Three Approaches to Dynamic Analysis

We have considered three different approaches to Dynamic Analysis:

- **Analytical Approach (by calculating e^{At})**
- **Numerical Approach (by using MATLAB to integrate dynamic equations)**
- **Simulation Approach (by using CHEMCAD to study dynamics)**

In each of these approaches, the dynamics of the process are first studied and then a controller (P, PI, or PID) is utilized to modify the dynamics of the process.

In this lecture, we will study how the controller parameters can be chosen so the dynamics of the closed-loop process follow a desirable behavior.

The Four Laws of Process Control

1. **Thou shalt not make the process unstable**

2. **Thou shalt minimize deviations from set-point in the presence of disturbances**

3. **Thou shalt track set-point changes as closely as possible**

4. **Thou shalt not use excessive control action**

Controller Tuning

Controller Tuning implies choosing the controller parameters (K_c, τ_I and τ_D) so that the process behaves in a predetermined way.

Tuning is a *compromise*.

- **Tuning for minimum deviation from set-point for normal disturbances is contrary to tuning the controller to remain stable for major disturbances.**
- **A controller tuned for the largest possible disturbance results in performance that is excessively sluggish for normal disturbances.**

Performance Assessment

Suppose we have a choice of two sets of controller parameters. How do we quantitatively assess which choice is better?

There are a number of performance statistics that can be used to evaluate *controller performance*.

1. **Integral Absolute Error (IAE)**

$$IAE = \int_0^\infty |y_{sp}(t) - y(t)|dt \tag{1}$$

2. Integral Time Absolute Error (ITAE)

$$ITAE = \int_0^{\infty} t|y_{sp}(t) - y(t)|dt \tag{2}$$

3. Integral Square Error (ISE)

$$ISE = \int_0^{\infty} \left[y_{sp}(t) - y(t)\right]^2 dt \tag{3}$$

4. Integral Time Square Error (ITSE)

$$IAE = \int_0^{\infty} t \left[y_{sp}(t) - y(t)\right]^2 dt \tag{4}$$

Each of these performance measures values the error from the set-point differently.

- **ITAE and ITSE penalize deviations at long time more severely than IAE and ISE.**
- **ISE and ITSE penalize larger deviations more severely than IAE and ITAE.**

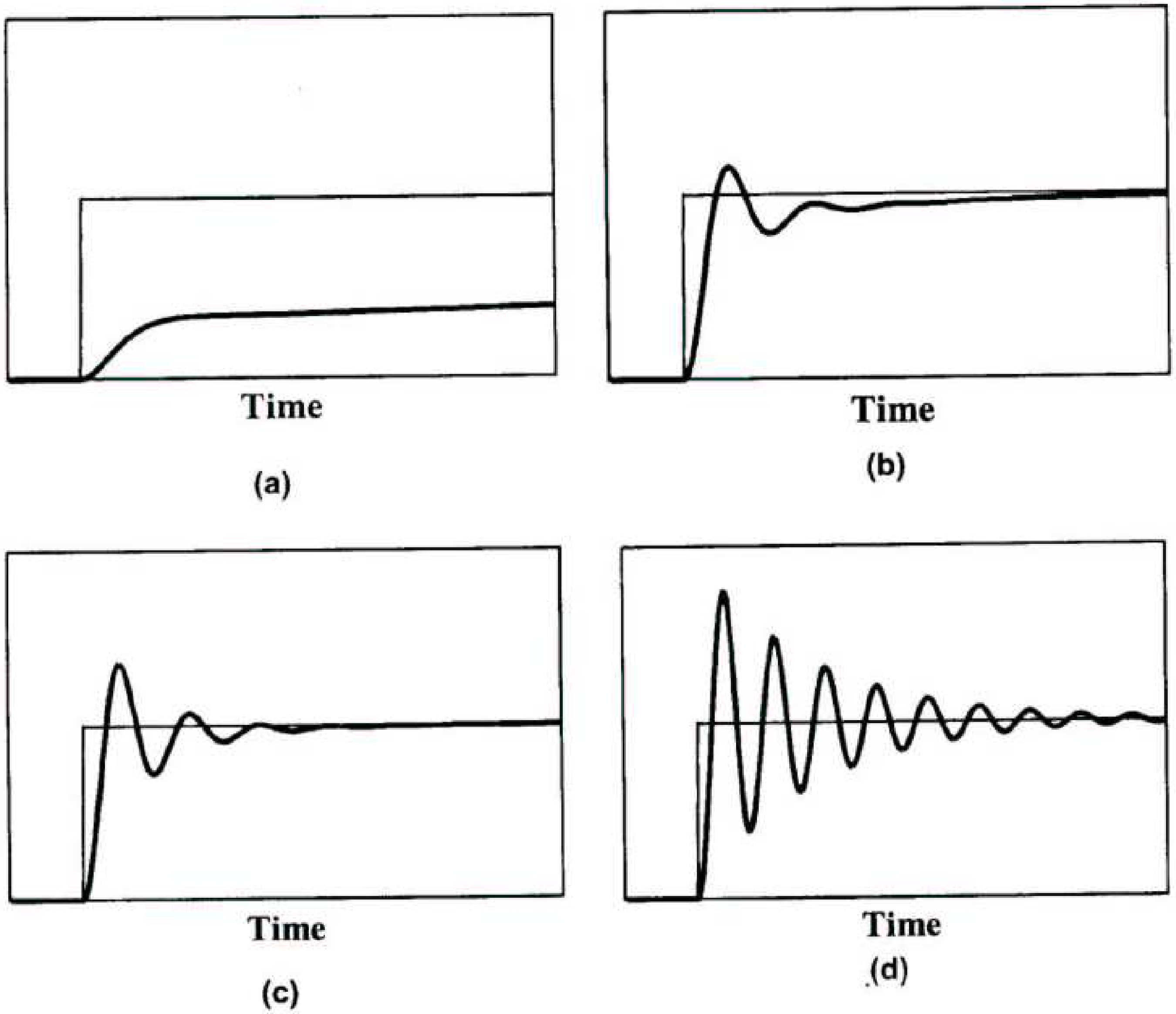

Figure 7.1 Control response for a setpoint change. (a) Controller tuned for sluggish response. (b) Controller tuned for 1/10 decay ratio. (c) Controller tuned for QAD. (d) Controller tuned for ringing response.

Several Performance Statistics as a Function of Decay Ratio

Decay Ratio	IAE	ITAE	ISE	ITSE
1/1.5	39.6	1244	31.1	470
1/2.0	28.3	628	22.8	231
1/3.0	20.9	347	17.8	117
1/4.0	19.8	387	16.8	92.8
1/5.0	20.7	503	16.8	91.2
1/6.0	22.0	635	17.1	97.4
1/8.0	24.9	903	17.9	119
1/10.0	27.4	1141	18.8	145

Ziegler-Nichols Tuning

Ziegler-Nichols (ZN) tuning uses experimental measurements of the *ultimate gain*, K_u, and the *ultimate period*, P_u, to calculate the controller settings. The procedure is as follows:

1. **Turn off integral and derivative action to give a P controller.**
2. **Increase K_c until oscillations are sustained for a relatively small set-point change.**
3. **K_u is the P controller gain that results in sustained oscillations.**
4. **P_u is the period of the sustained oscillations.**

5. Calculate the controller settings using the following table:

Controller	K_c	τ_I	τ_D
P	$0.5K_u$	-	-
PI	$0.45K_u$	$P_u/1.2$	-
PID	$0.6K_u$	$P_u/2$	$P_u/8$