably slow closed-loop response time;
 - b. if the PID approach is not providing the level of performance required, then a PID controller configured with a PID Gap algorithm or a DCS-embedded model based controller (if available) should be used;
 - c. when surge volume control is to be configured for more than one level in series, then advanced process control shall be used.

Use Platform for Advanced Control and Estimation (PACE) if it is available and if APC meets the application uptime requirements. If PACE is not available, and/or if the application has very high uptime requirements, then use the Shell Surge Volume Controller (SSVC^{Pro}) or individual DCS-embedded model based controllers.

3.5 FIN FAN CAPACITY CONTROL

3.5.1 General

1. Air-cooled heat exchanger outlet temperature control applications shall be subject to approval of the Principal.

The fan control applications described in this DEP conform to the layout and process control requirements for air-cooled heat exchangers as described in DEP 31.21.70.10-Gen. The following assumptions regarding layout and control apply:

- *identical parallel bays of exchangers;*
- *symmetrical fan arrangement;*
- *if two or more fans are present per bay, the variable speed fan is the furthest downstream;*
- *if two or more variable speed fans are to be used for control, the control is equal and simultaneous to all variable speed fans.*

3.5.2 Fixed speed applications

Fixed speed applications are characterized by one or more fixed speed fans that are switched on or off in order to meet an outlet temperature control objective.

1. Fixed speed fan switching should only be used when the quality of the outlet temperature control is not critical.

Refer to the Mode A temperature control requirements in DEP 31.21.70.10-Gen.

A control block diagram of a generic fixed speed fan control application is shown in Figure 3. Control logic is used to determine if a fan is to be switched on or off, and to identify the next individual fan to be switched on or off based on a prioritization algorithm. The process variable is the outlet temperature. The manipulated variable is the state of the fixed speed fans.

2. The outlet temperature should be controlled to within a target range, from T_{min} to T_{max} .
3. If the outlet temperature exceeds T_{max} then a fan should be switched on.
4. If the outlet temperature is less than T_{min} then a fan should be switched off.

When a fan is switched on or off, a deadband timer is started.

5. No fans shall be automatically switched on or off by the scheme until the deadband timer has expired.

The duration of the deadband timer is adjustable online by the engineer with the appropriate permissions.

6. The program should be able to detect saturation.
7. The program should be programmed to know when it is not possible to switch on any more fans, and when it is not possible to switch off any more fans.
8. The control logic should act accordingly in the presence of saturation.

For example, the deadband timer should not be started if $(T > T_{max})$ and all available fans are already running.

9. Run hours should be computed for each fan in the scheme, in order to provide information for switching prioritization.
10. It shall be possible for a person with engineer authority to reset the run hours for any fan in the scheme.
11. Operators should be able to do each of the following:
 - a. turn the entire switching program on or off;
 - b. add or remove fans from the list of eligible fans to be used in the scheme by setting a flag (Note: this is different than having the ability to manually switch a fan on or off);
 - c. manually turn any fan on or off that is flagged as removed from the automatic switching program;
 - d. adjust the values of T_{min} to T_{max} .

A fan is eligible to be automatically switched on or off by the switching program if all of the following conditions are met:

- *the mode attribute of the controlling switch is permitting program changes to be made to the run state of the fan;*
- *the in-service flag shows that the fan has been marked by the operator as eligible to be manipulated automatically by the scheme;*
- *the deadband timer has expired.*

12. If there is more than one fan in the scheme, an algorithm should be developed that determines which fan is next in line to be switched on or off.
 - *The next fan eligible to be switched on or off could be determined based on:*
 - o *maintaining an equal number of active fans in each parallel bank of air coolers. For example, if the switching logic indicates that a fan needs to be turned off, a fan in the bank with the greatest number of active fans running would be considered first in line to be switched off;*
 - o *the total run hours per fan. For example, the next fan to be switched on is the one with the fewest total run hours, the next fan to be switched off is the one with the greatest total run hours;*
 - o *the time that has elapsed since a given fan has been running or stopped.*

3.5.3 Variable speed applications

A control block diagram of a typical variable speed only application is shown in Figure 4.

The process variable is the outlet temperature. The manipulated variable is the fan speed (connected to one or more fans). A feedback control algorithm is used to compute the control moves.

In variable speed applications, the outlet temperature can be controlled to a temperature setpoint, T_{sp} , or to within a target range, T_{min} to T_{max} , if a gap algorithm is used.

If there is only one variable speed fan in the scheme, then the output from the temperature controller sets the setpoint of the fan speed controller in a standard primary/secondary cascade structure as defined in DEP 32.30.20.15-Gen.

If there is more than one variable speed fan, then the recommended configuration between the temperature controller and the speed controllers is a fanout scheme:

The fanout scheme sends the same temperature controller output to all participating secondaries in the scheme. A 'participating secondary' is a speed controller that is in a mode where its speed is set by the temperature controller output (normally Cascade).

The first secondary to be put in Cascade mode initializes the temperature controller output. Subsequent secondaries put into Cascade mode will be bumplessly integrated into the scheme by using a bias bleed-off function on the secondary.

1. Logic should be provided to automatically force the mode to Manual and the Output to 0% for any of the variable speed fans that are not turned on.

This provision will prevent bumps that might result from turning a fan on while the speed controller is in Cascade mode.
2. The operator shall have the authority to determine which fans are to be included in the fanout scheme.

The mode of each secondary speed controller is used to specify whether the fan is included in the scheme or not.
3. It should not be possible for an operator to add a non-operating fan as a participating secondary in the fanout scheme.
4. The feedback controller gain of the temperature controller should automatically and bumplessly be adjusted based on the number of secondary controllers participating in the fanout scheme.

3.5.4 Combined variable and fixed speed applications

A control block diagram of a fin fan outlet temperature control application with both fixed speed and variable speed fans is shown in Figure 5.

1. The recommendations listed in (3.5.2) and (3.5.3) shall apply to combined fixed and variable speed applications, with the following exceptions and additional recommendations:
 - a. the temperature objective is defined only for the variable speed (feedback controller) part of the scheme;
 - b. if the automatic switching logic for the fixed speed fans is disabled, the feedforward control action will still be in effect;
 - c. a separate switch should be provided to disable the feedforward control signal;
This configuration enables the benefits of the feedforward control action to be realized even if operators need to manually adjust the fixed speed fans.
 - d. the switching logic for the fixed speed fans is linked to the output of the PID controller rather than to high and low temperature limits;
 - i. A fixed speed fan can be switched on if the temperature controller output is greater than an upper threshold (usually 90%).
 - ii. A fixed speed fan can be switched off if the temperature controller output is less than a lower threshold (usually 10%).
 - iii. The high and low output limits should require engineering level access to modify.
 - iv. The connection between TC01 and Y05 is non-initializable (pulled to the switching logic program).
 - e. the following function blocks and associated connections in Figure 5 can be omitted if feedforward is not specified by the Principal: Y01, Y02, Y03, and Y04;
 - f. if feedforward is specified by the Principal for the combined application, then the following recommendations should apply;
 - i. the controller TC01 should be configured as a standard feedforward/feedback controller as defined in DEP 32.30.20.15-Gen.
 - ii. a function should be provided to bumplessly enable and disable the feedforward control action;
 - iii. the Principal should specify the permissions level for this function;
 - iv. the block Y01 counts the number of fixed speed fans currently in operation during the current cycle;
 - v. the block Y02 counts the number of participating secondary controllers, that is, the number of variable speed fans currently included in the fanout scheme;
Note that if a fan is running but in Manual or Auto mode, it does not count towards the total computed by Y02.
 - vi. the block Y03 is a calculation function that scales the feedforward signal based on the values it receives from Y01 and Y02;
 - vii. the block Y04 is a lead/lag function block for tuning the dynamic response of the feedforward control action;
 - viii. depending on the feedforward control template being used, this lead/lag function block Y04 may already be included in the feedforward module or it may need to be added separately.

3.5.5 Calculations

1. Refer to DEP 32.30.20.15-Gen. for the design procedure for feedforward control.
2. The feedforward gain on the PID function block should be set to 1.0.
3. The gain on the lead/lag block Y04 should be set to 1.0.

The dynamics of the feedforward controller will be set by the commissioning engineer on the lead/lag block Y04.

The number of participating secondary speed controllers in the temperature fanout at time t , $N_v(t)$, is counted by the block Y02.

The number of running fixed speed fans at time t , $N_f(t)$, is counted by the block Y01.

It is assumed the cooling duty contribution of each fixed speed fan is the same. The individual cooling duty of a fixed speed fan is denoted $Q_{f,i}$.

It is assumed the cooling duty contribution of each variable speed fan is the same. The individual cooling duty of a single variable speed fan at 100% speed is denoted $Q_{v,i}$.

The total duty accessible to the feedback controller is denoted $Q_v(t)$. Equation 6 provides an estimate of the duty at 100% fan speed across all participating variable speed fans:

$$Q_v(t) = N_v(t) \cdot Q_{v,i} \quad [EU_Duty] \quad \text{Equation 6}$$

Where $[EU_Duty]$ denotes the applicable engineering units for duty. The cooling duty of the active fixed speed fans is denoted $Q_f(t)$ in Equation 7.

$$Q_f(t) = N_f(t) \cdot Q_{f,i} \quad [EU_Duty] \quad \text{Equation 7}$$

The process gain in engineering units, $K_p(t)$ in Equation 8, is the change in variable speed duty for a 1% change in temperature controller output.

$$K_p(t) = 0.01 \cdot Q_v(t) \quad [EU_Duty/\%TC.OP] \quad \text{Equation 8}$$

The disturbance gain, K_d , is fixed at unity because a 1% change in fixed fan cooling duty translates into a 1% change in total duty.

The feedforward controller gain, $K_{ff}(t)$ in $[EU_Duty/\%TC.OP]$ is given by Equation 9:

$$K_{ff}(t) = -\frac{K_d}{K_p(t)} \quad [EU_Duty/\%TC.OP] \quad \text{Equation 9}$$

$TC.OP_{FFD}$ denotes the move that TC.OP needs to make to compensate for a change in $Q_f(t)$. The resulting condition is shown in Equation 10:

$$\Delta TC.OP_{FFD} = -K_{ff} \cdot \Delta Q_f(t) = -\frac{\Delta Q_f(t)}{0.01 \cdot Q_v(t)} \quad \text{Equation 10}$$

$[\%TC.OP]$

Or, in terms of the variables shown in Figure 5:

$$Y03.OP = -100 \cdot \left(\frac{Q_{f,i} \cdot Y01.OP}{Q_{v,i} \cdot Y02.OP} \right) \quad [\%TC.OP] \quad \text{Equation 11}$$

The differencing operation required is assumed to be performed automatically by the feedforward control block input processing.

Important: When $N_i(t)$ changes, a bump will occur in the feedforward channel. This is not a problem; it is expected and part of the design. When $N_v(t)$ changes there will also be a change in the process gain representing the change in available duty in the fanout. This bump should be removed from the feedforward channel. One suggestion for removing the bump would be to temporarily set the feedforward signal quality to Bad for the execution in which $N_v(t)$ changes. The feedforward controller will not process the bad input which will prevent the bump. The quality can be restored at the next execution.

3.5.6 Operational modes

1. Unless otherwise noted, controller response to Uncertain or Bad input data and controller response to the restoration of Good input data should be as per the requirements in DEP 32.30.20.15-Gen.
2. Table 3 indicates the major modes of operation for fin fan capacity control:

Table 3 Operational modes of fin fan capacity control

Mode of Operation	Scenario	Automatic Action	Operator Action
Normal Mode Fixed Speed Only	The fan switching program Y05 is in the Run state, and all available fixed speed fans are in Program mode.		
Normal Mode Variable Speed Only	TC01 is in Auto, all available secondaries are configured to receive remote setpoints from TC01 (could be Auto or Cascade depending on the control block used for the secondary loops).		
Normal Mode Fixed and Variable Speed	The fan switching program Y05 is in the Run state, and all available fixed speed fans are in Program mode. TC01 is in Auto, all available secondaries are configured to receive remote setpoints from TC01 (could be Auto or Cascade depending on the control block used for the secondary loops).		
Gain Update	A mode change is made on an SC while the TC is in Auto.	FF/FB control continues. The feedforward gain is updated by Y03. The feedback controller gain is updated (optional).	None
Crippled Mode	Combined operation with all fixed speed fans removed or Y05 in Stopped state.	Feedforward control continues based on operator changes to fixed fan states.	Turn off feedforward control separately if desired.
Crippled Mode	Bad PV Status for TC01.	Fixed speed fan switching program Y05 sheds to Stopped state. TC01 sheds to Man mode and holds its output value. Do not automatically re-start Y05 or change TC01 to Auto.	Turn the loop back on (TC01 to Auto and Y05 to Run) when the PV status for TC01 is restored to Good or Uncertain.

3.5.7 Operator interface

1. The entire control scheme should be shown on a single operating display.
2. Both the next fan to be started (if necessary) and the next fan to be stopped (if necessary), according to the fixed speed fan switching logic, should be displayed for the operator.
3. A flag or indicator should be displayed, showing which fixed speed fans are available to be switched by the logic and which can only be switched manually.
4. An indicator should be displayed, showing the status of the VFDs (Local/Remote) if the indications are brought into the DCS display.

3.5.8 Start-up/shutdown

1. The fin fan control programs shall include the following capabilities, as applicable, to ensure startup and shutdown:
 - a. fixed Speed Fans Only: To turn the fan switching program on, set the program switch to Run on Y05. To turn the switching program off, set the program switch to Stop on Y05;
 - b. variable Speed Only: To turn the loop on, ensure all desired SCs are in the correct mode to receive remote setpoints then switch TC01 to Auto. To turn the loop off, put TC01 in Manual;
 - c. combined Schemes: To turn the loop on, set the program switch on Y05 to Run. Put all desired SCs in the correct mode to receive remote setpoints and switch TC01 to Auto. To turn the loop off, put TC01 into Manual mode and set Y05 to Stop.

3.6 THREE ELEMENT LEVEL CONTROL

3.6.1 General

A control block diagram for a general three element level control application is shown in Figure 6. The three element level controller is a standard feedforward/feedback control application with the steam flow as the single feedforward input.

1. The level controller LC01 should be configured as a feedforward/feedback controller in accordance with the feedforward control specifications in DEP 32.30.20.15-Gen.
Set operator setpoint entry limits for LC01 inside of any boiler shutdown trip points on the steam drum level.
2. The boiler feed water (BFW) flow controller FC01 should be configured as a cascade secondary controller as per the specifications in DEP 32.30.20.15-Gen.
3. Switching the feedforward control action on and off or changing the feedforward controller gain should require engineering authority.
4. When specified by the Principal, the level measurement in the steam drum shall be compensated for density variations resulting from pressure changes in the steam drum.

3.6.2 Specific configuration conditions

There are no specific configuration requirements for three element level control applications.

3.6.3 Calculations

None.

3.6.4 Initialisations

1. The level controller LC01 should be configured a protective controller as per DEP 32.30.20.15-Gen. (PV tracking will be Off).
Set the PID equation type to Integral on error, and set the Proportional and Derivative on delta PV.

3.6.5 Operational modes

1. Table 4 indicates the main operation modes for three element level control applications.

Table 4 Operational modes of three element level control

Mode of Operation	Scenario	Automatic Action	Operator Action
Normal Mode	LC01 in AUTO, FC01 in CAS.		
Crippled Mode	Failure of BFW transmitter. The PV status of FI01 is Bad.	Standard rules for loss of input/output connections from DEP 32.30.20.15-Gen. apply.	-
Crippled Mode	Failure of level transmitter. The PV status of LI01 is Bad.	Standard rules for loss of input/output connections from DEP 32.30.20.15-Gen. apply.	-
Crippled Mode	Failure of steam flow transmitter. The PV status of FI02 is Bad.	Feed forward control action should automatically cease. LC01 should continue in feedback only mode. Upon restoration of good or uncertain quality in FI02, feedforward control should resume bumplessly.	Follow-up actions for the Bad PV alarm on FI02 should include a mitigation plan for extended operation of LC01 in feedback control mode only.

3.6.6 Operator interface

1. Standard PID face plates for feedforward and feedback control should be used.
2. The operator shall have access to change the SP, OP and MODE of LC01 and FC01.
3. All the control blocks used in three element level control applications should be visible on the same operator display.

3.6.7 Start-up/shutdown

There are special start-up or shutdown requirements for three element level control applications.

3.7 FURNACE COIL BALANCING**3.7.1 General**

1. Furnace coil balancing (also known as pass balancing) should be implemented using advanced control (PACE).
If the use of PACE is not practical for a given application then a base layer solution can be used.
2. The control objective for the balancing application should be specified by the Principal (e.g., coil outlet temperature or thermal conversion).
3. Furnace coil balancing should only be applied to non-coking service, and not to furnaces used as reboilers where the outlet temperature is insensitive to furnace duty.
4. In general a heat transfer specialist should be consulted before a furnace pass balancing scheme is implemented.

3.8 NO_x CONTROL

3.8.1 General

A control block diagram for a NO_x control application is shown in Figure 7. It is assumed that the NH₃ supply is in vapour form.

QC05 and FC02 are standard PID controllers.

FFC03 is an ammonia flow to combustion air flow ratio controller (NH₃-to-air). The wild flow is the combustion air flow.

1. Refer to DEP 32.30.20.15-Gen. for the requirements for configuring the ratio controller.
 - a. When FFC03 is in CAS mode the NH₃-to-air ratio setpoint is set by QC05.
 - b. When FFC03 is in AUTO mode the NH₃-to-air ratio setpoint is set by the operator.

QI01, QI02 and QI03 represent raw analyzer readings for O₂, NO_x and NH₃, respectively.

2. Refer to DEP 32.30.20.15-Gen. for the requirements for validating all analyzer process variables.
3. The Shell analyzer checking application Anacheck should be used if available.

In Figure 7, the validated analyzer PVs are denoted by QN.

The corrected NO_x controller QC05 has a calculated PV that is a function of the stack measurements for NO_x and O₂. The calculation is represented by the block Y01 in Figure 7. The form of the equation and coefficients contained by Y01 will be specified by the Principal.

4. The oxygen analyser used to measure the O₂ concentration required for the corrected NO_x calculation should be located close to the NO_x measurement.
5. When the furnace is shut down, a signal should be sent to FC02, forcing the controller mode to manual and the output to 0%.
6. The forcing signal shall be from a robust source to avoid unwanted shutdown of the NO_x control scheme during normal operation.
7. The forcing signal should automatically be removed once combustion is resumed.

It is up to the operator to update the mode and output of FC02 as per start-up procedures.

3.8.2 Calculations

The calculation block Y01 in Figure 7 is needed to convert the NO_x measurement from QN02 from a wet basis with variable O₂ to a dry basis with a fixed O₂. Unit conversions and the O₂ result from QN01 are needed to perform this calculation.

3.8.3 Initialisations

1. The NH₃-to-air ratio controller FFC03 shall have tracking and initialisation configured as per the standards for ratio controllers in DEP 32.30.20.15-Gen.
2. The corrected NO_x controller QC05 shall be configured with PV tracking OFF as per the protective controller requirements described in DEP 32.30.20.15-Gen.
3. The NH₃ flow controller FC02 shall be configured as a cascade secondary PID as per the standards in DEP 32.30.20.15-Gen.

3.8.4 Operational modes

1. Table 5 indicates the main operating modes for NO_x control applications.