Process Control

Module 3

Lesson 13

Controller Tuning

Instructional Objectives

At the end of this lesson, the student should be able to

- Explain the importance of tuning of controller for a particular process
- Name the three experimental techniques for controller tuning
- Explain the three methods for tuning of P, I and D parameters
- Explain the terms: Auto Tuning, Bumpless Transfer and Integration Wind Up.

1. Introduction

The importance of P-I-D controller and the features of P, I and D actions were elaborated in the last lesson. It was also mentioned that the controller could be easily incorporated in a process, whatever be the type of a process: linear or nonlinear, having dead time or not. It is needless to say that the controller parameters influence heavily the performance of the closed loop system. Again, the choice of the value of the P, I and D parameters is very much process dependent. As a result, thorough knowledge about the plant dynamics is important for selection of these parameters. In most of the cases, it is difficult to obtain the exact mathematical model of the plant. So, we have to rely on the experimentation for finding out the optimum settings of the controller for a particular process. The process of experimentation for obtaining the optimum values of the controller parameters with respect to a particular process is known as controller tuning.

It is needless to say, that controller tuning is very much process dependent and any improper selection of the controller settings may lead to instability, or deterioration of the performance of the closed loop system. In 1942 two practicing engineers, J.G. Ziegler and N.B. Nichols, after carrying out extensive experiments with different types of processes proposed certain tuning rules, there were readily accepted and till now are used as basic guidelines for tuning of PID controllers. Subsequently, G.H. Cohen and G.A. Coon in 1953 proposed further modifications of the above techniques. Still then, the methods are commonly known as Ziegler-Nichols method.

Substantial amount of research has been carried out on tuning of P-I-D controllers since last six decades. Several other methods have also been proposed. Most of them are model based, i.e. they assume that the mathematical model of the system is available to the designer. In fact, if the mathematical model of the system is available, many of them perform better than conventional Ziegler-Nichols method. But the strength of the ZN method is that it does not require a mathematical model, but controller parameters can simply be chosen by experimentation. We would be discussing the three experimental techniques those come under the commonly known Ziegler-Nichols method.

Now let us look back to whatever discussed in lessons 11 and 12. The closed loop system can be described as shown in Fig. 1.

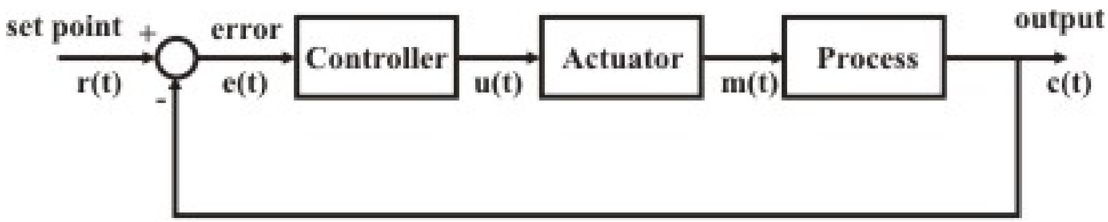

Fig. 1 Closed loop system.

The error signal is fed to the controller and the controller provides output u(t). Since the capacity of the controller to deliver output power is limited, an actuator is needed in between the controller and the process, which will actuate the control signal. It may be a valve positioner to open or close a valve; or a damper positioner to control the airflow through a damper. The controller considered here is a P-I-D controller whose input and output relationship is given by the equation:

$$u(t) = K_p \left[e(t) + \tau_d \frac{de(t)}{dt} + \frac{1}{\tau_i} \int_0^t e(\tau) d\tau \right]$$

Our objective is to find out the optimum settings of the P,I,D parameters, namely K_p, τ_d and τ_i through experimentation, which will provide satisfactory closed loop performance, of the particular process in terms of, say, stability, overshoot, setting time etc. Three methods of tuning are elaborated in the following sections.

2. Reaction Curve Technique

This is basically an open loop technique of tuning. Here the process is assumed to be a stable first order system with time delay. The closed loop system is broken as shown in Fig.2; a step input is applies at m', output is measured at *b*. In fact, a bias input may be necessary so that the plant output initially becomes close to the nominal value. The step input is superimposed on this bias value. The input and the output response are plotted by suitable means as shown in Fig. 3.

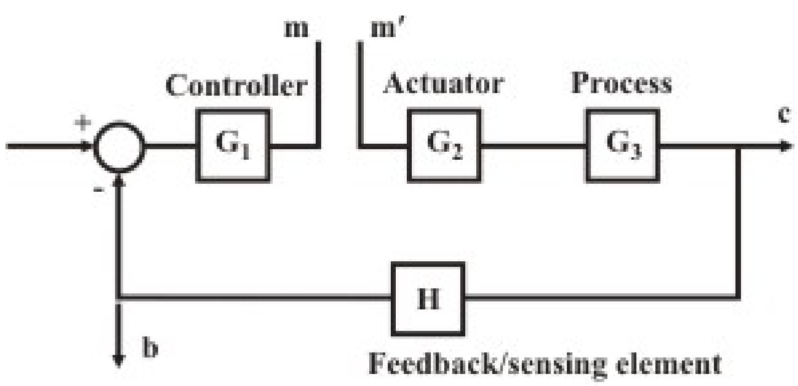

Fig. 2 Reaction curve technique for controller tuning.

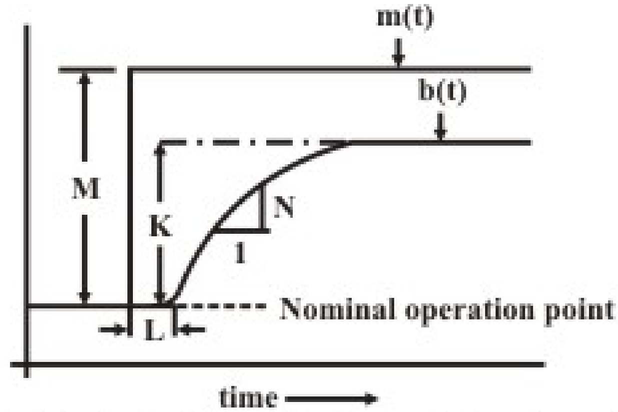

Fig. 3 Input and output plots under the condition shown in Fig. 1.

M,L and K are measured. Let us define the following terms corresponding to Fig. 2:

Slope = N,

Time Constant T=K/N

Lag Ratio R=L/T

Then, the recommended optimum settings, for P, P-I and P-I-D controller are as follows.

Optimum settings

P-Control: $$K_p = \frac{M}{NL}(1+\frac{R}{3})$$

P-I Control: $$K_p = \frac{M}{NL}(\frac{9}{10}+\frac{R}{12}); \qquad \tau_i = L\left(\frac{30+3R}{9+20R}\right)$$

P-I-D Control: $$K_p = \frac{M}{NL}(\frac{4}{3}+\frac{R}{4}); \qquad \tau_i = L\left(\frac{32+6R}{13+8R}\right)$$

$$\tau_d = L\left(\frac{4}{11+2R}\right)$$

3. Closed Loop Technique (Continuous Cycling method)

The major objection to the tuning methodology using reaction curve technique is that process has to be run in open loop that may not always be permissible. For tuning the controller when the process is in under closed loop operation, there are two methodologies. The first one, continuous cycling method is explained below.

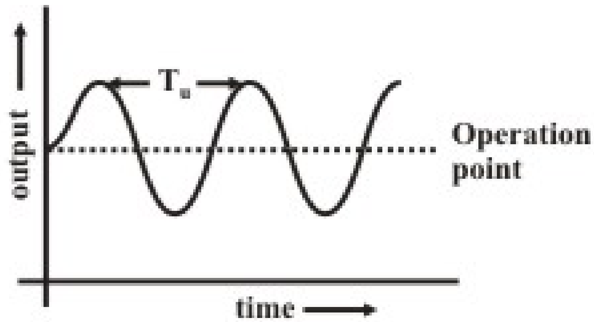

Fig. 4 Controller tuning continuous oscillation mode.

Referring Fig.1, the loop is closed with the controller output connected to the actuator input. Here, the controller is first set to P-mode, making $\tau_d = 0 \; and \; \tau_i = \infty$. The proportional gain K_p is increased gradually to $K_p = K_{p\max}$, till the system just starts oscillating with constant amplitude continuously. The output waveform is plotted as shown in Fig.4. The time period of continuous oscillation T_u is noted. The recommended optimum settings are:

P Control: $\mathrm{K_p = 0.5K_{p\max}}$

P-I Control: $\mathrm{K_p = 0.45K_{p\max}}, \; \tau_i = \frac{T_u}{1.2}$

P-I-D Control: $K_p = 0.6K_{p\max}, \; \tau_i = \frac{T_u}{2}, \; \tau_d = \frac{T_u}{8}$

Points to Ponder

a) Why is the proportional gain K_p for PI control is less than the value for P-only control?

b) Why K_p for PID control is more than that PI?

4. Closed Loop Technique (Damped oscillation method)

In many cases, plants are not allowed to undergo through sustained oscillations, as is the case for tuning using continuous cycling method. Damped oscillation method is preferred for these cases. Here, initially the closed loop system is operated initially with low gain proportional control mode with $\tau_d = 0 \; and \; \tau_i = \infty$. The gain is increased slowly till a decay ratio (p_2/p_1) of $1/4^{th}$ is obtained in the step response in the output, as shown in Fig. 5. Under this condition, the period of damped oscillation, T_d is also noted. Let K_d be the proportional gain setting for obtaining $1/4^{th}$ decay ratio.

The optimum settings for a P-I-D controller are:

$$K_p = K_d; \tau_i = \frac{T_d}{6}; \tau_d = \frac{T_d}{1.5}$$

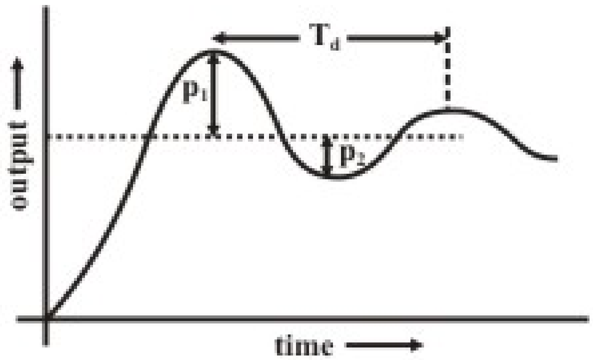

Fig. 5 Controller tuning using damped oscillation technique.

5. General comments about controller tuning

The different methodologies of controller tuning, known as Ziegler-Nichols method have been illustrated in the earlier sections. It is to be remembered that the recommended settings are empirical in nature, and obtained from extensive experimentation with number of different processes; there is no theoretical basis behind these selections. As a result, a better combination of the P, I, D values may always be found, that will give less oscillation and better settling time. But with no a-priori knowledge of the system, it is always advisable to perform the experimentation and select the controller settings, obtained from Ziegler-Nichols method. But there is always scope for improving the performance of the controller by fine-tuning. So, Ziegler-Nichols method provides initial settings that will give satisfactory, result, but it is always advisable to fine-tune the controller further for the particular process and better performance is expected to be achieved.

Nowadays digital computers are replacing the conventional analog controllers. P-I-D control actions are generated through digital computations. Digital outputs of the controllers are converted to analog signals before they are fed to the actuators. In many cases, commercial software are available for *Auto tuning* the process. Here the controller generates several commands those are fed to the plant. After observing the output responses, the controller parameters are selected, similar to the cases discussed above.

6. Integration windup and Bumpless transfer

Two major issues of concern with the close loop operation with P-I-D controllers are the *Integration Windup* and the requirement of providing *Bumpless Transfer*. These two issues are briefly elaborated below. The methodologies for providing Anti-integration Windup and Bumpless Transfer would be discussed in the next lesson.

Integration Windup

A significant problem with integral action is that when the error signal is large for a significant period of time. This can occur every time when there is large change in set point. If there is a sudden large change in set point, the error will be large and the integrator output in a P-I-D control will build up with time. As a result, the controller output may exceed the saturation limit of the actuator. This windup, unless prevented may cause continuous oscillation of the process that is not desirable.

Bumpless Transfer

When a controller is switched from manual mode to auto-mode, it is desired that the input of the process should not change suddenly. But since there is always a possibility that the decision of the manual mode of control and the auto mode of control be different, there may be a sudden change in the output of the controller, giving rise to a sudden jerk in the process operation. Special precautions are taken for *bumpless transfer* from manual to auto-mode.

References

1. B. Liptak: Process Control: Instrument Engineers Handbook
2. D.R. Coughanowr: Process systems analysis and control (2/e), McgrawHill, NY, 1991.
3. D. Eckman: Process Control, Wiley, NY, 1958.

Review Questions

1. What does controller tuning mean?
2. Name the three techniques for controller tuning, those are commonly known as Ziegler-Nichols method.
3. Explain the reaction curve technique for tuning of controller. What are its limitations?
4. What do you mean by *Auto Tuning*? Explain briefly.
5. What is meant by Bumpless Transfer?
6. Why provision for Anti- integration Windup is necessary for process with P-I-D control?

Answers to Points to Ponder

a) Addition of integral control action to P-only control tends to make the closed loop system more oscillatory; in order to overcome this problem, the suggested value of K_p with ZN tuning is reduced.

b) Addition of derivative action again damps down the oscillation; as a result larger value of K_p in a PID controller is permissible.