Lesson #3: CONTROLLER TUNING

MODULE 1: Controller Tuning Objectives

At the end of this module, you will be able to:

1. **Sketch a quarter decay recovery curve and explain why this is a desirable proportional control response.**
2. **State the two control loop conditions which when satisfied will result in continuous loop cycling with constant amplitude.**
3. **Define the term Gain Margin as it relates to control system stability and state a typical gain margin value.**
4. **Define the term Phase Margin as it relates to control system stability and state a typical phase margin value.**
5. **Describe the steps needed to complete the systematic trial method of controller tuning.**
6. **State and apply the Zeigler & Nichols equation sets for controller tuning.**

Module 1: Controller Tuning

Introduction

- **We have seen that a typical controller, either pneumatic or electronic, can be provided with up to three adjustable parameters or control modes, (*proportional*, *integral*, and *derivative*).**
- **The adjustment of these parameters is often not understood well, and so incorrect (or less than optimal) settings can result in a *poorly performing* control system.**

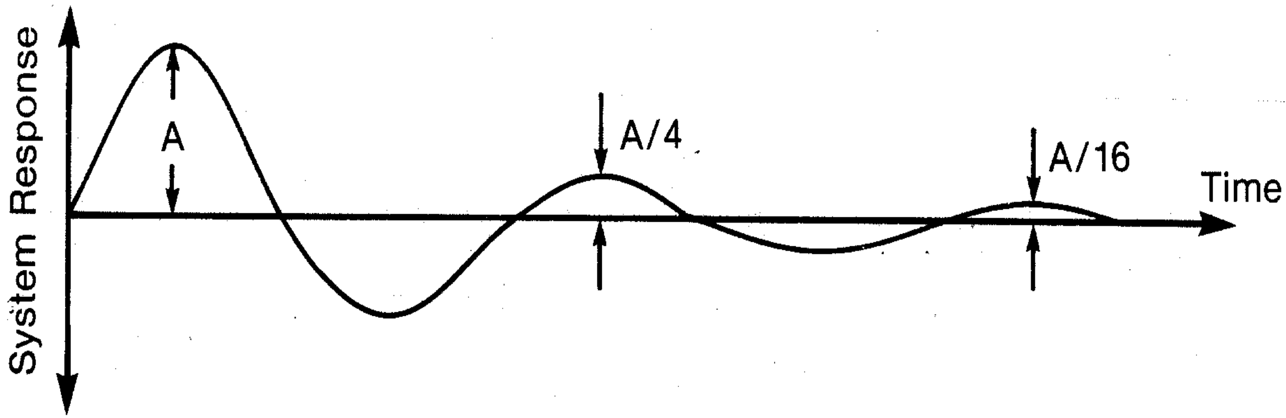

Figure 1: Typical 1/4 Decay Proportional Response – response plus stability.

- **The generally accepted performance goal for well adjusted or *tuned* proportional control is one that produces a *quarter decay* characteristic (Figure 1) following an applied upset or disturbance. Each subsequent peak is 1/4 the magnitude of the previous peak.**

The Control Loop

- **The controller is only *one hardware component* in a typical control loop.**

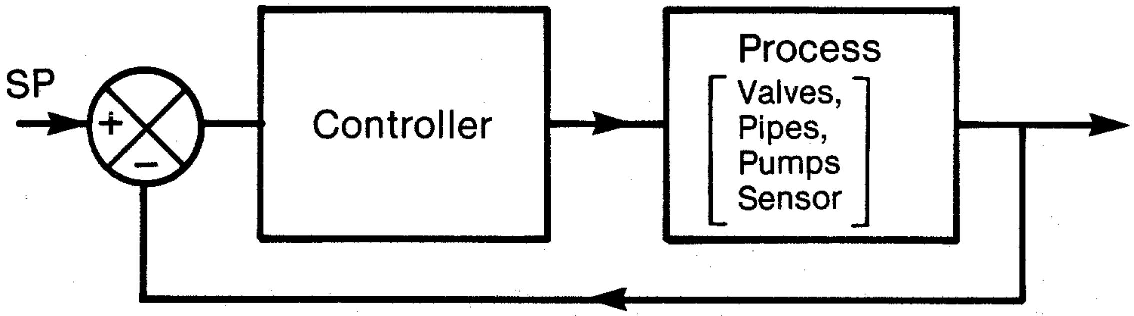

Figure 2: Simplified Control Loop.

- **All of the other loop items, including the process, are involved in the overall *loop gain* and *phase lag* of the system.**
- **It is convenient for the purposes of discussing controller tuning to divide the loop into two sections, the controller and "*every thing else*" (process, pipes, valves, pumps, etc.).**
- **In the section on process dynamics we discussed the effects of *capacitance* and *dead time* causing a phase lag in system response.**

Loop Stability

- **Recall that if an additional 180° of lag, over and above the inherent negative feedback 180° lag introduced by proportional control, is applied, then we no longer have a negative feedback system.**

- **We would then have *constructive interference* or excitation in phase with the input signal and, provided the gain is sufficient, the loop has the potential for oscillation.**

- **In practice it can be stated that most control loops have the ability to introduce more than 180∞ of lag.**

LOOP STABILITY MARGINS

- **A control system will just begin to cycle when:**
  the loop gain = 1 and the phase lag = 180 degrees.
  Loop Gain $K_L = K_C \times K_T \times K_V \times K_P$

- **The convenient means to prevent loop oscillation is *the controller gain setting*, although selection of transmitter, valve trim, valve accessories, etc. during design (and sometimes during commissioning) is very important.**

- **This is why controllers must be tuned at site during commissioning once all equipment is installed, since each process application is usually uniquely different from any other and all design uncertainties can not be resolved.**

Adjustable Loop Gain K_L = K_C x unchanged loop values

- **we speak of *margins to loop stability* based on *system gain* and *system phase lag***

Loop Stability Margins

- **The *Gain Margin* is the amount that the loop gain is less than 1 when the phase lag is 180 degrees**
- **Typical open loop design *Gain Margins* would be 5 to 10 dB (loop gains of approximately .3 to .6), where the magnitude ratio is calculated as $M = 20 \log_{10}(K)$ decibels**
- **The *Phase Margin* is the system lag in degrees below 180 when the loop gain is one.**
- **Typical open loop design *Phase Margins* would be 40 to 60 degrees.**

GENERAL LOOP PERFORMANCE ASSESSMENT

- **There are several methods available for tuning controllers - *Systematic Trial & Error*, *Ultimate Sensitivity* and the *Reaction Curve* methods.**

- **There should be *reasonably good agreement* for the tuning results from these different methods and you should be able to use *one method as a check* on another method if you require assurance that the tuning values make sense and are approximately correct.**

When does a loop need to be tuned?

- **New construction - *first commissioning***

- **Major *rehabilitation work*, maintenance outages, *system modifications***

- ***Optimizing* Performance - If a loop is mostly performing in a *satisfactory* manner(this is subjective so ensure you are *conservative* - that the loop has been challenged), a complete retuning may not be necessary. However, it may be possible to improve the loop's upset recovery performance by making small tuning adjustments and observing the results (make sure you allow enough recovery/observation time). The *composite* system performance can usually be improved significantly by making such small improvements to individual loops.**

SYSTEMATIC TRIAL & ERROR LOOP TUNING CONSIDERATIONS

ASSESS THE GENERAL PERFORMANCE OF THE CONTROL SYSTEM.

- **Talk to the *operator* to gain his insight into the process performance and *discuss* your impending *workplan*.**
- **It is essential that the operator know *what you intend* to do, and *how you intend* to approach this work so that he will be in the best position to help complete the loop tuning activities *while still maintaining stable control* of the overall process.**
- **Always note the *active interfaces* that the loop under tuning will effect.**
- **Also review any *potential hazard conditions* with the operator.**
- **Agree on the necessary work plan *'back out'* conditions under which the tuning activities will be terminated and the original settings restored.**

Loop Tuning - STARTING POINT

- **Note down the *'as found'* settings for the subject controller**
- **Obtain a *printout* or trend copy of the loop performance '*as found'* so that your starting condition is known and documented.**
- **Many times, it would be desirable to be able *to at least return to the safe, known starting point* if uncertainties occur making the tuning task more difficult than expected.**
- **An important rule to follow is to *only change one parameter at a time* so the change and the impact of that change can be assessed.**
- **If you begin to change too many things at one time, it will be a much *more complex problem* to analyze, along with a *high probability for errors*.**

BEGIN TUNING

- **If practicable, apply a small upset or *perturbation* to the system with the *original settings*, to obtain a copy of how the loop performed (disturbance response) with the initial settings (sometimes, people remember performance different from the current reality).**
- **Ensure that *adequate time* is allowed for the process *to recover* and stabilize - again so you are working from a known point (- *know where you are starting from*).**

ional Adjustment

- **At this time, you should now have a reasonable assessment of the process and general stability (i.e. is it slow, sluggish or fast and very dynamic) and any past performance difficulties.**

- **You should use this information to guide your controller mode setting adjustments.**

- **It is desirable to tune first the "*proportional band*", then the "*reset*" or "*integral*" and finally the "*derivative*" - in that order (if you are working with a 2 or 3 mode controller).**

- **Toward this goal, set the controller to *manual mode* (assuming there is automatic tracking and the loop was stable)**

- **Then set the *derivative time to zero minutes* (i.e. no derivative action) and as well set the *reset time to infinite minutes per repeat* - we now have no reset and no derivative actions (conversely, you would set reset rate to zero repeats per minute).**

PROPORTIONAL BAND ADJUSTMENT (continued)

- **Next choose a *proportional band setting* that you think is suitably wide (*low gain*) to ensure stability, while still having some responsiveness for the control loop.**
- **Restore the controller to Automatic mode (now performing *proportional only* control).**
- **Apply a small setpoint change, say increasing by 2% (or as needed to obtain a control response) and observe the process response.**
- **The control signal should respond in complete proportion to the control error and the valve should stroke in response to this signal change.**
- **Monitor both the *valve feedback signal* and *transmitter signal changes* for smooth and continuous action to ensure that the loop problems are not external to the controller.**
- **Likely you will find that this control setting is *very stable*, but *not very responsive* and so the control gain can be increased.**
- **Continue increasing the controller gain and '*bumping*' the process by setpoint changes in this manner until the *optimum proportional recovery* response is seen (1/4 decay recovery curve). Note that the subsequent setpoint changes should be *alternatively positive and then negative* so the process is maintained near the desired operating point.**
- **If the gain had been increased so much that the loop begins to cycle, widen the proportional band setting until loop stability is again achieved.**
- **Note (i.e. *record it*) the optimum proportional band setting found at this time.**

RESET MODE ADJUSTMENTS

- **If you are now going to adjust the reset mode, it is *important to widen the previously found optimum proportional band* somewhat (say by 10% of present setting) since reset is a *destabilizing mode* - otherwise you could force the loop to cycle.**
- **Recall that Reset mode *increases the low frequency loop phase lag* and *increases the low frequency loop gain***
- **Again - with the controller in *manual mode*, (with the *%PB widened* as suggested) begin to decrease the reset time setting and then restore the controller to automatic.**
- **Based on your knowledge of the process, you can select an appropriate reset time (i.e. if the process is *fast responding*, you can use a fast reset time, say 0.1 minutes per repeat, if the process is *slow responding*, you should use say 10 Minutes per repeat).**
- ***Monitor* the control *loop response* as the process is forced back toward the setpoint by reset action.**
- **Make sure you *allow enough time* for the process to completely recover.**
- **The desired response can be achieved my adjusting the reset time since the proportional gain is not being changed.**
- **Once the process is restored to the setpoint in an optimum recovery manner, that *reset time should be recorded*. along with the *widened proportional band setting.***

DERIVATIVE MODE ADJUSTMENTS

- **If this control application has derivative mode, the derivative time setting can now be increased in a *systematic manner* as described previously for *proportional plus reset* modes, with the controller set to manual mode.**
- **The *derivative time* should be gradually increased (i.e. start with say .01 or 0.1 minutes) and the corresponding loop upset response should be observed.**
- **You should see larger *control signal* response to a dynamic error condition with *smaller resultant process deviations* (due to the larger magnitude control corrections).**
- **Once the desired coordinated mode response is achieved, the controller *proportional band* can be reduced somewhat as derivative is a stabilizing factor**
- **Derivative mode *reduces the system high frequency phase lag* and *increases the high frequency gain*.**
- **Similarly, a *faster reset time* can now be used due to the compensating effect of derivative.**
- **This means that a few more iterations are necessary once the *apparent final settings* are obtained to see (this is a subjective exercise) if a better combination of gains and setting times can be obtained.**

SYSTEMATIC TRIAL METHOD CONCLUSION

- **At the end of the control mode adjustment process, you should *disturb the process* further (larger magnitude) *in both directions* to ensure that the final composite settings are stable.**
- **If possible, operation at other (preferably known difficult) conditions should be confirmed.**
- **All *findings*, observations and trends or records from the tuning exercise should be *collected and organized*.**
- **You should also have a *closeout discussion* with the operator to advise him of the new settings, the expected performance and to confirm that he is satisfied with the performance of the adjusted loop.**
- **You should also confirm with the operator that none of the *interfaced loops* have been adversely effected by this tuning exercise.**
- **You should leave the operator with a record of the *'as found values'* and the *'as left values'*.**
- **Upon returning to your work area, you should make a *brief work report* describing what you did and what you observed and summarize the findings (are they what you expected?).**
- **This sort of information will be invaluable later on during plant operations if a related problem occurs - the intent here is to try to *capture the benefit of work done for future reference* purposes.**

Systematic Trial & Error LOOP TUNING SUMMARY

1. Review *workplan* and *strategy* with operator

2. Record *'as found'* conditions and settings, and performance of interfacing systems

3. Switch controller to manual and turn off reset and derivative modes

4. Choose a widen Proportional Band (PB) Setting

5. Switch controller to Automatic and *apply a setpoint shift* (positive & negative shifts)

6. *Monitor* control and process responses - look for *smooth continuity*, allow *adequate time*

7. Repeat narrowing proportional band until *optimum PB response* is achieved

8. *Record* selected PB settings

9. If adjusting Reset mode - *widen PB* by 10% of present value

10. Systematically decrease Reset time *until PI optimum response* is obtained

12. If adjusting Derivative mode, systematically increase Derivative time

13. Assess *overall performance* (Narrow PB and faster Reset time as practical)

14. Confirm *expected loop performance* with *larger setpoint shifts* (+ve and -ve)

15. *Collect* data and *findings*

16. Discuss *'as left'* settings with operator, *explain expected response*

17. Leave a record of both '*as found'* and *'as left'* settings for the operator

18. Confirm *interfacing systems* are functioning as expected

19. Prepare a *short work report* to summarize findings, settings

ULTIMATE SENSITIVITY TUNING METHOD

- **A method which illustrates the principle of controller tuning very well is the one developed and described by Ziegler and Nichols in 1942.**
- **This is termed the *Ultimate Sensitivity Method*. The process must be able to cycle to apply this methodology - no stability recovery concerns must exist.**
- **One attraction of the Ziegler-Nichols method is that it was *empirically derived* as a result of observations carried out on many control loops and it presents a *simpler method* of tuning that is *less experience intensive*.**
- **Based on the fact that most control systems in closed loop mode (automatic) can be made to oscillate if the controller gain is increased progressively.**
- **If the system is made to oscillate at constant amplitude, then the overall loop gain is one.**
- **The setting of controller gain used to cause a loop gain of one is termed the *Ultimate Proportional Band (PBu).***
- **If the proportional gain is further increased the amplitude of the oscillations will progressively increase (*unbounded*) .**
- **If the gain is reduced the oscillations will eventually *attenuate*. This is shown in Figure 3.**

LOOP RESPONSE TO CONTROL GAIN CHANGES

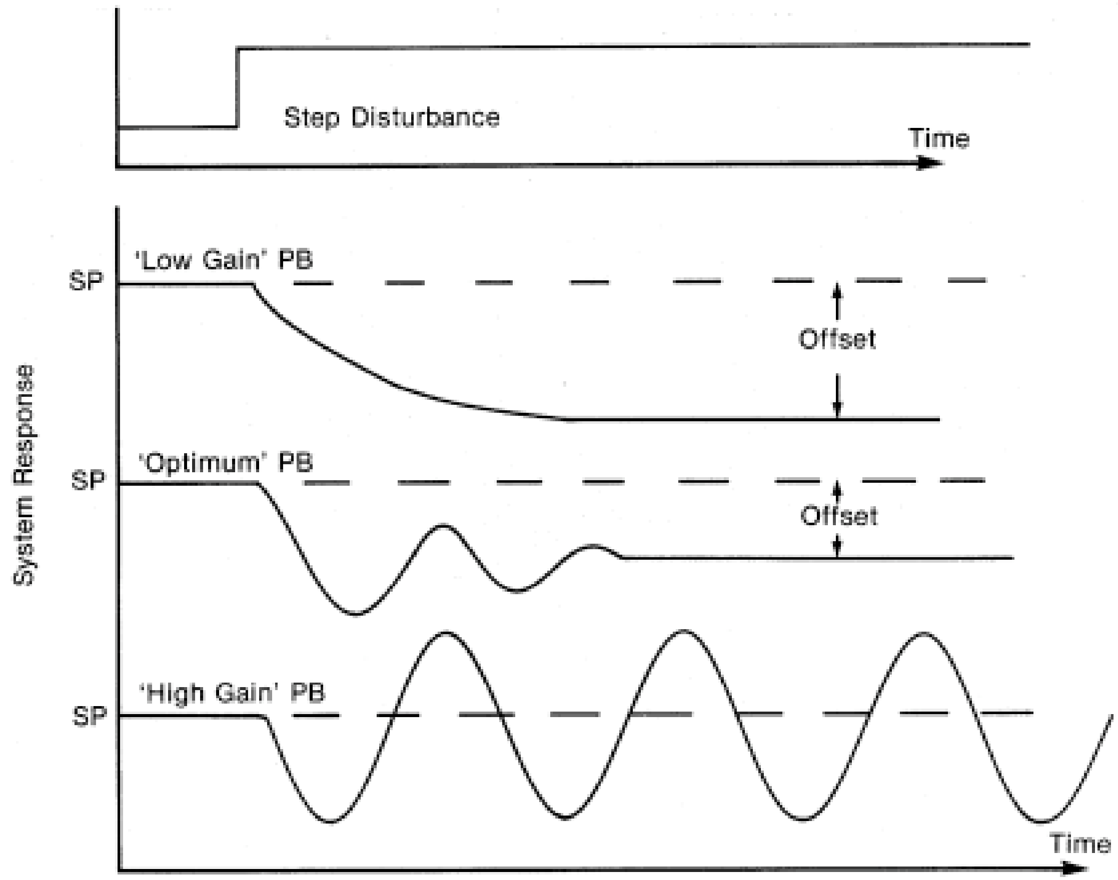

Figure 3: Responses to Varying Proportional Gains.

PROCESS PERIOD

- **There is another piece of information available from this method. It is the *period of the process oscillation* and it is representative of the natural frequency of the system.**
- **We will require this *process period* information to determine the best *reset and derivative settings* which are time related.**

ULTIMATE SENSITIVITY TUNING METHOD

1. **While in manual mode turn off, or increase reset time to maximum (if in MPR) or decrease reset rate (RPM) to minimum. Similarly switch off derivative or reduce derivative time to minimum value and then set the proportional control to *some arbitrary wide PB setting*.**
2. **With the controller in automatic mode, *subject the process to a small upset* (shift the setpoint to a new value)**
3. **If the response curve obtained from step 2 (recorder trend or CRT printout), does not damp out then the loop gain is too high (PB too narrow). Otherwise, the control gain setting should be reduced, (try halving the %PB, when in manual mode) and then repeat step 2.**
4. **If the response curve from step 2 damps out (upper and centre graphs), then the loop gain is too low (PB too wide) and the control gain must be increased.**
5. **Repeat the tuning process steps with different gains until *constant amplitude process cycling* is obtained. This PB setting is the PBu, and note the process ultimate period (Pu).**

SUMMARY

- **The PB at which the constant process cycling occurs is recorded, and is the *Ultimate Proportional Band* (PBu).**
- **Also recorded is the *process Ultimate Period* (Pu), the time taken, in minutes, for one cycle of process oscillation.**

Applying the Ziegler and Nichols formulae.

(1). PROPORTIONAL CONTROL only:

A 1/4 decay curve will be obtained if the PBu is doubled,(i.e. the gain is halved).

PB = 2.0 x PBu

(2). PROPORTIONAL PLUS RESET (P + I):

Recall overall gain must be reduced slightly when using Integral mode:

PB = 2.2 x PBu, Reset = Pu / 1.2 (MPR)

The reset time is the ultimate process cycle period (Pu) in minutes divided by 1.2

(3). PROPORTIONAL PLUS RESET PLUS DERIVATIVE (P + I + D)

PB = 1.6 PBu, Reset = Pu / 2 (MPR), Derivative = Pu / 8 (Mins)

The derivative time is the ultimate process cycle period (Pu) in minutes divided by 8

EXAMPLE APPLICATION of the Ziegler and Nichols formulae.

A temperature control loop is to be tuned by the Ziegler-Nichols method. It was found that the process cycled, at constant amplitude, with a PBu of 12% and an ultimate period of 22 Minutes (Pu). What would be the suggested Z&N settings for a three mode (P + I + D) controller?

The Zeigler and Nichols formulae for a three mode controller is:

P = 1.6 PBu

Proportional setting = 1.6 x 12 = 19.2% (perhaps 20% setting as possible)

R = Pu / 2 (MPR)

Reset setting, R = 22 / 2 = 11 MPR

D = Pu / 8 (Mins)

Derivative setting, D = Pu / 8 = 22/8 = 2.75 Minutes
(perhaps 2.7 or even 2.5 minutes depending on graduations)

THE REACTION CURVE TUNING METHOD

- **This third controller tuning method is worth noting in that this method only requires one upset to be applied to the process - it is not necessary to subject the process to a cycling condition.**
- **This approach requires that the loop be *opened* (say place the control in manual mode so that continual feedback control is not available)**
- **The process is then subjected to a *step input change* by open loop command.**
- **The resultant process *reaction curve to this input disturbance is then plotted* and analyzed to determine the best controller settings for the application.**
- **The following information must be noted or obtained as the tuning method is applied:**

   1. the *magnitude* of the change in final device posiiton in percent
   (%cvp - % change in valve position)

   2. the lag time from step change application until process response is seen
   (L - process time lag in minutes) - this is the approximate system dead time

   3. the process reaction rate approximation
   (R - %process change per minute)

THE REACTION CURVE TUNING METHOD (continued)

- **The reaction curve rate is found by sketching the tangent to the reaction curve point of inflection and then finding the slope of that line.**

- **The process reaction rate R is calculated in *% of process change per minute* from this tangent line slope.**

- **The reaction curve *tangent line* should be extended to the *time line* to allow the determination of the process time lag. The time (T_0) from *step change application start* until *the intercept of the reaction curve tangent point* (T_I) is the time delay lag value;**

  $L = T_I - T_0$ determined in *minutes.*

- **These values can now be used to determine the controller settings:**

  %cvp = % of change in final control device applied
  R = rate of change in process reaction curve (% per minute)
  L = process lag approximation seen from step change application

REACTION CURVE SETTINGS

A. STRAIGHT PROPORTIONAL:

%PB = [100 * R * L] / %cvp

Note #1: if the process reaction rate R is very large (responsive process), or the dead time L is quite long , then the %PB setting will be compensatingly large (i.e. a *low control gain*)

B. PROPORTIONAL PLUS RESET

%PB = [110 * R * L] / %cvp , Reset = 3.3 * L (MPR)

Note #2: the %PB setting for P+I is wider than for straight P since Reset is a *destabilizing mode*

Note 3: The longer the process dead time, the slower the reset time becomes

C. PROPORTIONAL PLUS RESET PLUS DERIVATIVE

%PB = [83 * R * L] / %cvp , Reset = 2 * L , Derivative = 0.5 * L

Note 4: the %PB setting for PID is narrower than P only as derivative is a *stabilizing mode*

Note 5: the longer the process dead time, the larger the derivative time becomes

REACTION CURVE METHOD EXAMPLE

Assume that a temperature process is found to have a Reaction Rate R of 10%/Min for an applied step change of 2.1 % in Control Valve position. The effective process dead time is found to be 30 seconds.

Reaction Curve Formula for PROPORTIONAL PLUS RESET PLUS DERIVATIVE

30 seconds = 0.5 minutes dead time

%PB = [83 * R * L] / %cvp

%PB = [83 * 10 * 0.5] / 2.1 = 415 / 2.1 = 197.6% (likely 200 %)

Reset = 2 * L

R = 2 * 0.5 = 1 MPR

Derivative = 0.5 * L

D = 0.5 * 0.5 = 0.25 Minutes

Reaction curve 3 mode settings are: PB = 200%, R = 1 MPR, D = 0.25 Min

CHAPTER 8 MODULE 1: CONTROLLER TUNING ASSIGNMENT

1. **Sketch a *quarter decay recovery curve* and explain why this is a desirable proportional control response.**
2. **State the two control loop conditions which when satisfied will result in continuous loop cycling with constant amplitude.**
3. **Define the term *Gain Margin* as it relates to control system stability and state a typical gain margin value.**
4. **Define the term *Phase Margin* as it relates to control system stability and state a typical phase margin value.**
5. **Describe the steps needed to complete the *systematic trial method* of controller tuning.**
6. **State and apply the *Zeigler & Nichols equation* sets for controller tuning.**
7. **A level control system is tuned by the Ziegler-Nichols method. The PB setting for constant amplitude cycling was 20%. The process cycled with an ultimate period of 1.8 minutes. What would be the Ziegler-Nichols settings for P + I control?**
8. **State and apply the *Reaction Curve equation* sets for controller tuning.**
9. **Briefly review each control mode (proportional, reset and derivative) with respect to loop gain and loop phase lag to describe how the inclusion of that mode will effect loop stability.**

<u>CANDU Control Computer System</u>

- Computers perform all major ***monitoring***, ***annunciation*** and ***control*** functions in the CANDU nuclear power plants.

- Figure 1. shows a simplified schematic of a ***dual-redundant*** control computer system (i.e. this means there are two computer systems, either which is ***individually capable*** of completing the assigned control task successfully).

- The two central control computers, with near identical inputs and outputs, operate in a ***master/standby*** configuration - so that ***either*** computer system can control the plant when called upon to do so.

- The outputs from the computers are wired through interlocking logic so that only the outputs from the ***controlling*** (i.e. master or in-control) machine are connected to the field.

- The active computer must ***recognize and confirm*** that it is in control and then will assume the role of ***master*** computer. In this manner the master computer is able to energize the output controlling switching relays.

- The ***disabled*** computer, having failed either the program (application S/W) or the computer itself (platform H/W), is unable to satisfy the ***'in-control'*** or ***'Master'*** logic requirements and so ***can not energize*** the necessary output controlling relays.

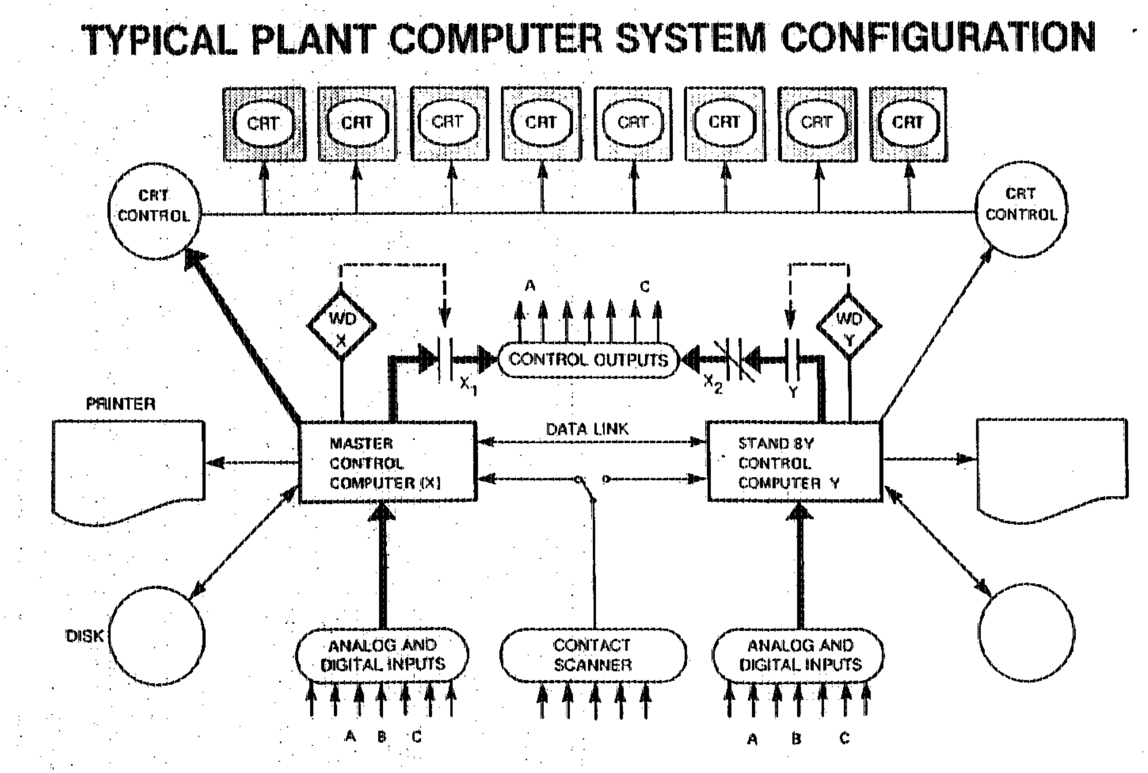

Figure #1 - A Dual Redundant Control Computer Configuration

<u>Wiring the Controlling Computer to the Field Device</u>

- By wiring the ***'Master in-control'*** logic via normally-open (N.O.) contacts in series with the ***'not in control'*** normally-closed (N.C.) contacts allows only the designated Master Computer to access the field.

- For example allow that DCC-X signal outputs are routed through a ***N.O.*** DCC-X controlled relay (say contact xc1 of relay #1) contact and then through a ***N.C***. DCC-Y controlled relay (say yc1 of relay #2) contact before being wired ***to the field device***.

- In this way, with DCC-X in-control, relay #1 will be energized causing contact xc1to ***close*** and relay #2 will be de-energized causing contact yc1 to also be ***closed*** so that both contacts in the circuit to ***connect DCC-X to the field*** are closed.

- Similarly, allow that DCC-Y outputs are routed through a ***N.O.*** DCC-Y controlled relay (say contact yc2 of relay #3) contact and then through a ***N.C.*** DCC-X controlled relay (say contact xc2 of relay #4) contact before being wired ***to the field device***.

- In this way, with ***DCC-X in-control***, relay #4 will be energized causing contact xc2 to ***open*** and relay #3 will be de-energized causing contact yc2 to also be ***open*** so that both contacts in the circuit to connect DCC-Y to the field are opened . ***DCC-Y is not connected*** to the field since DCC-X is in-control.

- On detection of a ***disabling*** program or computer ***fault***, that computer is no longer able to satisfy the logic conditions for being ***'in-control'*** and so is unable to energize its output signal selection control relays.

Determination of the Controlling Computer

- At the same time, the ***former standby*** computer is able to now fulfill the ***'in-control'*** logic requirements and so is able to ***energize*** its output control relays.
- The change in state of these output control relays then ***switches*** the control of the field devices from the former master computer to the previous standby machine completing the automatic transfer from say DCC-X to DCC-Y.
- Each computer is fully capable of ***individually*** running the plant independently and the operator can select the desired 'master' computer by handswitch control.
- The two machines are connected by a ***data-link*** which can transmit non-essential information for annunciation and display purposes.
- Both computers provide CRT based ***operating displays*** and log sequential operational information resulting from normal operations or an event.
- Computerized ***alarm information*** is displayed on the central annunciation CRT's.
- Stylized ***system displays*** and ***graphical updates*** (analog trends, bar charts, point data, etc) are provided on the system panel and the console CRT's.

Computer Program Checks

- Either computer can drive any of the CRT displays and the two annunciation CRT's - usually the 'Master' computer is selected to drive these CRT's but the standby computer can be selected to ***cross-check*** indications that are being obtained.

- It is important to indicate (at all times) ***which Computer*** information is being displayed as well as showing which computer is in control.

- The computer system checks for faults at the ***program level*** (i.e. are the conditions satisfied necessary to allow this program to run automatically?) and at the computer ***system level*** (i.e. are the correct power supplies available for the computer, are expected operations being performed, necessary interfaces available and are operations being performed within the expected time slice, etc).

- External countdown registers are used to schedule programs and to time their execution.

- A program will ***fail*** (i.e. not satisfy the requirements for continued operation) if it does not ***execute within a specified time interval*** or if a specified number or combination of its inputs are not deemed to be ***rational***.

- At the system level, a machine fails if it does not update a ***watch-dog timer*** within a specified time interval, if a fault is detected in the ***input/output subsystem*** or if a ***memory parity fault*** is detected.

- On a system fault, all ***digital outputs*** for that computer are ***opened***, the ***analog outputs*** are set to the ***fail-safe*** condition (usually zero signal), and control is automatically ***transferred*** to the standby machine.

<u>Control Computer Availability</u>

- Each computer continuously performs extensive ***self-check*** tests on its peripheral hardware (i.e. analog inputs or outputs, etc) and on its internal computer components (i.e. CPU, ALU, memory, etc).
- Minor faults are annunciated to the operator or maintenance staff (as appropriate) for repair purposes while major faults will initiate the ***transfer of control*** logic so that the ***'in-control'*** status is relinquished to the standby computer.
- The design approach is to avoid the loss of ***monitoring***, ***control*** or ***annunciation*** due to the occurrence of one ***single failure***.
- In keeping with this philosophy, most sensors are ***duplicated*** or ***triplicated*** as is appropriate for the application.
- For ***duplicated*** measurements, the average value is used if the two signals are in good agreement, otherwise the most conservative value to ensure the safest decision (i.e. say the highest pressure) is selected for control sensing.
- Where ***triplicated*** signals are provided and they are all rational, then the ***median*** signal is selected for control sensing. Otherwise, the unacceptable parameter is ***rejected*** and annunciated as being irrational and the signal selection reverts to that of a duplicated system.
- ***Redundancy*** is also provided for the ***final devices*** so that control valves can be driven in parallel or configured in a master/standby manner.
- In addition, ***interchannel*** and ***computer to computer*** comparisons will check for differences in signals, thus facilitating early recognition and maintenance of signal degradations.
- This information ***monitoring*** and the ability to perform ***on-line maintenance*** contributes significantly to the high capacity factors achieved by CANDU plants.

<u>ANNUNCIATION and DISPLAY FUNCTIONS</u>

- A wide variety of display functions are available to the operator. These include:
  - annunciation
  - graphical trends
  - bar charts
  - status displays
  - schematic displays
  - point data displays
  - summary data displays

- A standard ***keyboard interface*** to the computer driven CRT system has been developed for all of the operator information functions. This keyboard is the operator's prime means of communicating with the computer system.

- The CANDU main control room operations keyboard is divided into three groups:
  - numeric keys for data entry
  - function keys to initiate displays
  - keys for operator functions

- The labeled, special function select keys provide very rapid access to the various system data formats associated with each CRT.

- Typically the computer display ***response time*** to an operator request for a new data format is less than one second.

- Changes to data (that are allowed for the operator) stored in the computer such as control ***setpoints*** or ***alarm limits*** and changes for parameters appearing on a trend or bar chart; are done by the numeric key pad and control keys.

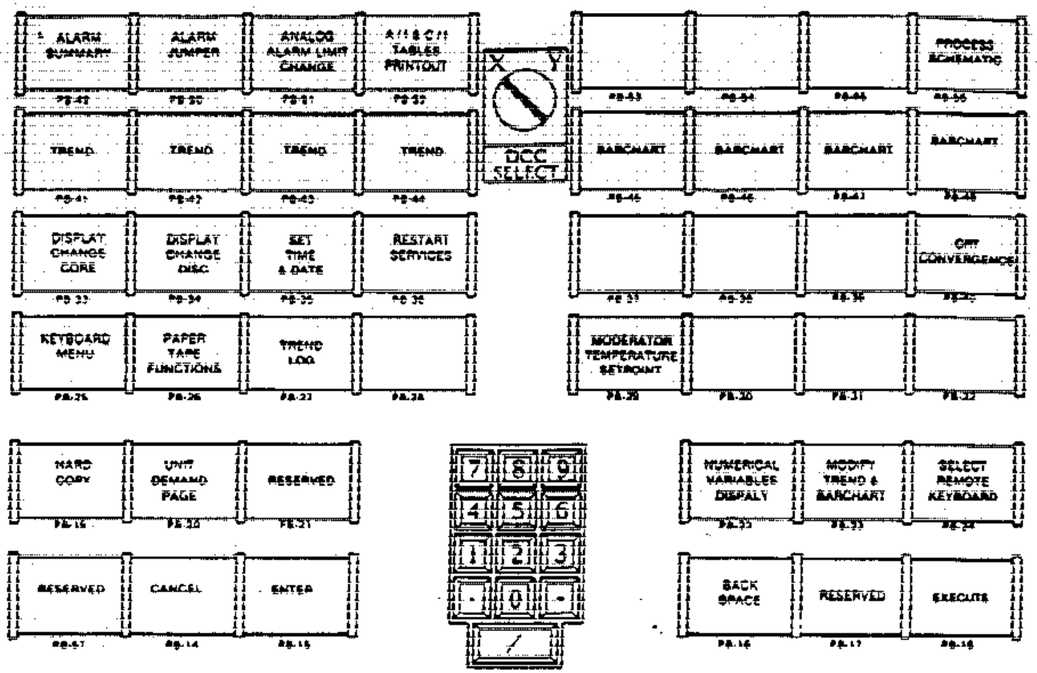

Figure 2. Typical Computer Control Keyboard Layout

ANNUNCIATION CRT DISPLAYS

- Early traditional designs used ***hardwired alarm windows*** located above the control panels to annunciate faults.

- These alarm windows, although effective at attracting the operator's attention, provide limited information and are impractical when a lot of alarms are needed.

- In current designs, the hardwired windows alert the operator of the ***general occurrence*** of an important fault while further details are provided by the ***annunciation CRTs***.

- The annunciation data can now be manipulated as any batch data system to ***prioritize*** the display of alarms as well as to ***logically group*** the alarm messages, allow ***unique*** summaries to be prepared and to link the alarms to necessary follow-up operating or maintenance actions.

- During a plant upset (such as a reactor trip or stepback) minor alarms (i.e. low priority) are ***inhibited*** from being displayed on the CRT - only ***major*** (i.e. high priority) alarms are presented until the upset has cleared.

- This prevents the CRT from being '***flooded***' with messages during ***critical recovery periods*** while allowing the operator to respond to those alarms which are ***more important*** for station operations.

- However, all alarms with their ***time of occurrence*** and the ***unique alarm reference number*** are all saved to disc. At the operator's request, a ***summary*** of all existing alarms on a system or total plant basis can be displayed and this summary can be reviewed on the CRT or printed out for further review or documentation purposes.

GRAPHICAL TREND DISPLAYS

- Graphical trends display the status and change of a parameter in a continuous analog manner with respect to a selected ***time frame*** and ***magnitude scaling***.
- ***Historic data*** may also be retrieved from disc storage to review a previous operating event. The operator specifies the ***time period*** of interest and the ***scale range*** for the display and a static display of the request is prepared.
- Different variables in the graphical trends are identified by ***colour*** to assist the operator's ***discrimination***.
- Parameters can be set up by default to have ***pre-selected*** ranges and time servicing or those attributes can be uniquely set.
- Similarly, the option of ***dummy variables*** is provided so that the operator can link any parameter to that dummy trend.
- Parameters can also be specified as part of the automatic ***historical logging*** process (so that previous performance can be assessed) or as a ***temporary parameter*** (i.e. not historical) so that viewing the trend is only possible if that parameter has been selected for display.

BAR CHARTS

- Up to sixteen signals can be displayed on a ***bar chart***, each having an ***identification code***, ***scale values***, ***alarm limits***, ***current value*** and ***units***.
- This approach allows ***high density displays*** of multiple similar parameters from which any variance can very easily be seen.

OTHER DISPLAYS

- A variety of special purpose displays are ***unique*** to particular systems and operating conditions. For some displays, the data processing capabilities of the computer system provide ***information not normally available*** with conventional instrumentation.

- For instance, a dynamic plot of the reactivity control system operating point relates the ***reactor power control error*** to the ***average liquid zone level*** on an X-Y display to show the ***action points*** for initiating the various control mechanism operations - this provides an easy to understand ***overall reactivity*** control mechanism ***coordination***.

- Similarly, a ***plant block*** schematic diagram with superimposed operating data provides an overall plant condition status indication with navigation icons to allow direct access to the associated subsystem displays.

- CRT plant displays can be assessed by operators in an ***on-going*** manner so that operational feedback can be used to modify existing displays or to create new ones to achieve an enhanced operations performance.

- Such a plant-wide summary display also provides an ***understandable navigation approach*** to allow the operator to quickly and conveniently select major system displays from one central coordinating display so as to maintain unit status continuity knowledge.

CANDU DCC Assignment

1. Explain the term dual-redundant by referencing the Master/Standby DCC configuration as a practical example.

2. Make a simple sketch to show how interfacing relays can be used to ensure that only one computer (the one identified as the present Master computer) can be connected to the field output device while the standby computer is disconnected by this same logic.

3. Explain briefly how the provision of a data cross-check feature between two computers can help the operator to very quickly recognize a potential problem condition.

4. What is the function of a 'watch-dog' timer in a digital control application?

5. Why can the variation of a parameter in a triplicated measurement system be recognized and identified as a problem much more easily than is the case in a duplicated measurement system?

6. Why is it important to display the computer-in-control identification at all times for a redundant computer system?

7. What purpose would a two key sequence (i.e. enter key and execute key) serve when made as a requirement to complete a control data entry action? If this is a good idea for control data entries. why not make it a requirement for all operator data entires?

8. Provide an illustrative list of five (5) CRT display types that can be provided for operators and briefly describe their main features.

9. What information do you think is essential to be included in a CRT alarm message? Explain the four or five key information features that you would recommend as being essential to efficiently advise an operator of a potential problem situation. How should this information be presented to best help the operator understand the new situation?

<u>CANDU DCC Assignment – sample answers</u>

1. Explain the term dual-redundant by referencing the Master/Standby DCC configuration as a practical example. *Dual-redundant is a design strategy to provide two completely functional devices, either of which is capable of performing the assigned mission. Should one device fail, the other would be able to assume control providing uninterrupted automatic action.*

2. Make a simple sketch to show how interfacing relays can be used to ensure that only one computer (the one identified as the present Master computer) can be connected to the field output device while the standby computer is disconnected by this same logic. *The key idea here is to have the designated Master actively enable its devices (so use N.O. configuration for these) while the standby passively allows connection (so use N.C. configuration there). If the Master is enabled (N.O. contact will close) and the standby is disabled (N.C. contact will close) – allowing the circuit connecting the Master DCC to be completed to the field.*

3. Explain briefly how the provision of a data cross-check feature between two computers can help the operator to very quickly recognize a potential problem condition. *Usually, there should be good agreement between the values obtained for both computers –so if differences in similar parameters on two computers are recognized, then this is one indicator that a potential problem exists – perhaps the measurement is different due to testing or maintenance (and it shouldn't be), or a ground fault has changed the reading, or a transmitter fault, or Input conversion problem etc - in any event, such a discrepancy should be investigated.*

4. What is the function of a 'watch-dog' timer in a digital control application? *The watch-dog timer is a separate (from the computer) counter which can keep track of execution cycle durations and independently disconnect that computer if the time threshold is not achieved – in this way, the plant operation is guarded against stuck routines or processors that would otherwise prevent expected loop servicing.*

5. Why can the variation of a parameter in a triplicated measurement system be recognized and identified as a problem much more easily than is the case in a duplicated measurement system? *In a duplicated system, if there is not good agreement between two indicators we only know that there is a problem but we do not know which parameter is the most trustworthy without making further inference comparisons. In a triplicated system, if one parameter drifts away, the other two will be in good agreement and so we can use a majority agreement rule and immediately know that the one which has drifted is the problem parameter.*

6. Why is it important to display the computer-in-control identification at all times for a redundant computer system? *This information should be displayed so that the operator knows that information read or entered to a computer that is not in control will not effect plant operations. This can be a problem if for example the operator entered a manual command and was expecting to see plant response when in fact no change is made to the operating unit.*

7. What purpose would a two key sequence (i.e. enter key and execute key) serve when made as a requirement to complete a control data entry action? If this is a good idea for control data entries. why not make it a requirement for all operator data entries? *The two key sequence requires that the operator actively confirms the entry of a desired change so that inputs are not casually made. This provides an error catching step to be sure that the operator, for example, does want to raise power at a particular rate.*

8. Provide an illustrative list of five (5) CRT display types that can be provided for operators and briefly describe their main features. *Plant overview display, system display, device status, point data, trend display, annunciation summary, bar chart display.*

9. What information do you think is essential to be included in a CRT alarm message? Explain the four or five key information features that you would recommend as being essential to efficiently advise an operator of a potential problem situation. How should this information be presented to best help the operator understand the new situation?
The parameter, the limit exceeded, the system name or identification number, the time & date, any procedural cross references.