# CHAPTER 8: CONTROLLER TUNING

## MODULE 1: ULTIMATE SENSITIVITY METHOD

### Introduction

**We have seen that a typical controller, either pneumatic or electronic, can finish up with three adjustable parameters, (proportional, integral, and derivative). The adjustment of these parameters is often poorly understood, and incorrect settings can result in a poorly performing feedback control system.**

**In the module on proportional control the accepted ideal setting was one that produced a 1/4 decay characteristic (Figure 1).**

**There is no real mathematical justification for this response, but it does represent a good compromise between speed of response and stability. This criterion should be the cornerstone of controller tuning.**

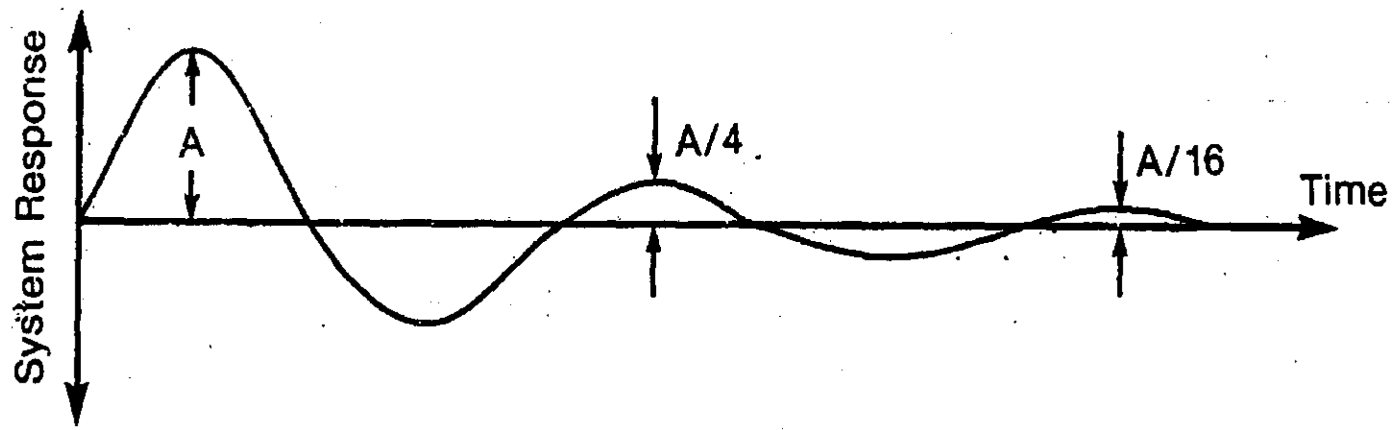


**Figure 1: Typical 1/4 Decay Response.**

## The Control Loop

**The controller is but one piece of hardware in a typical control loop. The other items are also involved in the overall "balance" of the loop. It is convenient for the purposes of discussing controller tuning to divide the loop into two sections, controller and "every thing else" (process, pipes, valves, pumps, etc.).**

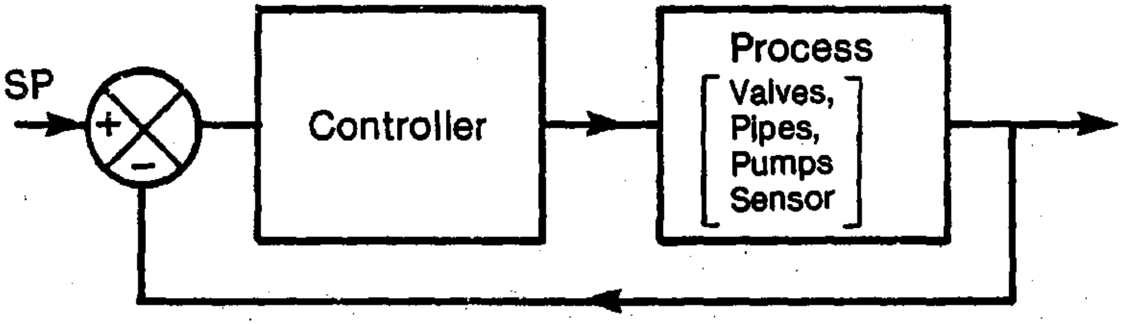


**Figure 2: Simplified Control Loop.**

- **In the section on process dynamics we discussed the problems of capacitance and dead time causing a lag in response.**
- **Recall that an additional 180° of lag, over and above the inherent 180° lag introduced by proportional control, and we no longer have a negative feedback system.**
- **We have feedback in phase with the input signal and, provided the gain is sufficient, have potential for oscillation.**
- **In practice it can be stated that all control loops have the ability to introduce more than 180° of lag.**
- **The limiting factor to prevent oscillation is the controller gain setting. This should explain why controllers must be tuned on site, each process is different from any other.**

**There are several methods available for tuning controllers. If a loop is performing reasonably satisfactorily, a complete retuning may not be necessary, but it may be possible able to improve the loop's performance by making small adjustments and observing the results. However, such a trial and error process does require a good deal of experience of instrumentation systems to carry out without upsetting the process too much.**

**The method which best illustrates the principle of controller tuning is the one developed and described by Ziegler and Nichols in 1942. This is termed the Ultimate Sensitivity Method.**

## Ultimate Sensitivity (Ziegler-Nichols) Method

One attraction of the Ziegler-Nichols method is that it was empirically derived as a result of observations carried out on many control loops. It is based on the fact, as described above, that any control system 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 the overall loop gain is one. The setting of controller gain at this point is termed the Ultimate Proportional Band (UPB). If the proportional gain is further increased the amplitude of the oscillations will progressively increase and if the gain is reduced the oscillations will eventually die out. This is shown in Figure 3.

There is another piece of information available at this point. It is the period of oscillation and it is representative of the natural frequency of the system. We will require this to determine reset and derivative settings which are time related.

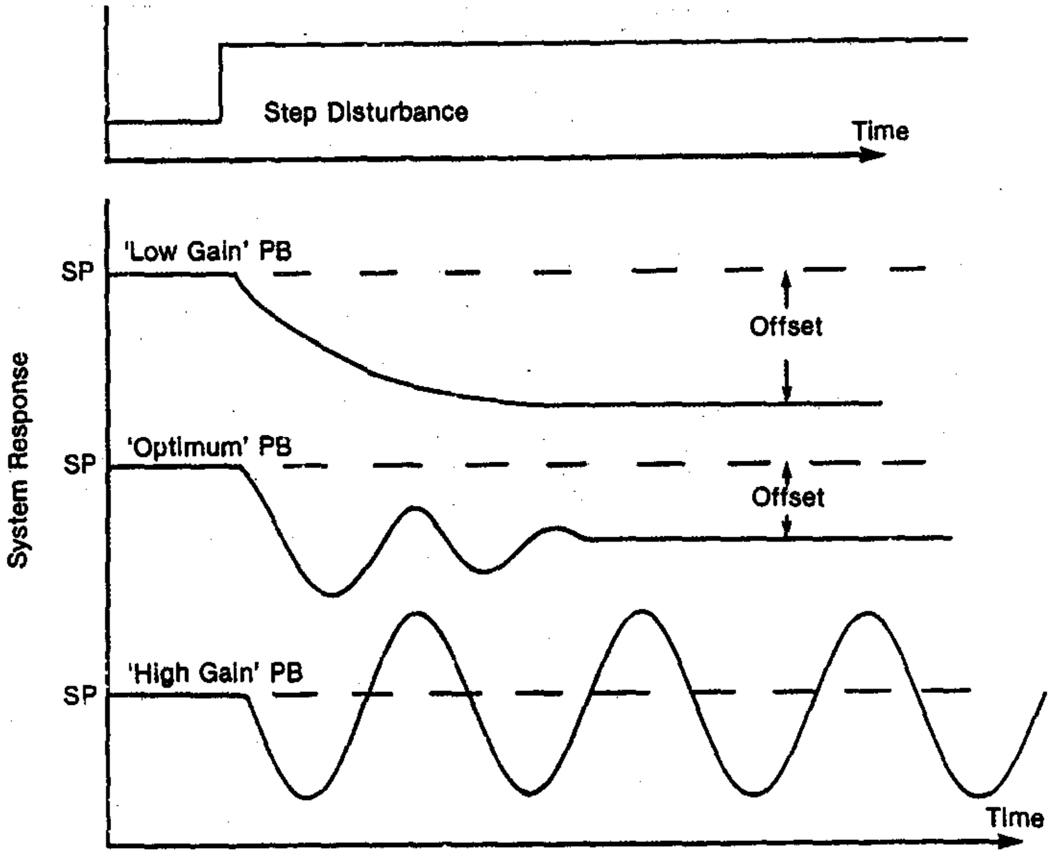


**Figure 3: Responses to Varying Proportional Gains.**

## 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.

2. With the controller in automatic mode, and with the proportional control set at some arbitrary wide PB setting, subject the process to a small upset (move setpoint to a new value for a few seconds and then return to original setting).

3. If the response curve obtained from step 2, on the process recorder, does not damp out then the gain is too high (PB too narrow). The gain setting should be reduced, (try halving, when in manual mode) and then step 2 should be repeated.

4. If the response curve in step 2 damps out (upper and centre graphs) the gain is too low (PB too wide) and the gain must be increased.

5. Repeat the process with different gains until constant amplitude cycling is obtained. The PB at which this occurs is recorded, and is the Ultimate Proportional Band (UPB). Also recorded is the Ultimate Period (Pu), the time taken, in minutes, for one cycle of oscillation.

**Applying the Ziegler and Nichols formulae.**

**(1). For Proportional control only:**

**A 1/4 decay curve will be obtained if the UPB is doubled, gain halved.**

$$\text{PB} = 2.0 \text{ UPB}$$

**(2). Proportional plus Reset. (P + I)**

**Recall reset adds lag to the system, i.e., less stable, therefore overall gain must be reduced slightly.**

$$\text{PB} = 2.2 \text{ UPB}$$

$$\text{Reset} = \frac{\text{Pu}}{1.2} \text{ (MPR)}$$

**(3). Proportional Plus Derivative (P + D)**

**Derivative action reduces lag, i.e., system slightly more stable, more gain can be used.**

$$\text{PB} = 1.6 \text{ UPB}$$

$$\text{Derivative} = \frac{\text{Pu}}{8} \text{ (Mins)}$$

**(4). Proportional Plus Reset Plus Derivative (P + I + D)**

$$\text{PB} = 1.6 \text{ UPB}$$

$$\text{Reset} = \frac{\text{Pu}}{2} \text{ (MPR)}$$

$$\text{Derivative} = \frac{\text{Pu}}{8} \text{ (Mins)}$$

**Remember the above equations were essentially empirically derived and exceptions are possible. They are designed to produce a quarter decay ratio. A major disadvantage is that the loop must be made to oscillate. In a working plant this is not always possible.**

## Example

**A temperature control loop is to be tuned by the Ziegler-Nichols method. The process cycled, at constant amplitude, with a UPB of 12% and an ultimate period of 22 minutes. What would be the control settings for a three mode (P + I + D) controller?**

**For three mode controller:**

**P = 1.6 UPB**

$$I = \frac{Pu}{2}\ \text{(MPR)}$$

$$D = \frac{Pu}{8}\ \text{(Mins)}$$

**Proportional setting = 1.6 x 12 = 19.2%**

$$\text{Reset setting} = \frac{22}{2} = 11\ \text{MPR}$$

$$\text{Derivative setting} = \frac{22}{8} = 2.75\ \text{Minutes}$$

## Setting the Gains on Controllers

The problem now arises in putting these figures obtained into practice. For example the process is controlled by a Fischer Porter electronic controller. We find that to set the PB setting at 19.2% will require a good deal of "guesstimation"; the control is not that precisely calibrated.

- The switched reset control gives a choice of 12 MPR or 6 MPR - there is no position for 11 minutes.
- The rate controller setting has figures of 4 Minutes or 2 Minutes. Which settings should be used?
- The example used a temperature control process, a typically sluggish system. With sluggish systems reset windup is a potential problem - set the reset to 12 minutes.
- Sluggish systems generally benefit from derivative action, set D to 4 minutes (increased derivative) and check for stability. If there is evidence of instability due to the increased derivative action the setting will have to be reduced to the 2 minute setting.

Decisions of this type must be based upon both the type of process being controlled and previous experience. In general it can be said that:

Temperature Processes are generally sluggish. They are more tolerant of high derivative settings than high reset settings.

Flow Processes are fast acting - tolerant with respect to higher reset settings, hardly if ever feasible to use derivative action.

Level Processes - response dependent upon capacitance of system - each case must be considered on its merits.

Note: We have discussed only one (possibly the best known and widely accepted as one of the best) tuning technique. There are many other techniques available which vary considerably in approach and implementation. Tuning controllers is as much an art as it is a science.

## ASSIGNMENT

1. **Why, for example, do not all level control loops have the same tuning parameters?**

2. **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?**

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