Technical Information

Intelligent
Self-Tuning Controllers

YEWSERIES 80

CONTENTS

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1. INTRODUCTION

The enhanced YEWSERIES 80 (Style E) is the second generation in a single-loop control system. The first-generation YEWSERIES 80 controllers employed microprocessors to provide, in a single instrument, many more functions — such as control, signal computation, sequence control and communication functions — than conventional analog instruments of comparable cost and size.

The second-generation YEWSERIES 80 controllers have enhanced their functional concentration and, in addition, feature self-tuning control (STC) functions which adjust the PID parameters to optimum values based on advanced computer software technology.

At a location where a control system operates, an increase in more precise controllability is required to improve product quality, reduce material and energy requirements, and to respond to the adoption of multi-product small-volume production systems, to more than one type of raw or fuel, and to frequent changes in operating conditions or loads.

A number of PID controllers are used in process control systems.

To implement and maintain the optimum control conditions of a control loop, PID parameters must be tuned. This has been done based on the adjustment experience and knowledge of a skilled operator or instrumentation engineer and his operational know-how specifically related to each process. Hence, the operator is always expected to perform precise tuning depending on the process operating conditions.

However, owing to the wide range of complex jobs handled by veteran operators, insufficient tuning of PID parameters may occur.

The intelligent self-tuning controller incorporates an STC function in which the process identification technique based on the control theory is combined with PID parameter calculation.

The objectives of self-tuning functions are summarized in the following two points:

- To maintain optimum control following static and dynamic process-characteristic changes.
- To reduce an operator's burden of the tuning workload during process start-up.

The intelligent STC function is incorporated in the YEWSERIES 80 SLCD-□81 indicating controller and SLPC-□81 programmable controller to configure to the STC controllers. The function can be used in conjunction with the powerful control functions of these controllers.

The features of YEWSERIES 80 intelligent STC controllers are as follows:

- The STC controller estimates process characteristics through a single setpoint change or MV changes by an on-demand command and calculates the optimum PID parameters in a short time. Thus, there is no need to wait a long time for waveform observation results.
- The process is not disturbed because a periodical application of test signals is not necessary.
- Since the estimated process characteristics (dead-time, time-constant, and gain) are displayed during self-tuning, the characteristic changes can be monitored.
- The user does not need any special knowledge of control theory.
- The intelligent self-tuning functions of YEWSERIES 80 controllers are easy to use, as there are only a few selections necessary for setting parameters.
- High or low limit values for PID parameters can be set for safe operation.
- Self-tuning can be switched ON/OFF.
- Self-tuning controllers have an automatic PID updating mode (with the computation and setting of optimum PID parameters) and a non-updating mode where optimum PID parameters are only computed and displayed. Also, when the self-tuning mode is OFF, the controller functions as a conventional PID controller.

2. OPERATING PRINCIPLES OF AN INTELLIGENT SELF-TUNING CONTROLLER

2.1 Intelligent Self-Tuning

In general, since a self-tuning controller updates PID parameters by following after process-characteristic changes, in order to improve controllability it is necessary to capture the characteristic changes quickly. In intelligent self-tuning, the controller observes fluctuations in the measured value (PV, process variable) and manipulated variable (MV), and estimates in a very short time a process characteristic model from the resultant waveform response to SV (setpoint) change or MV changes by an on-demand command to calculate PID parameters. If the accuracy for the estimated model is low, PID parameters are not updated in order to prevent a mis-setting.

2.2 Estimating Process Characteristics

The STC controller estimates process characteristics by continuously observing the PV and MV in a way similar to that of a skilled operator determining the next manipulated variable by monitoring the PV and MV behaviors on the recorder chart.

When the STC controller ascertains a PV signal change exceeding the preset level after processing such as detecting process abnormalities (input signal abnormalities), it starts an estimating computation of process characteristics by collating the PV and MV waveform response. Different from conventional process-characteristic estimation techniques, as the STC estimates process characteristics once using waveforms, it can be performed using a very short response time. A process characteristic is expressed with the dead-time, LM, time-constant, TM, and gain, GM. PV signals fluctuate affected by disturbances and noise signals as well as MV signals. Thus, if these influences are large, the certainty factor (estimation accuracy) of the estimated result becomes low. The STC controller does not set PID parameters if the estimation accuracy is low, considering the safety of the process.

Once estimating computation is carried out, the controller observes the waveforms again for every preset time and, if it detects a change in response, it repeats the process-characteristic estimation.

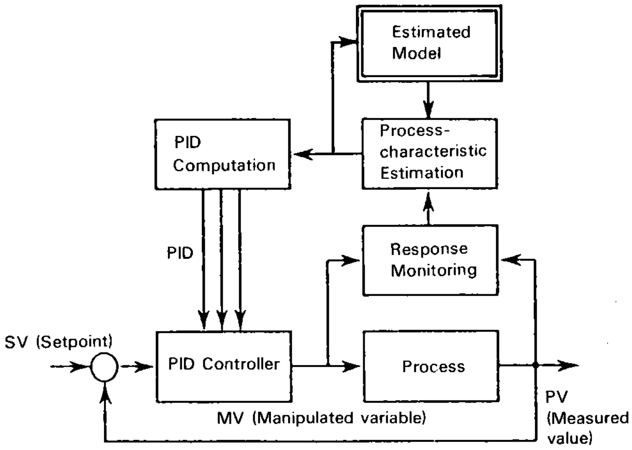


Figure 2.1.1 Self-Tuning Function Block Diagram

2.3 Setting the Tuning Target

For the STC controller, the user must first specify the desired control target response waveform.

The desired response waveform differs depending on the types of processes and operating procedures. Overshoot is generally not preferred in temperature control of heat treatment processes or reaction process, while in pressure or flow control, a quick response is the first priority and thus a small overshoot is permissible in most cases.

The STC controller has control target types (OS) as shown in Table 2.3.1, one of which the user can select and set from the tuning panel depending on the process.

OS 0 This type involves no overshoot.

OS 1 The time integral of the product of absolute error and time is minimized for this type, resulting in a small overshoot and a moderate settling time.

OS 2 The control area shown in Figure 2.3.1 is minimized. This type is recommended and is adopted in the YEWSERIES 80 STC controller as the default setting.

OS 3 The time integral of deviation squared is minimized for this type of response, resulting in a large overshoot and a fast rise time.

Table 2.3.1 Control Target Types

OS	Features	Performance criteria
0	Overshoot: None	Overshoot: Zero
1	Overshoot: Small (About 5%) Settling time: Short	Weighted control area: Minimum (ITAE criteria—time integral of product of time and absolute error) Min $\int_0^\infty \|e\| t\,dt$
2	Overshoot: Medium (About 10%) Rise-time: Medium-fast	Control area: Minimum (IAE criteria—time integral of absolute error) Min $\int_0^\infty \|e\|\,dt$
3	Overshoot: Large (About 15%) Rise-time: Fast	Square control area: Minimum (ISE criteria—time integral of squared error) Min $\int_0^\infty e^2dt$

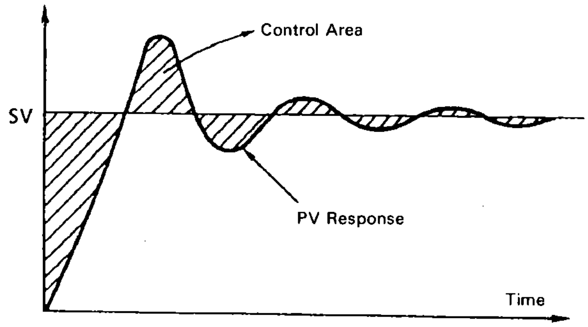


Figure 2.3.1 Control Area (Example of Response to Setpoint Change)

2.4 PID Parameter Tuning

The STC controller calculates the optimum PID parameters depending on the designation of the control target type (OS), control computational expression (CNT5), and derivative term presence/absence (R05/R10), in response to the process-characteristic estimated result.

In the PID controller, generally, optimum PID parameters are different when following the setpoint and when suppressing disturbances. The STC controller calculates PID parameters for disturbance suppression when the control computational expressions are of a "PV proportional type PID control (I-PD)" type and of an "SVF" type, and calculates PID parameters for the following setpoint when the expressions are of a "PV derivative type PID control (PI-D)" type. It is recommended that the STC controller employ the SVF type which is capable of optimizing in cases of both suppressing disturbances and following setpoints. In this case, the optimum value of SVF parameter PX is also calculated.

$PB_N = f_1$ (LM, TM, GM, IP, OS, CNT5)
$TI_N = f_2$ (LM, TM, GM, IP, OS, CNT5)
$TD_N = f_3$ (LM, TM, GM, IP, OS, CNT5)

where:

PB : Proportional band; TI : Integral (reset) time; TD : Derivative (rate) time; OS : Target response type; IP : Process type; CNT5 : Control computational expressions; L : Equivalent dead-time; T : Equivalent time constant; and G : Equivalent process gain.

Usually, the STC controller calculates PID parameters based on the estimated result, but when it decides that the response begins to oscillate, it ensures system safety by carrying out tuning once to stop oscillation and, if increasing the controller gain, by limiting the gain with a smaller width. In addition, when control deviation does not decrease for long time, the controller gain is increased.

2.5 Operation Mode of a Self-Tuning Controller

The intelligent self-tuning controller is provided with operation modes (STC) to designate the self-tuning operation. These modes can be set on the tuning panel on the side of the controller.

Table 2.5.1 STC Operation Modes

STC	Description
OFF	STC operation stopped. Normal PID control.
0	Displays new PID parameters (PID parameters are not automatically updated).
1	STC on. PID parameters are automatically updated.
2	Automatic start-up (see subsection 3.2.2).
0, 1	On-demand tuning (see section 3.3).

The STC controller operates as shown in Figure 2.5.1 depending on the operation modes.

(1) When the STC mode is 0 or 1, self-tuning proceeds through the central path and acquires PV and MV values.
(2) If PV fluctuation is within the preset value, controllability is regarded as good.
(3) If PV fluctuation exceeds the preset value, the process characteristics are estimated and PID parameters are calculated when the estimation accuracy is high.
(4) The user can specify whether the latest PID parameters are updated and used for control computation or not. When not updated (STC = 0), the new parameters are only displayed. If updated (STC = 1), PID parameters are updated to the new values.

This self-tuning program is executed once every control cycle.

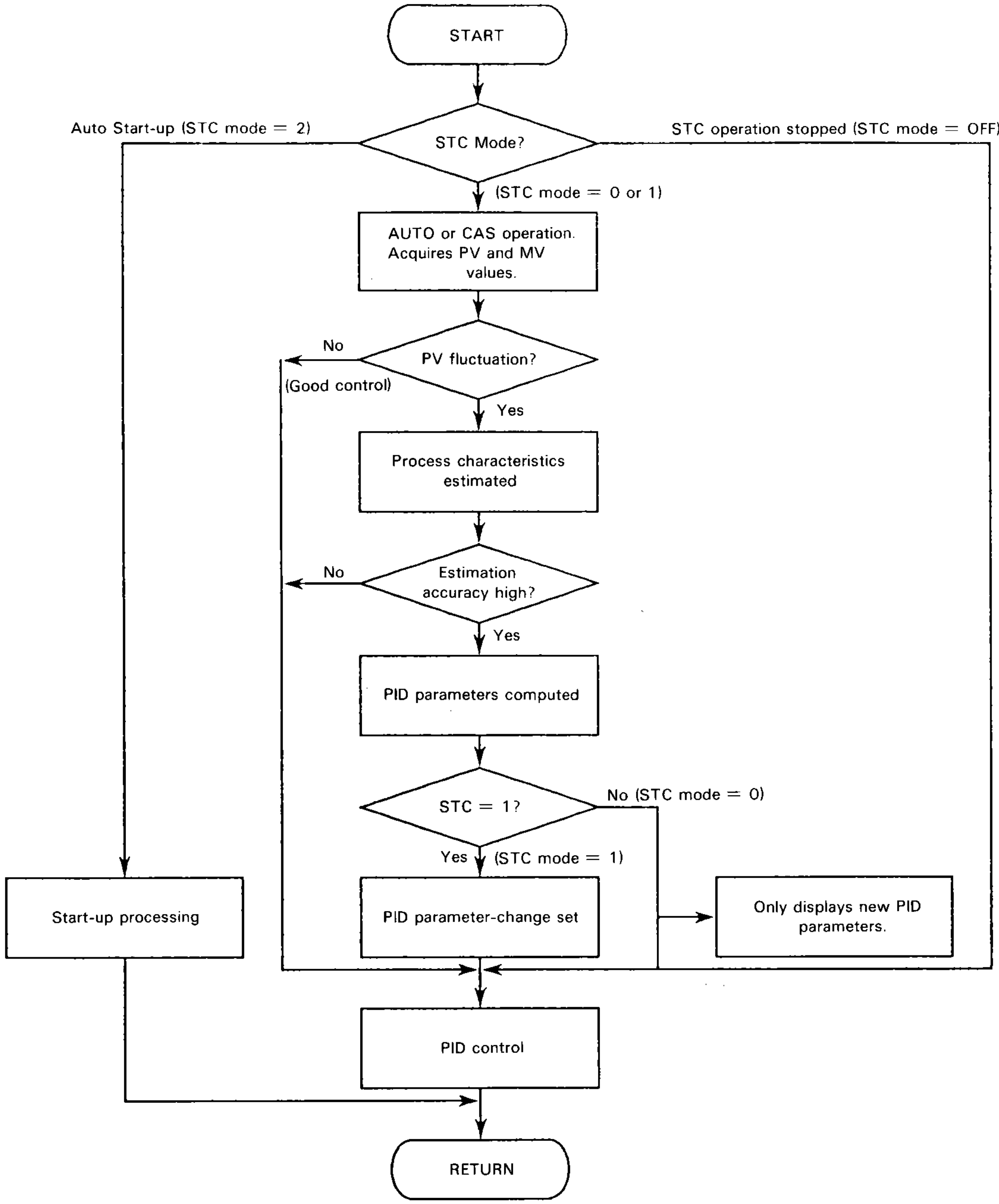


Figure 2.5.1 Self-Tuning Operation Flow Chart

2.6 Detecting Process-Characteristic Fluctuations

To detect process-characteristic variations, when the PV changes, an estimated process model is used. The STC controller displays the ratio of the PV value variance to the model output variance (RT).

When STC = 1, if the estimation accuracy of process characteristics is high, the model is updated, self-tuning is executed, and RT shows approximately 1.

When STC = 0, RT varies with the characteristic changes because the latest model in an STC = 1 operation is used as internal model for calculating RT. In conditions where RT $\leqq$ 0.5 or RT $\geqq$ 2, an alarm (large characteristic change) is issued to annunciate the necessity of re-tuning PID parameters.

3. USER-SPECIFIED SELF-TUNING DISPLAY SETTING PARAMETERS AND OPERATIONS

3.1 Display Setting Parameters

Table 3.1.1 shows a list of user-specified self-tuning parameters.

These parameters are assigned to the [PID STC] key on the tuning panel. Each time this key is pressed, the parameters listed in the table are displayed in the order shown. Item number (N) for each type may be changed with key [N].

Descriptions for each item are given below:

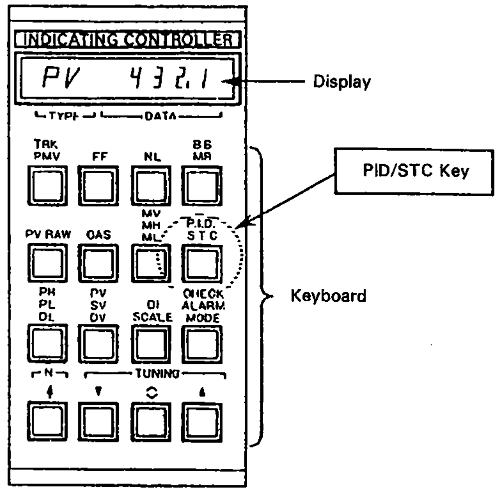


Figure 3.1.1 Tuning Panel of SLCD Indicating Controller

Table 3.1.1 Self-Tuning Parameter Names and Contents

Type	Item No. (*1) (N)	Name and Content	Display and Setting Range	Unit	Default Value	Data Setting (*2) OFF	0	1	2
STC	–	Self-tuning mode designation	OFF, 0, 1, 2	–	0	○	○	○	○
PB	1, 2	Proportional band	(*3) 6.3 to 999.9	%	999.9	○	○	○	–
TI	1, 2	Integral time	1 to 9999	sec	1000	○	○	○	–
TD	1, 2	Derivative time	(*4) 0 to 9999	sec	0	○	○	○	○
IP	1, 2	Process type	0, 1	–	0	–	○	○	–
TR	1, 2	Process response time	4 to 9999	sec	300	–	○	○	–
NB	1, 2	Noise band	0 to 20	%	0	–	○	○	–
OS	1, 2	Control target type	0, 1, 2, 3	–	2	–	○	○	○
MI	1, 2	Signal deflection applied to MV	0 to 20	%	5	–	△	△	○
R	01, 06	Proportional band upper limit value	(*3) 6.3 to 999.9	%	999.9	–	○	○	–
	02, 07	Proportional band lower limit value	(*3) 6.3 to 999.9	%	6.3 (*3)	–	○	○	–
	03, 08	Integral time upper limit value	1 to 9999	sec	9999	–	○	○	–
	04, 09	Integral time lower limit value	1 to 9999	sec	1	–	○	○	–
	05, 10	Derivative time upper limit value	0 to 9999	sec	2000	–	○	○	–
PA	1, 2	New calculated proportional band	(*3) 6.3 to 999.9	%	999.9	/	/	/	/
IA	1, 2	New calculated integral time	1 to 9999	sec	1000	/	/	/	/
DA	1, 2	New calculated derivative time	0 to 9999	sec	0	/	/	/	/
CR	1, 2	Estimation accuracy error	0.00 to 99.99	%	0.00	/	/	/	/
RT	1, 2	Signal variance ratio	0.000 to 9.999	–	1.000	/	/	/	/
LM	1, 2	Equivalent dead-time	0 to 9999	sec	0	/	/	/	/
TM	1, 2	Equivalent time-constant	0 to 9999	sec	100	/	/	/	/
GM	1, 2	Equivalent process gain	0.000 to 9.999	–	1.000	/	/	/	/

(*1) SLPC: N = 1 in types other than R and R01 to R05 is for Controller 1.
N = 2 in types other than R and R06 to R10 is for Controller 2.
SLCD: R1 to R5 only. Ns is not displayed in types other than R.

(*2) ○ : Types required to be set.
– : Types not required to be set.
/ : Display only types.
△ : To be set for On-Demand.

(*3) For SLCD, it is 2.0.

(*4) Action range is 2 to 9999 sec.(0 & 1 : OFF)

3.1.1 STC (Self-Tuning Mode Designation)

Designate the STC operation mode listed in the table below:

Table 3.1.2 STC Operation Mode

STC	Description
OFF	STC operation stopped. Normal PID control.
0	Displays new PID parameters (PID parameters are not automatically updated).
1	STC on. PID parameters are automatically updated.
2	Automatic start-up (see subsection 3.2.2).
0, 1	On-demand tuning (see section 3.3).

(1) STC Mode

The "STC = 0" mode is convenient for a preliminary test of the self-tuning operation. In the "STC = 0" mode, since calculated values are displayed as PA, IA, and DA values, validity of the self-tuning function can be ensured in advance with these values. PID parameters (PB, TI, and TD) are not updated.

In the "STC = 1" mode, when the controller is placed in AUTO mode after all the parameters have been set, the self-tuning function starts.

In the "STC = 2" mode, by the setting of the control target type OS, the signal step change (MI) applied to the manipulated variable (MV), and the derivative time TD only (PI control is designated with the derivative time TD = 0 and PID control is designated with the TD greater than or equal to 1), the controller measures a step response and calculates parameters other than the above. After the parameters are set, the controller moves to "STC = 1" mode and starts self-tuning. For automatic start-up, see subsection 3.2.2.

(2) Setting and Display

To set the STC mode, use the [▼] and [▲] keys on the tuning panel. Note that STC = 2 can only be set in MAN mode.

[▲] key: OFF → 0 → 1 → 2

[▼] key: 2 → 1 → 0 → OFF

When the self-tuning function is operating with STC = 0 or 1, a flashing "0" or "1" is shown on the display tuning panel. When start-up is executed with STC = 2, a "2" flashes on the display in the same manner and the indicator [C] or [A] on the front panel also flashes at the same time.

3.1.2 PB, TI, TD (PID Parameters)

These PID parameters are used in control computations. When self-tuning action starts at STC = 1, the default values of these parameters are used and they are automatically updated if the self-tuning function operates properly after start-up.

Initial PID parameters are set in the following manner:

(1) Newly Installed Process

1) If PID parameters can be determined by analogy or calculated from other process results, then use them.
2) If PID parameters are difficult to determine by analogy or calculate from other process results, then,
(a) Use automatic start-up if possible.
(b) If automatic start-up cannot be used, start self-tuning with STC = 0 and use the values displayed as updated PA, IA, and DA values.

(2) Replaced in the Existing Process

Where the control system is to be replaced in the existing process, use PID parameter values before replacement.

3.1.3 IP (Process Type)

Designate whether the process is static (0) or astatic (integral system) (1). For static process, as shown in Figure 3.1.2 1), when step change is applied to a manipulated variable MV, the process variable (PV) equilibrates to a settled value after time elapses. As shown in Figure 3.1.2 2) an astatic system is a process where the measured value rises or drops infinitely when a step change is applied to a manipulated variable (MV). Almost all the processes are static systems except for level control where liquid is drawn at a constant flow rate by a metering pump.

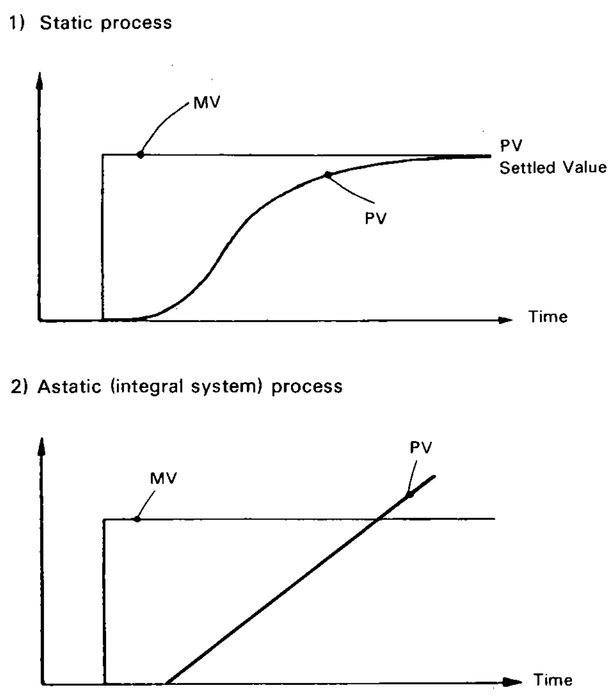


Figure 3.1.2 Step-response for Each Process

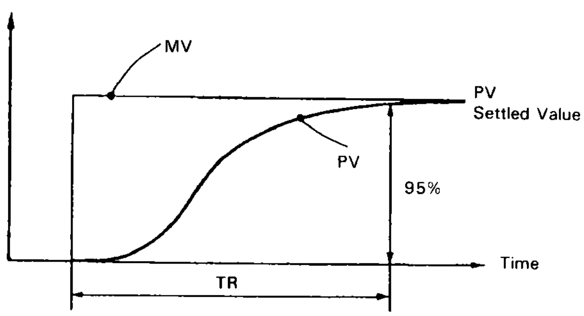
3.1.4 TR (Process 95%-Response Time)

Designate an equivalent time for a 95% process step-response time (in an open loop). The STC controller computes the observed time for measured signal waveforms and the sampling time for estimating the process characteristic.

The proper value of TR is set in the following manner (Figure 3.1.3):

1) Estimation from the process step-response waveform:
   Time until the PV change ΔPV reaches 95% of the final PV-settled value. If the step-response is approximated with the dead-time L and the first-order lag-time constant T, then TR = L + 3T.
2) For an astatic (integral-characteristic) process:
   Time until the PV change ΔPV reaches 95% of the final PV-settled value when a pulse input is applied to the MV output.
3) Estimation from the state operated up to that point:
   Read the period T_p of an almost satisfactory damped oscillation waveform and set it as TR = T_p.
4) When response time variation is expected:
   Match TR to that of the response waveform to be controlled. If the PV response time is different between the rise and fall as in furnace temperatures, set TR to the larger one.
5) Notices:
   Since 1/20 of TR becomes the sampling period T_S for estimating the process, a response waveform having a period smaller than $2T_S$ cannot be properly captured. In general, the process-characteristic estimated value error becomes smaller when TR is set larger than the proper value compared with setting it smaller than the proper value.
   If TR is changed, the self-tuning function is not operated during 4TR because the data file is initialized.

1) Estimation from a step-response waveform



2) Estimation from a damped oscillation waveform

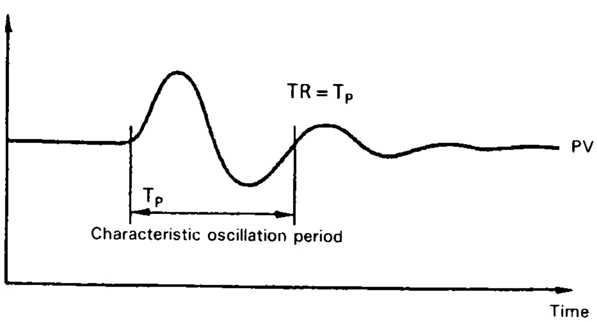


Figure 3.1.3 TR Estimation

3.1.5 NB (Noise Band)

Set at approximately two times the height of the peak value of a random noise signal superimposed on the PV signal (Figure 3.1.4).

NB is used to prevent the process-characteristic estimation from being disturbed by noise. If NB is set, the STC controller estimates the process characteristics when the PV response waveform oscillates by more than (preset value + NB).

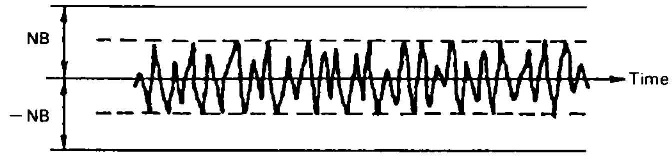


Figure 3.1.4 Noise Band

3.1.6 OS (Control Target Type)

Set a response waveform code by selecting a type of which the self-tuning controller makes a target from the following table (same as Table 2.3.1).

Table 3.1.3 Control Target Types

OS	Features	Performance criteria
0	Overshoot: None	Overshoot: Zero
1	Overshoot: Small (About 5%) Settling time: Short	Weighted control area: Minimum (ITAE criteria – time integral of product of time and absolute error) Min $\int_0^\infty \lvert e \rvert t\,dt$
2	Overshoot: Medium (About 10%) Rise-time: Medium-fast	Control area: Minimum (IAE criteria – time integral of absolute error) Min $\int_0^\infty \lvert e \rvert dt$
3	Overshoot: Large (About 15%) Rise-time: Fast	Square control area: Minimum (ISE criteria – time integral of squared error) Min $\int_0^\infty e^2 dt$

3.1.7 MI (Signal Deflection Applied to MV)

Designate test signal step change applied to the manipulated variable MV in the "Auto start-up" mode or "on-demand" mode (section 3.3). Set it so that the measured value deflects about 5%.

The applied signal is given in the direction where the sign of the current deviation extends since it is in the MAN state in the "Auto start-up" mode, but in the "on-demand" mode, the applied signal is given in the direction where current deviation is decreased, since it is in the AUTO state.

Table 3.1.4 Direction of an MV Step Change

Deviation \ Action mode	DIR (Direct action)	RVS (Reverse action)
SV > PV	+MI% (−MI%)	−MI% (+MI%)
SV ≦ PV	−MI% (+MI%)	+MI% (−MI%)

Out of parentheses: For Auto start-up
In parentheses: For On-demand tuning

3.1.8 R01 - R10 (PID Parameter Limit Values)

These parameters are used to limit the range of PID parameter changes during self-tuning. If the PID parameter changes appear to adversely affect the process by exceeding certain limits, set the limit values in advance.

If an upper-limit value is set that is less than or equal to the lower-limit value, the parameter is fixed at the lower-limit value.

When the PID parameters reach the limit values during the self-tuning operation, the STC alarm (see section 3.6) is activated.

For STC = 0, 1, when R5/R10 are set to 0, PI control is designated. When they are set to upper limit value, PID control or PI control is designated depending on the self-tuning result.

3.1.9 PA, IA, DA (Newly Calculated PID Parameters)

If STC = 0 (the mode in which calculated PID parameters are used only for display), the optimum parameters calculated from the estimated process characteristics can be displayed but are not used in control computation.

When a PA, IA, or DA parameter reaches the limit value (Rn), an STC alarm occurs. The displayed value is not limited.

When STC = OFF or 1, the PA, IA, and DA parameters displayed are the same as those for PB, TI, and TD respectively.

3.1.10 CR (Estimation Accuracy Error)

An error of the estimation accuracy when the process characteristics are estimated. The STC controller calculates and sets PID parameters when CR is less than 5%.

3.1.11 RT (Signal Variance Ratio)

A ratio of the PV signal variance to the set model output variance. The STC controller calculates the above ratio using the estimated model (For STC = 0, the latest model in the "STC = 1" mode), to detect the process-characteristic changes. If the model matches the process, RT shows the value nearly equal to 1. If RT ≧ 2 or RT ≦ 0.5, an alarm (large characteristic change) occurs.

3.1.12 LM, TM, GM (Estimated Equivalent Models)

The STC controller expresses the estimated process model by approximating it with a dead-time and a first-order lag system (with a response to pulse input in integral systems). LM, TM, and GM shows the equivalent dead-time, equivalent first-order lag-time constant, and equivalent gain, respectively.

For LM, TM, and GM, the latest values where the STC-mode is 0 or 1 and the estimation accuracy error CR is less than 5% are maintained. PID parameters computed from the displayed values correspond to PA, IA and PA for STC = 0 and to PB, TI and TD for STC = 1.

CR is updated every time the process characteristics are estimated but if CR is 5% or more, LM, TM, and GM are not updated.

3.2 Start Mode

The STC controller has the two start modes described below:

3.2.1 Start-up with Preset Values (STC = 1)

When reasonable values of PID parameters have been estimated, set these values as preset values. In the STC = 1 mode, the controller starts self-tuning after the time TR by setting the process type IP, process 95%-response time TR, noise band NB, control target type OS, and PID limit values Rn and by switching to AUTO.

3.2.2 Automatic Start-up (STC = 2)

For a process in which step response is applicable, setting STC = 2 results in the automatic start-up. In this condition, the STC parameters (PB, TI, TD, IP, TR, NB, PX, and R) and PX are automatically computed by the step-response method to start self-tuning.

(1) Applied Control Modules

Applicable to the SLCD indicating controller and the following modules of the SLPC programmable controller.

- BSC control module
- CSC control module

Applied to the secondary loop when cascade is open and to the primary loop when cascade is closed.

(2) Setting Parameters

Set STC, OS, MI, and if required, TD.
Set TD = 0 for PI control.
Set TD = 1 or more for PID control.
However, if PID control is selected, it may be changed to PI control when PI control is preferred depending on the automatic start-up result.

(3) Operating Procedure and Operation

(a) Confirm first that an STC alarm STALM (see section 3.6) is not occurring.
(b) Set the STC mode to 2 in the MAN mode.
(c) Fully stabilize the process variable (PV) signal manually at an appropriate value.
(d) Switch the operation mode to AUTO or CAS. Automatic start-up begins and the [A] or [C] indicator lamp on the front panel blinks. The controller holds the current MV for 30 seconds.
(e) With PID control not yet started, the controller automatically gives a step change by a value of MI in the safe direction (where the deviation is not reversed but extends) to the control output MV. (See Table 3.1.4)
(f) Observes the PV signal response to the step-change. If the process gain is high, when the PV variation width ΔPV exceeds 1.5MI, the MV is automatically returned to the original value.
(g) After the PV signal stabilizes, the controller automatically returns the manipulated output to the initial MV value and ascertains the response.
If the process gain is low and ΔPV is less than 2%, automatic start-up is considered inappropriate and so the operation mode switches to MAN and STC = 0 after the max. observation time (about 80 minutes) has passed and an STC alarm is issued.
(h) The controller estimates the process characteristics and calculates the initial PID parameters using the data obtained from the step response, similar to the case in STC = 1. PID limit values (R01 - R10) are set to four times the initial PB, TI, and TD values (upper limit) and 1/4 times the above initial values (lower limit). The 95% process response time TR is set to "LM + 3TM" seconds. The process type is decided from the PV at start-up and that at the end of response and then set to IP. If the controller decides the process-characteristic estimated result is inappropriate, the controller issues an STC alarm and stops auto-start.
(i) The controller observes the noise peak value for a succeeding definite time (2TR, a minimum of 2 minutes and a maximum of 5 minutes) and calculates the noise band NB using the observed peak value.
(j) When all of the setting parameters have been computed and correctly set, the STC mode is automatically set to 1 and the PID control and self-tuning start. The [A] or [C] indicator lamp changes from a flashing to an illuminated state.
(k) If any of the following occurs during automatic start-up, the controller stops start-up operation and moves to the MAN mode and the STC = 0 state (see Table 3.6.1).

- Power failure
- STC alarm STALM occurred

3.3 On-Demand Tuning

In the "on-demand" mode, the STC controller applies a step test signal to the manipulated variable MV in a closed loop state at the operator's request and implements self-tuning from the response of the PV at that time. This is effective where the setpoint cannot be changed. Figure 3.3.1 shows the response in the on-demand mode.

(1) Applicable Conditions

This mode operates only when the following conditions are all satisfied:

- The basic control BSC or cascade control CSC function is specified. (Invalid for selector control SSC.)
- The operating mode is automatic AUTO or cascade CAS (Invalid in the DDC or SPC mode).
- STC mode = 0 or 1.

(2) Setting Parameters and Operation

(a) Set the parameters in the STC = 0 or 1 mode.
(b) Designate the MI, the amplitude of the test signal to be applied. Set it so that the PV deflects about 5%. The MI is output to add it to the MV in the direction where deviation is decreased depending on the position of the switch designating the direction of action and the current deviation. (See Table 3.1.4)
For astatic systems, add a pulse signal having a duration of TR/5 is added.
(c) To operate from the user program, set the FL21 flag to 1 from 0.

(3) Operating Procedure

(a) Check the value of MI and confirm that the operation mode is AUTO or CAS.
(b) Confirm that STC mode is either 0 or 1.
(c) Press the "N" key once and check that the tuning request, "RQ," is displayed.
(d) Allow the controller to be left for more than one second and then press the "N" key once again. If cancellation is desired, press any other key.
(e) The MI is added to the MV and the "RQ" flashes for TR/5 seconds. During this period, any pressing of the "N" key is ignored.
When the process variables change a little or oscillate greatly, self-tuning may not work. In such cases, use the automatic start-up or change the setpoint.

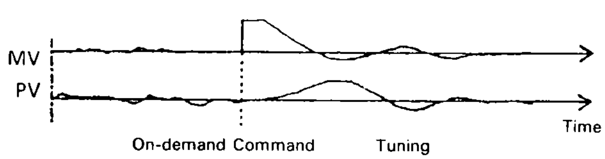


Figure 3.3.1 Response in On-Demand Tuning

3.4 Starting and Stopping Self-Tuning Function

In the intelligent STC controller, the self-tuning function can be started and stopped in association with the ON/OFF operation of the contact input signal. This start/stop function is effective in suspending the self-tuning function in batch-process stopping and transient states, or when a foreseen disturbance occurs in the process.

3.4.1 Starting and Stopping STC with a Contact Input Signal in an SLCD Indicating Controller

Set all the EXT subswitches of the DIP switch on the tuning panel on the right side of the controller to the OFF position. Then STC start and stop can be implemented by combining the MODE 2 and MODE 3 settings on the tuning panel as shown in Table 3.4.1.

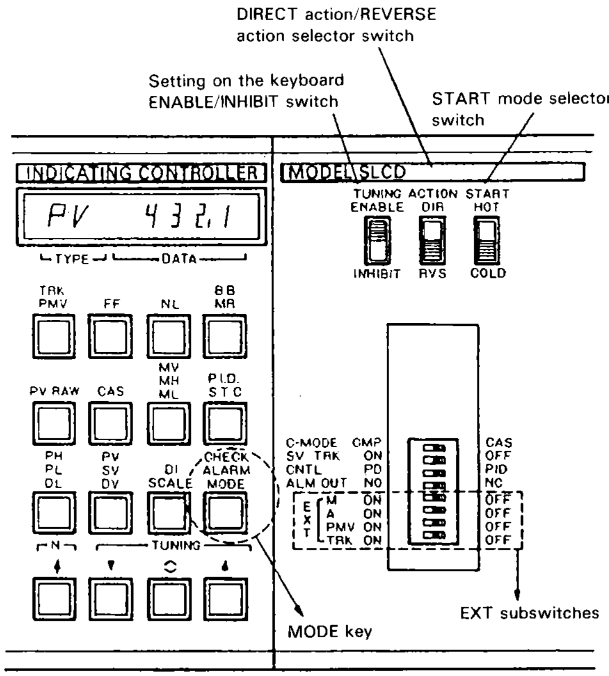


Figure 3.4.1 Tuning Panel of an SLCD Indicating Controller

Table 3.4.1 STC Function Start and Stop Mode Setting with a Contact Input Signal in an SLCD Controller

<table>
<tr><th>Mode</th><th>Set Value</th><th>Operating Status</th><th>Default Value</th></tr>
<tr><td rowspan="2">MODE 3
Designating the STC stop function with condition input.

Enabled only for SLCD-□81. When this function is used, set all the EXT subswitches of the DIP switch on the tuning panel on the right side of the controller to the OFF position.</td><td>0</td><td>STC stop function with condition input is not available.</td><td rowspan="2">0</td></tr>
<tr><td>1</td><td>STC stop function with condition input is available.
<table>
<tr><th>MODE 2 \ Condition input</th><th>OPEN</th><th>CLOSED</th></tr>
<tr><td>0</td><td>STC function stops.</td><td>STC function (Note 1) does not stop.</td></tr>
<tr><td>1</td><td>STC function does not stop.</td><td>STC function stop.</td></tr>
</table></td></tr>
</table>

(Note 1) Carries out operations as set on the tuning panel.

3.4.2 Starting and Stopping STC from a User Program in an SLPC Programmable Controller

The SLPC programmable controller is provided with user flags (FL18, 30, and 31) corresponding to designations for the STC modes (OFF, 0, 1, and 2) and the on-demand flag (FL21). All flags can be read and written by user programs.

FL18: STC function stop flag (Table 3.4.2)

When FL18 = 1: The STC function stops independent of the STC mode designation, the FL30, and the FL31 settings.

When FL18 = 0: The STC function that is set by the STC mode designation or by FL30 or FL31 operates.

FL21: On-demand mode designation flag

On-demand tuning operates when FL21 = 1.

FL30 and 31: STC mode designation flags (Table 3.4.3) FL30 and 31 correspond to the STC mode designations (OFF, 0, 1, and 2). In other words, the STC modes can be identified by reading the FL30 and 31 values and the STC mode can be set by writing appropriate values in FL30 and 31.

Table 3.4.2 STC Function Stop Flag

FL18	Description
1	STC function stops.
0	STC function does not stop (other STC modes can be operated).

FL21: On-demand mode designation flag
On-demand tuning operates when FL21 = 1.

FL30 and 31: STC mode designation flags (Table 3.4.3) FL30 and 31 correspond to the STC mode designations (OFF, 0, 1, and 2). In other words, the STC modes can be identified by reading the FL30 and 31 values and the STC mode can be set by writing appropriate values in FL30 and 31.

Table 3.4.3 Correspondence between the FL30 and 31 and STC Modes

FL30	FL31	STC Mode	Description
0	0	OFF	STC function stops.
1	0	0	Displays new PID parameters.
0	1	1	STC on. PID parameters are automatically updated.
1	1	2	Automatic start-up

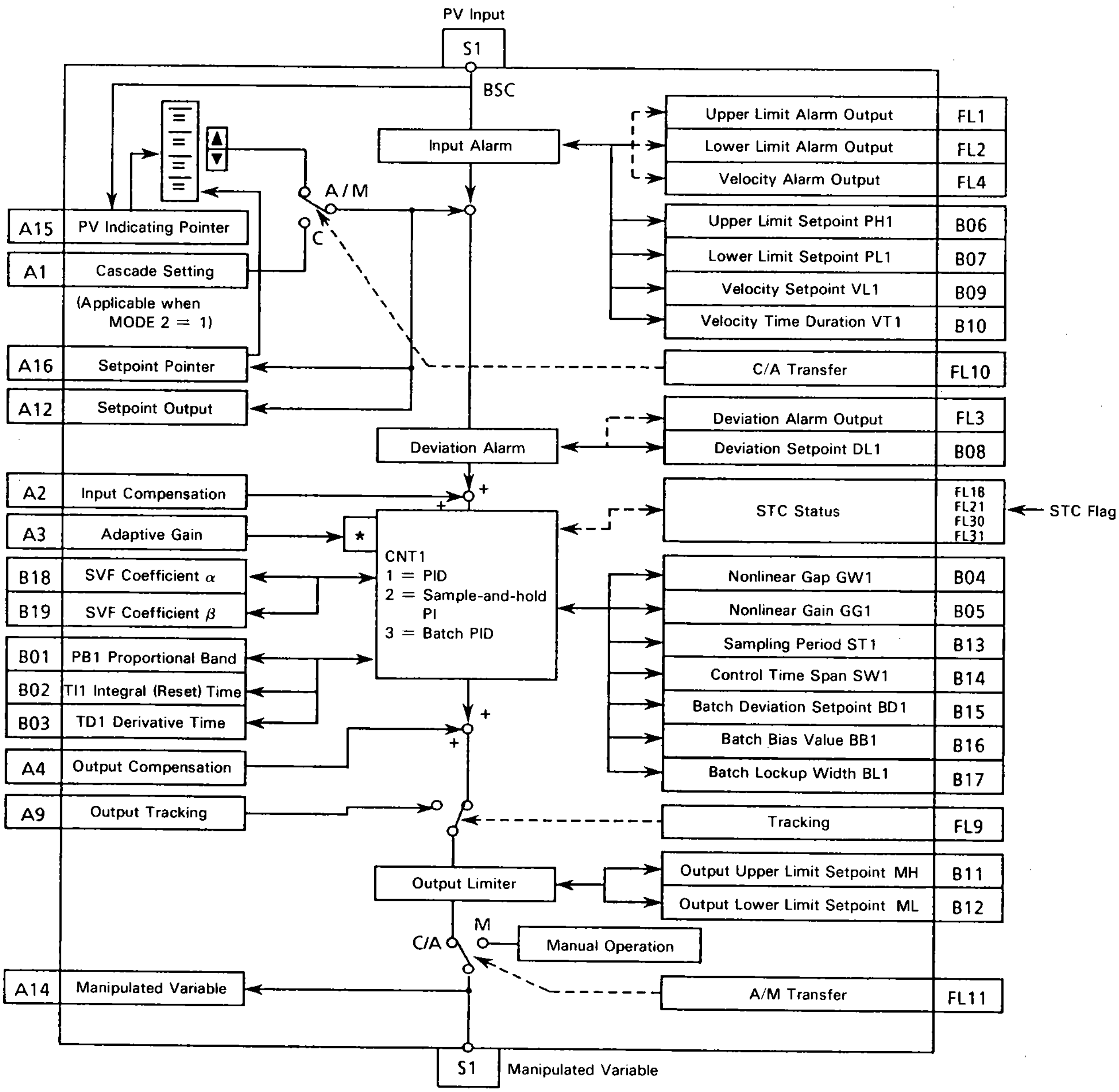


Figure 3.4.2 BSC Functional Block of SLPC Programmable Controller

3.5 Combining STC with Various Control Functions

STC is applied to PID control that composes feedback loops. Hence, if a feedback loop cannot be configured by combining operation mode switching and sequence computations, the self-tuning function should be stopped.

3.5.1 Combining STC and Control Computational Expressions

(1) PV Proportional Type PID Control (I-PD Control)
It is mainly oriented to fixed setpoint control and is not likely to overshoot without actuating proportional and derivative actions against the setpoint change.

(2) PV Derivative Type PID Control (PI-D Control)
It is oriented to follow-up control and quickly responds to the setpoint change, proportional and integral actions being exerted.

(3) Adjustable Setpoint Filter PID Control (SVF type)
It can continuously change the setpoint follow-up characteristics from PI-D control to I-PD control by adjusting Px and Py parameters.

The STC controller PID parameters are computed to suppress disturbances in types (1) and (3) and to follow the setpoint change in type (2). Conclusively, SVF control is advisable for the STC controller. In this case, since optimum Px is computed also for setpoint follow-up, both disturbance suppression and setpoint follow-up are improved.

3.5.2 Combining STC with SLCD Control Functions

Table 3.5.1 shows these combinations:

Table 3.5.1 Combination of STC with SLCD Control Functions

Control Function		Combination
PID control, with output limiter		○
PID control, with reset bias function		○
PID control, with nonlinear elements		○
PID control, with feed-forward compensation		×
PD control, with manual reset		–
Operation mode switching by contact input	CAS ⟷ AUTO switching	○
	C, A ⟷ MAN switching	○ *
	Output tracking	○ *
	Preset MV	○ *
Operation mode	CAS, AUTO, SPC	○
	MAN, DDC	–

Combination ○ = Combination available
× = Not recommended
– = Combination not allowed
* = STC does not operate in MAN, output tracking or preset MV output status.

- Combinations with feed-forward compensation are not recommended because it is difficult to observe the PV if the feed-forward signal selection and compensation computation are improper.

3.5.3 Combining STC with SLPC Control Functions

Table 3.5.2 shows these combinations:

Table 3.5.2 Combining STC with SLPC Control Functions

Control Functions		Combination
Control module	Basic control (BSC)	○
	Cascade control (CSC)	○
	Selector control (SSC)	○
Control element	Standard PID control	○
	Sample-and-hold PI control	–
	Batch PID control	–
Optional functions	Nonlinear elements	○
	Input compensation (dead-time compensation)	×
	Variable gain	×
	Output compensation (feed forward)	×
Operation mode switching by contact input	CAS ⟷ AUTO switching	○
	C, A ⟷ MAN switching	○ *
	Output tracking	○ *
Operation mode	CAS, AUTO, SPC	○
	MAN, DDC	–

Combination: ○ = Combination available
× = Not recommended
– = Combination not allowed
* = STC does not operate in MAN or output tracking status.

- With dead-time compensation control, it is difficult to measure the process dead-time accurately. If an inaccurate dead-time is set, the STC may result in improper operation.
- Generally, it is not recommended that the variable-gain function is combined with the STC function because it overlaps the STC function. However, in applications in which the relationship between temperature and gain in a reactor is incorporated in advance (gain scheduling) it is effective to combine the variable-gain function with the STC function.
- The combination of the STC function with a feed-forward function is not recommended for the reasons mentioned in the previous description for the SLCD controller.

3.5.4 Combining STC with SLPC Control Modules

(1) Cascade Control Module (CSC)

A single SLPC can implement the cascade control function. The self-tuning function tunes the secondary controller with the cascade loop open and tunes the primary controller with the cascade loop closed as shown in Figure 3.5.1.

The SLPC controller is provided with the self-tuning parameters for both primary and secondary loops.

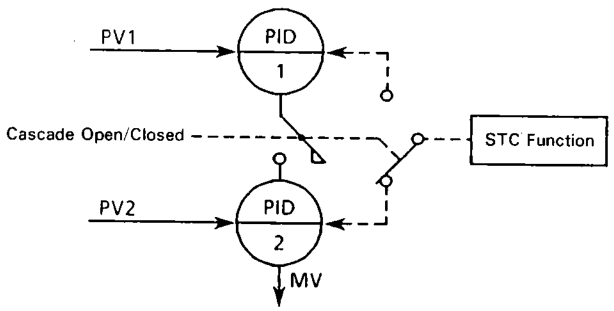


Figure 3.5.1 Cascade Control Module (CSC)

(2) Selector Control Module (SSC)

With the selector control module, the STC tunes the selected loop as shown in Figure 3.5.2, except when in the auto-start or on-demand mode.

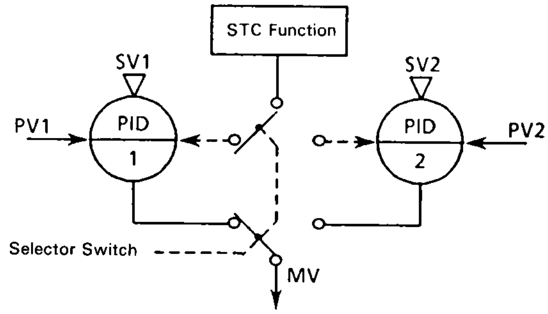


Figure 3.5.2 Selector Control Module (SSC)

3.6 Self-Tuning Alarm

The self-tuning alarm STALM display is assigned to the [CHECK ALARM MODE] key for the SLCD controller and the [CHECK ALARM] key for the SLPC controller.

When the self-tuning function cannot operate normally, the STALM status is displayed with a 2-digit numerical value.

Table 3.6.1 shows the diagnosis which corresponds to the STALM display code.

When two or more alarms occur simultaneously, the sum of the individual alarm display codes is displayed (in a hexadecimal number).

The STC controller is provided with manipulated-variable output-signal upper and lower limiters (MH and ML). If there's a possibility that the MV value may have an adverse effect on the process when it exceeds a certain limit, set the limit values in advance.

Table 3.6.1 Self-Tuning Alarm Display Items

STALM display	STC mode	Diagnosis	STC operation	To clear alarm
00	All	Normal (always 00 when STC = OFF)	Continues	–
01		● Attempting to use a control element that is inhibited when used in combination with the STC (for the SLPC). ● Control module is not executed every cycle (for the SLPC). ● Attempting to use control (PD control with manual reset) that is inhibited when used in combination with the STC (for the SLCD).	Stops	● Remove the cause of the alarm. ● Turn the STC OFF. ● Press the [N] key.
02	0, 1	● PID parameter values are limited by the upper and lower limiters. ● Process characteristic changed largely and does not match the model for computation. (RT ≧ 2, or RT ≦ 0.5) (STC = 0)	Continues	
04		● Current output open	Stops	
		● The manipulated-variable output is limited by the output limiter.	Continues (Note 2)	
08		● PV input is out of range.	Continues (Note 3)	
10		● Attempting to use a control element that is inhibited when used in combination with the STC (for the SLPC). ● Control module is not executed in every cycle (for the SLPC). ● Internal cascade ON/OFF switching is executed in the CSC mode (for the SLPC). ● Attempting to use control (PD control with manual reset) that is inhibited when used in combination with the STC (for the SLCD).		
20	2	● STC mode is requested to change or stop by the user program or operation (for the SLPC). ● The operation mode is transferred to the BACK UP MAN state (for the SLPC). ● The STC mode is changed (e.g., switching STC = 2 to 0)(for the SLCD). ● The STC is stopped by external switching (for the SLCD). ● The operation mode is transferred to the BACK UP MAN state or EXT MAN (for the SLCD).	Transfer to MAN mode, STC = 0. Stops.	● Restart STC = 2. ● Turn STC OFF. ● Press the [N] key. ● Remove the cause of the alarm.
40		● Power failure ● Current output open ● There is a possibility that a step change in the MV may cause the output to reach the limit value or MV over-range. (Note 4)		
80		● The PV input is out of range. ● The change in the PV is too small to execute automatic start-up (the maximum observation time (about 80 minutes) has been exceeded).		

(Note 1) Items in the diagnosis column with no SLCD/SLPC indication are common to both the SLCD and SLPC.

(Note 2) If an MV output is limited and the deviation is not eliminated in cases such as before starting or after stopping a batch process, it is regarded as a process abnormality and may not be tuned.

(Note 3) If an PV input is always out of range in cases such as before starting or after stopping a batch process, it is regarded as a process abnormality and may not be tuned.

(Note 4) In this case, the operation mode can not be transferred to AUTO. If [A] is pressed, an alarm occurs and STC mode remains as 2.

4. SIMULATION TEST

4.1 Scope of Application

To determine the scope of application of the self-tuning controller, process simulations and field tests were performed in a wide range of processes and of initial PID parameters.

Most industrial processes can be approximated by a combination of gain, dead-time, and several first-order lag elements, as shown in the following equation:

$$Gp(S) = \frac{Ke^{-LS}}{(1+T_1S)(1+T_2S).....(1+T_nS)}$$

The self-tuning controller exhibits good tuning characteristics for changes in the PV due to setpoint changes and MV changes. The controller performs tuning if the process shows similar response to the above against the changes in operating conditions or load which change the process characteristics (gain, dead-time and lag-time constants).

It has been confirmed that a self-tuning operation is possible for a dead-time to lag-time constant ratio L/T of approximately 3.

The following conditions are necessary for application of the self-tuning controller:

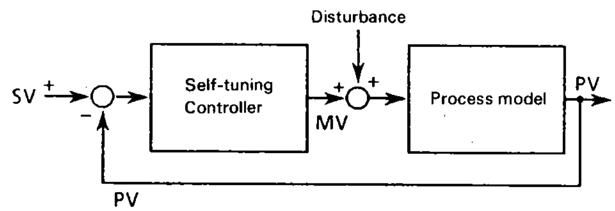
(1) PID control must be possible.

(2) Periods of the factors that cause deviation changes (such as process-characteristic and setpoint changes) must be greater than the natural oscillation period of the control loop.

(3) The response of the PV to the MV can be approximated with a dead-time and a first-order lag system (or an integral system). (The high order system shown above can also be approximated with a dead-time and a first-order lag system.)

4.2 Simulation Examples

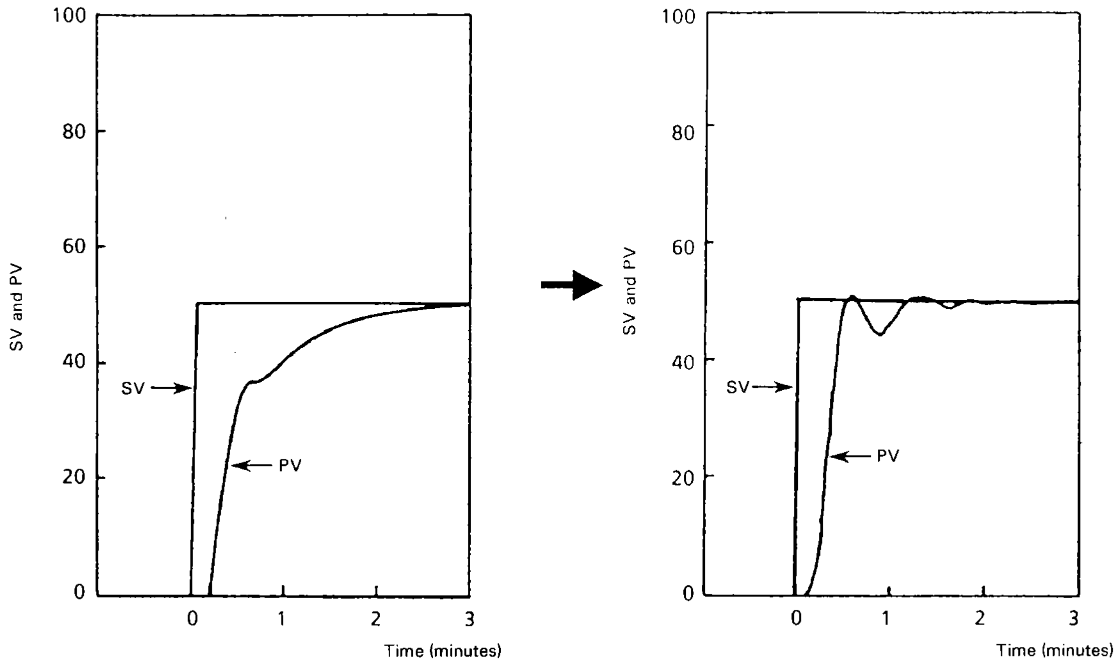
Figures 4.2.2 and 4.2.3 show examples of self tuning at a setpoint change, for the simulated model shown in Figure 4.2.1 assuming that the control target type is 2 and the PID control is an SVF-type. Figure 4.2.2 shows that the response before tuning is like critical damping and Figure 4.2.3 shows that the response before tuning is oscillatory. The self-tuning can make the system converge along almost the same desired response pattern from the different initial PID values in both cases.



Process model characteristics $Gp(s) = \frac{e^{-10s}}{1+10s}$

Gain: 1; Time constant: 10 seconds; Dead-time: 10 seconds

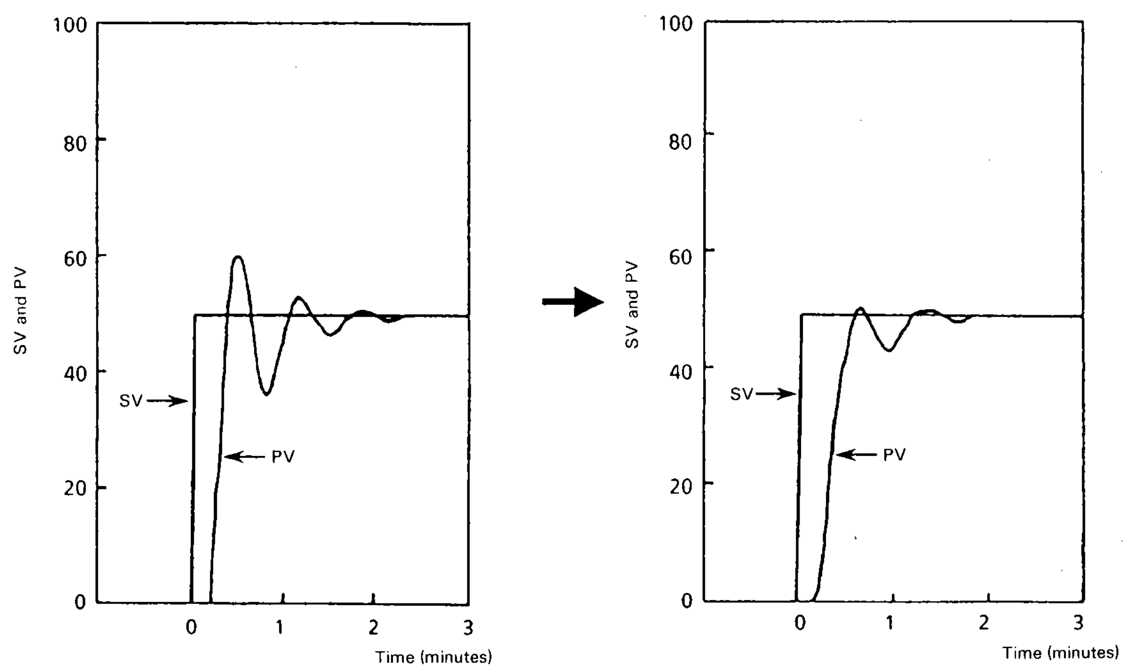
Figure 4.2.1 Simulation Model



(Response before STC operation)
P=160%, I=20 seconds, D=0 second, PX=1.0

(Response after STC completion)
P=89%, I=14 seconds, D=2 seconds, PX=0.465

Figure 4.2.2 Example of Simulation



(Response before STC operation)
P=80%, I=20 seconds, D=0 second, PX=1.0

(Response after STC completion)
P=90%, I=14 seconds, D=2 seconds, PX=0.450

Figure 4.2.3 Example of Simulation

5. APPLICATION GUIDANCE

This chapter provides instructions for applying the self-tuning function (STC) to various controlled systems and control loops.

5.1 Stable Control Loop (Continuous Control)

For a stable control loop where the number of setpoint changes is less and the process characteristics change little, first determine the optimum PID parameter values using the STC function and then operate the STC by narrowing the PID parameter ranges using the PID limits or turn OFF the STC function.

5.2 Controlling Processes Where Dead-Time Is a Dominant Factor

It has been confirmed by simulation that good operating conditions are obtained until the ratio L/T (dead-time/lag-time constant) increases to 3 if the STC is used together with the basic PID control.

If the L/T ratio is greater than 3, a simple PID control is difficult. In these cases, investigate Smith's dead-time compensation control or sample-and-hold control. However, the STC cannot be used together with these controls.

5.3 Cascade Control

5.3.1 Quick Response in a Secondary Loop

Most cascade controls such as the temperature control – flow control shown in Figure 5.3.1 feature flow control in the secondary loop with quick response.

To operate the STC, first set the secondary loop PID parameters to the optimum values with the cascade open and then turn OFF the STC. Next, operate the primary loop STC. Generally, it is recommended that the STC be operated only in the primary loop unless frequent process-characteristic changes occur in the secondary loop because of the quick response of the secondary loop.

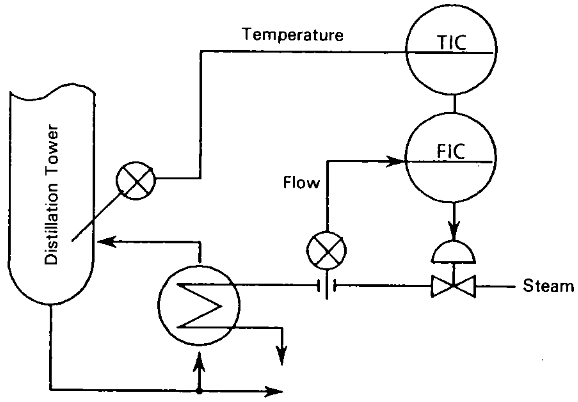


Figure 5.3.1 Cascade Control – 1

5.3.2 Slow Response in a Secondary Loop

Slow response in the secondary loop (such as temperature control – temperature control) is shown in Figure 5.3.2.

In this case, first set the optimum PID parameter values to the secondary loop with the cascade open and then turn OFF the STC and next operate the STC in the primary loop only. Generally, to avoid mutual interferences, it is recommended that the STC be operated normally in the primary loop only which is the main objective of the control.

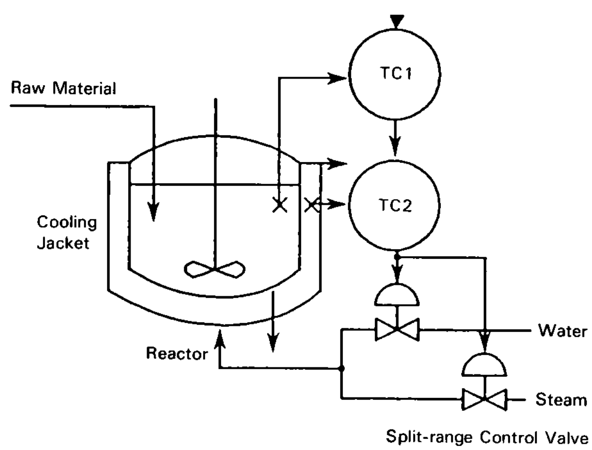


Figure 5.3.2 Cascade Control – 2

5.4 Following Fluctuations in Controlled System Characteristics (Gain, Lag-Time and Dead-Time)

A system to control outgoing flow F is shown in Figure 5.4.1 as an example.

Large periodic fluctuations in inflow F_1 into the tank result in level-control actuation causing intermediate flow fluctuations in F_0. The fluctuations in F_0 are equivalent to fluctuations in the gain of the process controlled by FIC.

Regarding fluctuations in the characteristics of the controlled system, if the fluctuating period is longer than the natural oscillating period of the control loop, the STC can follow the fluctuations. If a change in PV response due to the controlled system characteristic change is detected, the STC operates. The STC follows faster if a trigger from the on-demand tuning exists.

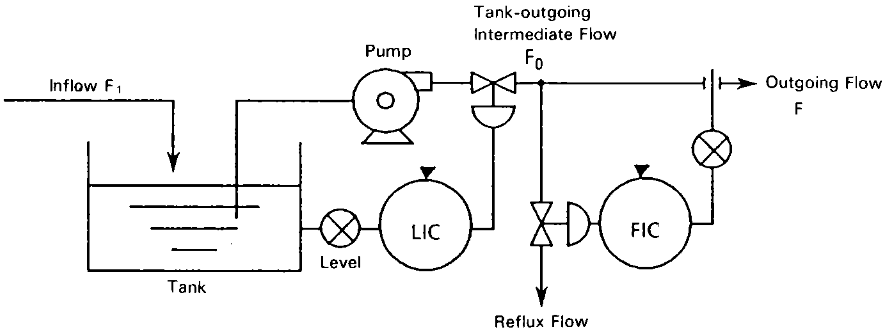


Figure 5.4.1 Process Whose Gain Changes

5.5 pH Control (Neutralizing Process)

In the neutralizing control shown in Figure 5.5.1, the pH control process exhibits a nonlinear characteristic which features maximum gain in the vicinity of pH=7 and small gains at either end as shown in Figure 5.5.2.

If the STC is directly applied to the pH controller, the optimum PID parameters are calculated in the vicinity of the neutralizing point causing the proportional band to converge at the rate of several hundred percent, thus no good control is expected. In this case, linearize the characteristics by combining the nonlinear elements of the controller and then apply the STC. (For combinations, see TI 1B4C1-03E page 13 (SLCD) or TI 1B4C2-02E page 62 (SLPC).)

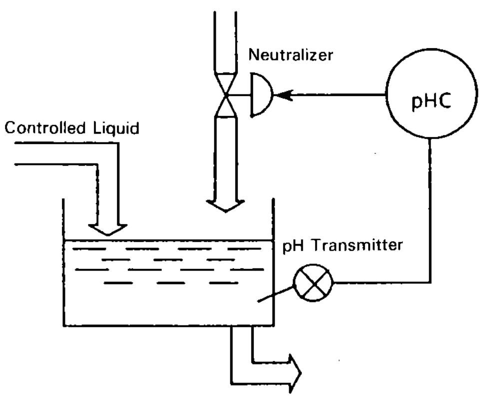


Figure 5.5.1 Neutralizing Control (pH Control)

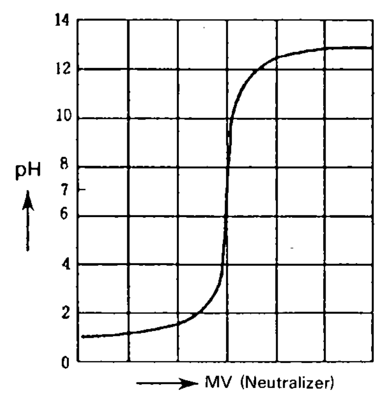


Figure 5.5.2 pH Process Characteristics

5.6 Control of Tank Level with Integral Characteristics

An example of the level control shown in Figure 5.6.1 uses a constant flow pump to draw liquid at constant flow rate independent of the level.

In this case, level H rises linearly as inflow Q_1 increases, showing that this process is an integral-mode process without self-balancing. The integral-mode process becomes unstable when the integral action is increases. Thus, control is usually performed by PD action with integral action weakened (with the integral time increased).

In such an integral-mode process, operate the STC with the process type IP = 1. The STC executes PD control by setting the integral time long if IP = 1.

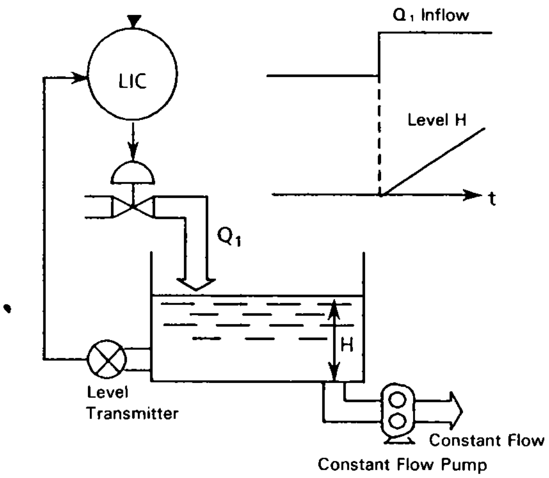


Figure 5.6.1 Level Control

5.7 Control of Process with Hysteresis Characteristics

In some cases — as in temperature control of a heating furnace or heat exchanger — the process response times in the heating and cooling processes differ (Figure 5.7.1). When the STC is to be applied to such a process, set the process 95%-response time TR to the larger response time. The PID parameters fluctuate between the PID parameters optimal to both processes according to the operating direction of the PV response.

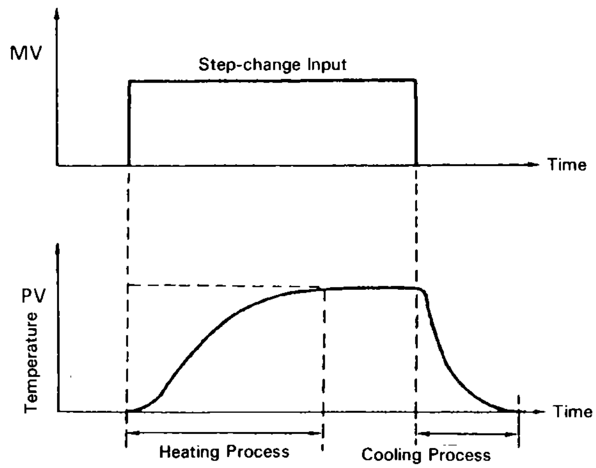


Figure 5.7.1 Hysteresis Characteristics (Stepped Response)

5.8 Control of Process with Slow Response of Final Control Element

When a motor valve is used for the flow control as shown in Figure 5.8.1, the response time of the motor valve may become the dominant control factor since the motor valve response time is larger than the flowmeter response time. If the STC is to be applied to the system, PB is set somewhat larger than the case where no lag in the final control element would exist, because the STC estimates the process characteristics including the lag in the final control element.

If controllability needs to be further improved, investigate the phase compensation (see Figure 5.8.2) by first-order lead computation to make up for the derivative action.

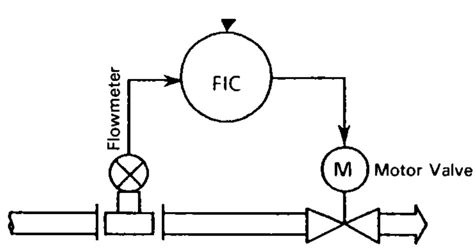


Figure 5.8.1 Flow Control with a Motor Valve

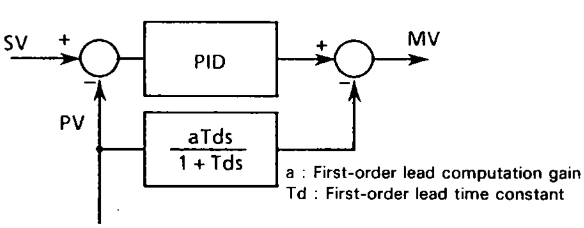


Figure 5.8.2 Output Compensation by First-Order Lead Computation

5.9 Temperature Control Using a Program Pattern

If the STC is to be applied to a programmed control in which the temperature controller setpoint is changed along a definite temperature increase/decrease pattern as shown in Figure 5.9.1, the following instructions are to be followed:

Select either PI-D (PV derivative type PID control) or SVF (Adjustable setpoint filter) control expressions. I-PD (PV proportional type PID control) control expressions make the capability of a follow-up to SV changes worse because PID parameters are set for suppressing disturbances. For minimizing overshoot when the temperature rise reaches the programmed temperature, set the STC control target to OS = 0 and select SVF.

Generally the PID controller causes offset when the setpoint gradually changes in a ramp as seen in increasing or decreasing temperature. When on-demand tuning is executed to eliminate the offset, the offset decreases because the MV is applied in the direction that decreases the deviation and, at the same time, the PID parameters are computed and set from the response.

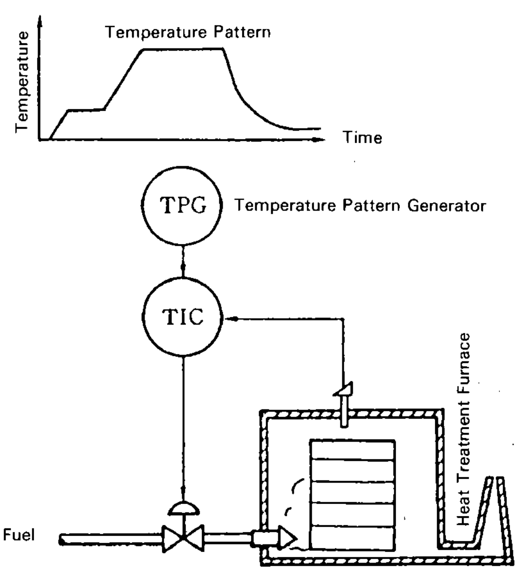


Figure 5.9.1 Programmed Temperature Control

5.10 Combining Control with Sequence Control (Batch Control)

A simple batch control process may be affected by a large disturbance that exceeds the practical correction range in feedback control, such as the additional charge of a large amount of raw materials or extraction of products during PID control.

In this case, compose a sequence to temporarily stop the STC operation using the STC start/stop function (see Figure 5.10.1).

If the SV is to remain constant in the AUTO mode after a batch is completed, stop the STC to prevent unnecessary STC operation (Figure 5.10.1).

The STC function cannot be used if the SLPC batch PID control function is used.

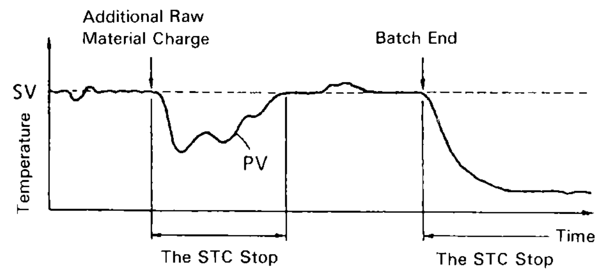


Figure 5.10.1 Batch Control

5.11 Control of Loops With Interference

5.11.1 When Interference Cannot Be Eliminated

If the STC operates in both loops of a system with interference such as the pressure control — flow control system shown in Figure 5.11.1, oscillation occurs due to the interference as the PID parameters converge to the optimum values.

For this situation, set one controller in which the PV fluctuation is permitted to STC OFF and select larger PB and TI values (Ex.: PB = 100 to 200%, TI = 30 to 80 seconds), and apply the STC only to the other controller.

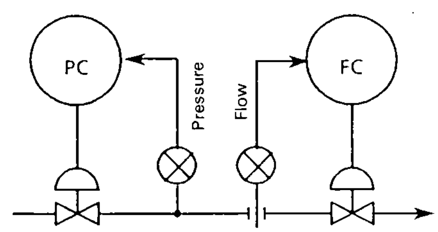


Figure 5.11.1 Pressure Control/Flow Control System

5.11.2 When Interference Can Be Eliminated

When mutual interference exists such as top and bottom temperature controls in a distillation tower, first carry out non-interference control as illustrated below and compose the STC after verifying the non-interference effect.

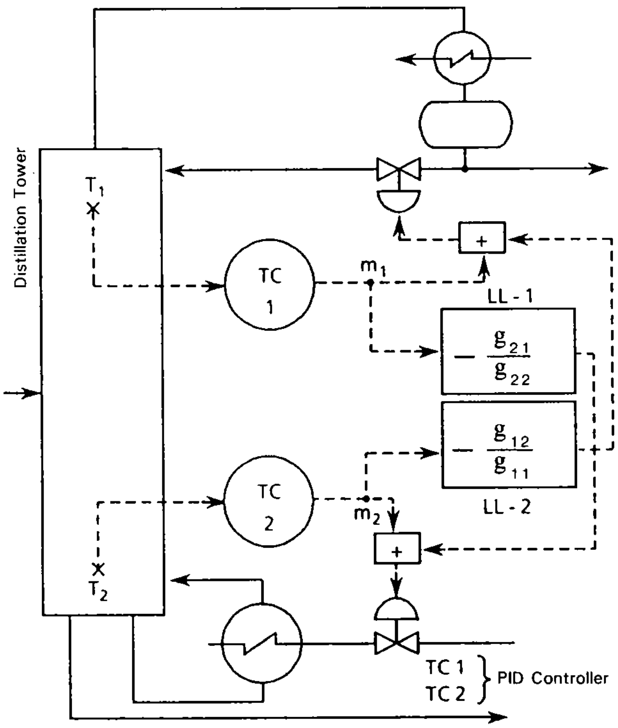


Figure 5.11.2 Non-Interference Control in Distillation Tower

(Non-Interference Control)

In Figure 5.11.2, let the transfer function between the output m_i of controller TCi and temperature T_j be g_{ij}. By adding non-interference elements LL-1 and LL-2 to the system, T_1 and T_2 are expressed as shown below.

$T_1 = (g_{11} - g_{12} \cdot g_{21}/g_{22})m_1$
$T_2 = (g_{22} - g_{12} \cdot g_{21}/g_{11})m_2$

As a result, two independent control loops are obtained.

5.12 Control of a Loop Containing Impulse Noise

The STC estimates the process characteristics after removing impulse noises. If noises are frequent, set a noise band NB. If noises frequently occur in a short interval (TR/10 or less), consider noise rejection using a filter.