Design Considerations

The material covered so far has been concerned with the tuning of a controller that is already connected to a process. However, this does not answer questions such as:

- **Where should the sensors be placed?**
- **Where should the controllers be placed and what should they control?**

In this lecture, we develop a systematic approach for implementing controllers assuming no controller hardware is in place.

We focus on the PROCESS in Process Control

Analysis Procedure

The following steps are followed:

1. Identify process objectives
2. Identify process constraints
3. Identify significant disturbances
4. Determine the type and location of sensors
5. Determine the location of control valves
6. Apply a degree-of-freedon analysis
7. Implement energy management
8. Control process production rate

9. **Select manipulated inputs that meet the control objectives**
10. **Address how disturbances are handled**
11. **Develop a constraint handling strategy**
12. **Control inventories**
13. **Check component balances**
14. **Control individual unit operations**
15. **Apply process optimization**

Distillation Column Example

1. **Process description**

   Consider the design of a control system for an ethylene/ethane (C_2) splitter with the following characteristics:

   - **The feed contains about 70% ethylene. Impurities to the feed could be hydrogen and methane.**
   - **High purity ethylene (less than 0.1%ethane) is produced at the top and is the product of interest.**
   - **Ethane is produced in the bottom (about**

1% ethylene) and is recycled to the furnace where it is cracked to produce more ethylene.

- The major disturbances are feed flow rate and feed composition upsets.

2. **Identify process objectives**

   The process objectives are to produce an ethylene product with low variability while satisfying its impurity specification in the face of process disturbances. It is desired to recover as much ethylene as possible while minimizing energy costs.

3. **Identify process constraints**

There is more than adequate reboiler and condenser duty. Thus, when the feed rate to the column increases, the column eventually **floods**.

A differential pressure across the column should reliably indicate the onset of flooding.

4. **Identify significant disturbances**

   The primary disturbances are feed flow rate and feed composition changes.

5. **Determine the type and location of sensors**

   Figure 1 shows the sensors applied to this column.

6. **Determine the location of control valves**

Each of the streams equipped with a flow transmitter (FT) should also have a control valve installed. A control valve is also placed on the refrigerant feed to the condenser. Figure 1 shows the location of control valves.

7. Apply a degree-of-freedom analysis

- There are six control valves indicating that there are six manipulated flow streams.
- There are five column control objectives: (1) overhead product composition, (2) tray temperature in the stripping section,

(3) the level in the accumulator, (4) the level in the reboiler, (5) overhead pressure. In addition, the flow rate of the feed to the column can be set.

- Since the number of controlled variables is equal to the number of manipulated inputs, the system is exactly determined. When the column reaches flooding conditions, the differential pressure measurement across the column becomes a constraint and the control problem becomes underdetermined.

8. Implement energy management

The flow of steam to the reboiler provides the reboiler duty and the flow of refrigerant to the condenser provides the condenser duty for this column.

9. **Control process production rate**
   The production rate of this column is set by a flow controller on the feed to the column. The operator selects the setpoint for this controller to maintain the level in the column feed tank.

10. **Select manipulated variables**
    The primary objective is to maintain the ethylene product on specification. The

secondary objective is the bottom composition control, which is directly related to the control of the tray temperature in the stripping section.

- Choose the "LV" configuration for manipulated inputs as this has a fast dynamic response and is less sensitive to feed disturbances.
- Distillate and bottoms rate are set by level controllers.
- Overhead pressure is controlled by the flow rate of refrigerant to the condenser.

Figure 2 shows this configuration.

11. **Address how disturbances are handled**
    The feed composition is not measured but the LV configuration is the best one to handle this kind of disturbance. The feed flow rate disturbances are measured and so the overhead composition control loop can be improved by applying ratio control (L/F control) as shown in Figure 2.

12. **Develop a constraint handling strategy**
    The primary constraint is flooding, which occurs when the feed flow is excessive.

    - **When flooding occurs, one control objective must be discarded.**

- **Ethylene product purity as well as reboiler and accumulator levels must be maintained. So, discard stripping section temperature control (i.e. purity of bottoms product).**
- **This approach is implemented by combining the output from the tray temperature controller with the output of the differential pressure controller as shown in Figure 3. When the column is not approaching flooding, temperature is controlled. When the column is approaching flooding, pressure is controlled.**

13. **Control inventories**
    The level controllers on the reboiler and accumulator handle the liquid inventories. The gas inventories are addressed by the pressure controller on the overhead.
14. **Check component balances**
    When methane and hydrogen appear in the feed, they accumulate in the overhead. A vent line connected to the vapor space is necessary to purge these uncondensed vapors to avoid pressure buildup, as shown in Figure 3.
15. **Control individual unit operations**

The process under consideration is a single unit; thus this step is skipped.

16. **Apply process optimization**
    The unassigned setpoints for this process include the setpoint of the ethylene product, the setpoint for the tray temperature controller, the setpoint for the overhead column pressure, and the setpoints for the accumulator and reboiler levels.
    - The setpoints for the levels does not affect the steady state optimization.
    - The impurity setpoint for the ethylene product is set by customer specifications.

- **The setpoint for the tray temperature is an optimization problem that requires a tradeoff between ethylene recovery and energy usage of the column.**
- **The overhead pressure affects the relative volatility of the separation. The minimum overhead pressure is set by the temperature of the refrigerant. The column should be operated as close to this value as possible for the most efficient separation.**